SINISTER INTERSECTIONALITY
A LEFT-HANDED HISTORY OF NEURO-CENTRISMS, 1865–2017

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ABSTRACT

SINISTER INTERSECTIONALITY

A LEFT-HANDED HISTORY OF NEURO-CENTRISMS, 1865–2017

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M. Susan Lindee

This work is a *longue durée* history of neuroscientific classification practices through the lens of handedness research, and it affirms the importance of ostensibly outmoded concepts for contemporary knowledge production. The study draws on close readings and digital analyses of publications in English, French, and German; archival collections; and oral history interviews. In 1865, Paul Broca postulated that the speech center sits in the left hemisphere of the brain and that humans are right-handed because they are left-brained. Subsequently, a virtual obsession with the causes of manual preference and its association with human identity spread throughout the mind-, brain-, and neurosciences in Europe and North America. A progression of closely entwined anatomical, physiological, genetic, hormonal, mirror-neuron-based, and epigenetic models of manual preference all rested on the idea that right-handedness is a distinctive marker of superiority both among humans and across species. With the rise of molecularization and statistical methods, scientists further transformed left-handedness into a manageable "risk" factor for nonconformity. By the late twentieth century, handedness research had become an innocuous umbrella under which to pursue inquiries into the biological underpinnings of controversial socio-medical categories. The past one and a half centuries of research on

manual preference exemplify the idea that the reach of scientific classifications extends far beyond the characteristics that such classifications are supposed to categorize. The insight that handedness has functioned as a proxy for mental and physical dis/abilities, sex/gender, sexual behavior, class, and race/ethnicity challenges our concept of intersectionality and suggests that we must include even seemingly neutral categories in our considerations of governance, inclusion, and citizenship. Furthermore, the layering of theories and methodologies in handedness research offers examples of an epistemological multiplicity among diverse conceptual and experimental frameworks. Frequently incompatible ways of approaching the brain have led to a parallelism of incommensurable ideas of fixed localization and dynamic plasticity in present-day neuroscience. This multiplicity of understandings of “the brain” simultaneously leads to epistemic inconsistencies in neuroscientific theories and endows the neurosciences with a seemingly all-encompassing expertise.

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PREFACE

In case you were wondering: No, I am not a leftie. However, over the course of my research and writing about manual preference, I realized that I am not a straight-up right-hander either. For example, I use my left hand to thread a needle; unscrew lids; gesture while speaking; and to button, unbutton, zip, and unzip my clothes. This realization was a consequence, not the cause, of my interest in manual preference.

The idea for this book-to-be was born in Vienna in September 2012. During psychologist Daphna Joel's keynote address at the conference *NeuroCultures – NeuroGenderings II*, Joel shared her dream about a world in which sex/gender is as neutral a category as handedness.[1] If one wants to buy scissors, handedness is important, but no parent asks their child if their playmates are left-handed or right-handed. Similarly, Joel depicted a world in which parents do not ask their children about their playmates' sex/gender, and where sex is only meaningful when, for instance, one considers with whom to conceive a child.[2]

After the talk, I asked Joel how manual preference has lost its socio-cultural meaning, considering that left-handedness had been a highly stigmatized category even fifty years prior (my father was slapped in the face by his kindergarten teacher for using

[1] Daphna Joel, "Sex, Gender and Brain: A Problem of Conceptualization," Keynote address at *NeuroCultures - NeuroGenderings II*, University of Vienna, September 13–15, 2012, accessed March 15, 2019, https://www.youtube.com/watch?v=kKeKCxPApKQ.
[2] Other feminists have drawn similar comparisons between sex/gender and manual preference; see, e.g., Cordelia Fine, *Delusions of Gender: How Our Minds, Society, and Neurosexism Create Difference* (New York: W.W. Norton & Company, 2010), 209–10. Fine portrayed a world in which left-handers wear pink clothes and spend their time drawing, while right-handers spend their time with technology and wear any color except for pink and purple.

his left hand in the early 1960s—he never went to kindergarten again). Joel responded that she did not know, and that it was up to historians to figure this one out.

I was a historian, I *am* a historian! Thus, I set out to write the history of how left-handedness came to be acceptable over the course of the twentieth century, and the role that science has played in this process. I wanted to use this liberating history as a model for how to abolish sexism, racism, homophobia, transphobia, ableism, and any other discrimination that derives from being on the wrong side of an alleged "natural" binary or from defying binary classification altogether.

This might sound far-fetched, but it really is not. The common perception of left- and right-handedness as innate dichotomous characteristics mirrors not only our distinctions between female and male or feminine and masculine but also between gay and straight, black and white, disabled and able, to name only a few. None of these characteristics are in fact binaries, and none of them are purely "natural" (if we understand the "natural" as an objective realm free of politics and socio-cultural meanings). I thought that if I were able to explain how science has contributed to eliminating the stigma of left-handedness, then we would have a working model for how science can push back against other forms of discrimination that are based on socio-cultural (and only seemingly "natural") binaries.

I failed. Little did I know that the history of scientific handedness research is one of continuous stigmatization. Throughout the twentieth century and into the twenty-first century, physicians and scientists have perpetuated old nineteenth-century prejudices against left-handers in medical terms. They have framed handedness as a sign of abnormal brain anatomy and suggested that left-handedness correlates with mental inferiority and psychiatric illnesses.

In fact, many physicians and scientists tried to *stop* educational reformers who advocated for the abandonment of left-hander conversion. Whether right-hand usage should be enforced among all children, no matter their manual preference, continued to be "vigorously debated at least through the 1950s."[3] Anecdotal evidence (that is, people who hear that I am working on a dissertation about handedness and tell me about their own or their father's/mother's/uncle's/aunt's/grandparent's fate in a rural community or Catholic school) suggests that left-handers were physically abused well into the second half of the twentieth century in Europe and North America, and that emotional abuse in certain schools in these countries continues to this day.

I also learned that other countries are even farther from a left-hander liberation than North America and Europe. When I travelled to India, for example, I was instructed to pay close attention to never use my left hand for eating, reaching for something, or handing something to somebody (such as my passport to the border control officer), to not offend anyone by using my "dirty" hand. Similarly, when a teenager from Liberia heard that my father was left-handed, she expressed her sympathy for the shame that this brings over my family. She was surprised to hear that my father is still alive. In her home town, she told me, children who refuse to eat with their right hand are left to starve (no pun intended). I do not believe that all persistent lefties starve in Liberia, but the sentiment is clear.

[3] Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 65.

It pains me to say that numerous scientists and physicians since the nineteenth century have perpetuated seemingly politically correct versions of such appalling and physically harmful forms of handedness-based discrimination. This is the story of how, when, and where they did it. As for the “why,” I believe that not even the scientists themselves can tell. The handedness researchers I met in person are without exception kind and generous people (and mostly right-handers—maybe herein lies the problem!).

CHAPTER 1

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INTRODUCTION

> Few questions of common biological interest can boast of so many and varied explanations as the age-old riddle of right- and left-handedness. Almost every conceivable influence has been invoked, at one time or another, and many of the alleged causes are so grotesque and irrational that one wonders if the authors were really serious in their attempts to find some adequate explanation. With the exception of a certain amount of evidence bearing on the inheritance of handedness, it can not [*sic*] be said that we know much more about the factors which really determine whether an individual will be right-handed or left-handed than did the person in whose mind the question first arose.[4]

Causes

When Ingalls complained about the "grotesque and irrational" theories of handedness in 1928, he had no way of knowing that the causes of manual preference would still prove elusive almost a century later. The long search for an etiology of handedness has been driven by the cultural stigma of non-right-handedness (that is, left-handedness, true

[4] N. W. Ingalls, "On Righthandedness," *Scientific Monthly* 27, no. 4 (1928): 307.

ambidexterity, and partial ambidexterity)[5] that was prevalent in Europe and Northern America until the mid-twentieth century and lives on in many other cultures.[6]

Linguists, cultural historians, and other scholars have traced the associations between the word “left” and all things sinister in numerous languages.[7] These verbal patterns of stigmatization and exclusion have correlated with a close monitoring of non-right-handed individuals since biblical times.[8] In 1646, English polymath Thomas Browne (1605–1682) surveyed and debunked theories of the origins of handedness as a natural or spiritual deviance and criticized the wide-spread perception of left-handedness as a “digression or aberration.”[9] Although Browne’s *Pseudodoxia Epidemica*, which contained these critiques, reached noteworthy fame as the book of *Vulgar Errors*, the notion

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[5] The term “non-right(-)handedness” was introduced by Geschwind and Galaburda; see, e.g., dust cover of Norman Geschwind and Albert M. Galaburda, eds., *Cerebral Dominance: The Biological Foundations* (Cambridge: Harvard University Press, 1984). It is widely used in the literature, although some researchers, including McManus, find that clumping together left-handers and ambidexters (or weak right-handers, because McManus does not believe in the existence of true ambidexterity) can distort handedness statistics; Ian Christopher McManus, interview by Tabea Cornel, July 12, 2016, London.

[6] For a psychological argument that left-handers are no longer stigmatized, see Gina M. Grimshaw and Marc S. Wilson, “A Sinister Plot? Facts, Beliefs, and Stereotypes about the Left-Handed Personality,” *Laterality* 18, no. 2 (2013), https://doi.org/10.1080/1357650X.2011.631546. For an overview of investigations of the incidence of left-handedness in other cultures and/or previous generations, and on the ways in which such studies are problematic, see Howard I. Kushner, “Why Are There (Almost) No Left-Handers in China?” *Endeavour* 37, no. 2 (2013), https://doi.org/10.1016/j.endeavour.2012.12.003; Howard I. Kushner, *On the Other Hand: Left Hand, Right Brain, Mental Disorder, and History* (Baltimore: Johns Hopkins University Press, 2017), ch. 3.

[7] Pierre-Michel Bertrand, *Histoire des gauchers: Des gens à l’envers* (Paris: Imago, 2001), 27–32; Léon Faure, “Essai d’étude comparative de l’homme droit et de l’homme gauche” (M.D., Faculté de Médecine et de Pharmacie, Université de Lyon, 1902), 9–19; Lars Axel Daniel Fryklund, *Les changements de signification des expressions de droite et de gauche dans les langues romanes et spécialement en français* (Upsala: Almqvist & Wiksell, 1907), 116–19; Ian Christopher McManus, *Right Hand, Left Hand: The Origins of Asymmetry in Brains, Bodies, Atoms, and Cultures* (Cambridge: Harvard University Press, 2002), 60–65; Ira Solomon Wile, *Handedness, Right and Left* (Boston: Lothrop, Lee and Shepard Company, 1934), 30–57; Daniel Wilson, *The Right Hand: Left-Handedness* (London: Macmillan and Co., 1891), 62–76.

[8] Bertrand, *Histoire*, 13–54; Thomas Browne, *Pseudodoxia Epidemica: Or, Enquiries into Very Many Received Tenents, and Commonly Presumed Truths*, 2nd ed. (London: Edw. Dod and Nath. Ekins, 1650), 159–64; Lauren J. Harris, “Left-Handedness: Early Theories, Facts, and Fancies,” in Herron, *Neuropsychology of Left-Handedness*, 51–53; Johanna Barbara Sattler, *Links und Rechts in der Wahrnehmung des Menschen: Zur Geschichte der Linkshändigkeit* (Donauwörth: Auer Verlag, 2000), 228–30.

[9] Browne, *Pseudodoxia Epidemica*, 159. See also Caoimhghin S. Breathnach, “*Of the Right and Left Hand* (1646): Sir Thomas Browne’s Historical Survey of ‘Handedness’,” *Irish Journal of Psychological Medicine* 22, no. 1 (2005), https://doi.org/10.1017/S0790966700008788.

of the sinister left-hander persisted in the absence of a conclusive theory of manual preference.[10]

Historian of art and mentalities Pierre-Michel Bertrand has traced the social standing of left-handers since antiquity through representations in art and literature as well as in changing social norms.[11] He suggested that while left-handers have been regarded as curiosities since antiquity (for example, as artists, geniuses, or criminals),[12] their systematic oppression started only after the Middle Ages.[13] In the Renaissance, a desire for normalization and standardization, not least in the education in writing, led Europeans to attach the meaning of politeness to the right hand,[14] although right-handedness did not carry much pragmatic importance in the daily life during pre-industrial times.[15] Nevertheless, Browne and others tried to abolish the stigma of left-handedness from the seventeenth century onwards.[16]

With the last third of the nineteenth century arrived "the high period of intolerance" against non-right-handers.[17] For reasons that are hard to disentangle, non-right-handers faced unprecedented discrimination until after World War I—in their homes, the workplace, schools, science, literature, art, and religious life. During the decades following World War I, Bertrand diagnosed a slow decline in the discrimination against non-

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[10] Bertrand, *Histoire*, 131–32; McManus, *Right*, 285–87.
[11] Pierre-Michel Bertrand, "La symbolique de la droite et de la gauche au Moyen Âge et au début des Temps modernes: Études d'anthropologie sociale et d'iconographie" (Thèse de doctorat, Université Paris 1 Panthéon-Sorbonn, 1998); Bertrand, *Histoire*; Pierre-Michel Bertrand, *Nouveau dictionnaire des gauchers* (Paris: Imago, 2011).
[12] Bertrand, *Histoire*, pt. IV.
[13] Bertrand, *Histoire*, 117–19. The absence of an exclusively negative view of left-handedness before the Renaissance was also suggested by Sattler, *Links*, 27–101; 187–226.
[14] Bertrand, *Histoire*, 120–27.
[15] Bertrand, *Histoire*, 128–30.
[16] Bertrand, *Histoire*, 131–40.
[17] French original: "la haute époque de l'intolérance"; Bertrand, *Histoire*, 88–91 (quote on p. 88).

right-handers in European and North American schools, families, art, and literature. This shift required “a true cultural revolution”[18] that commenced with the immense numbers of mutilated World War I veterans, many of whom had lost their dominant right hands, thus drastically increasing the number of left-handers in Europe.[19] The destigmatization of non-right-handedness was a slow process, and most European schools only fully abolished the cruel retraining methods for left-handers in response to the reformist pedagogy of the 1960s.[20]

This trajectory is not surprising. While non-right-handedness was mainly a private aesthetical issue in pre-industrial societies, it advanced to a practical public problem in the age of factories, compulsory schooling, and multinational wars. Many machines were built for right-handers and hence unsafe for use by left-handers, who lost their dominant hands in industrial accidents at disproportional rates.[21] The loss of the dominant hand meant the immediate loss of labor to factory owners and potential financial liabilities to mutilated workers.[22]

Even more frequent, and sometimes equally debilitating, was the conversion of left-handers into right-handers in schools. While not all parents required their children to use the right hand for skilled tasks, virtually every educator taught students to write with

[18] French original: “une véritable révolution culturelle”; Bertrand, *Histoire*, 117.
[19] Bertrand, *Histoire*, 154–57.
[20] Bertrand, *Histoire*, 141–154; 227–233.
[21] Sattler, *Links*, 234–35. On retraining partially mutilated hands, see also Denis Gerlac, *Histoire de la rééducation de la main en France: D’Ambroise Paré à nos jours* (Montpellier: Sauramps Médical, 2010).
[22] Ludwig Wilhelm Liersch, *Die linke Hand: Eine physiologische und medicinisch-praktische Abhandlung für Aerzte, Pädagogen, Berufsgenossenschenschaften und Versicherungsanstalten* (Berlin: Richard Schoetz, 1893).

the right hand.[23] Retraining methods for persistent left-handers included scolding, beating, and tying the left hand behind the back for extended periods of time.[24]

Furthermore, with the rise of nationalism leading up to and during World War I, military authorities were concerned about unfit soldiers. The presumably unfit included extreme right-handers or left-handers who were too lopsided to withstand physically demanding tasks, those traumatized by handedness conversion, and those who had lost (or might lose) their dominant hands in combat and required retraining after being discharged as mutilated veterans.[25]

Besides drawing workers into factories, congregating children in schools, and speeding up nationalist competition, the Industrial Revolution changed the perception of causality. Historian Stephen Kern traced the transformation of "the epistemology of

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[23] Sattler, *Links*, 234.

[24] Bertrand, *Histoire*, 91–102; Kushner, *On*, ch. 4. Others apparently tried hypnosis; Anton Hasseroth, "Rechts- und Linkshändigkeit," in *Festschrift zur Einweihungs-Feier des neuen Klassengebäudes am 13. und 14. August 1911*, ed. Königl. Pädagogium und Waisenhaus bei Züllichau (Züllichau: Herm. Hampel & Sohn, 1911), 86–87. Numerous scientists and educators believed that violent retraining methods led to stuttering; Howard I. Kushner, "Retraining the King's Left Hand," *Lancet* 377, no. 9782 (2011), https://doi.org/10.1016/S0140-6736(11)60854-4; Howard I. Kushner, "Retraining Left-Handers and the Aetiology of Stuttering: The Rise and Fall of an Intriguing Theory," *Laterality* 17, no. 6 (2012), https://doi.org/10.1080/1357650X.2011.615127. However, this theory does not figure prominently in histories of stuttering and speech disorders; Benson Bobrick, *Knotted Tongues: Stuttering in History and the Quest for a Cure* (New York: Kodansha International, 1996); Denyse Rockey, *Speech Disorder in Nineteenth Century Britain: The History of Stuttering* (London: Croom Helm, 1980); Marc Shell, *Stutter* (Cambridge: Harvard University Press, 2005).

[25] On the historical problem of one-handed and handless veterans, see Sattler, *Links*, 231–34. German primary sources on the topic are numerous and include Robert Gersbach, *Schönschreiben und Stenographie für Linkshänder: Eine Anweisung mit Leitsätzen, Winken, Schriftvorlagen, einer Übungstafel, Abbildungen usw. für den Schul- und Selbst-Unterricht* (Berlin: Kameradschaft, 1916); Rudolf Görlach, "Das Schicksal der Ohnhänder," *Arbeit und Gesundheit* 19 (1931); Rudolf Herbst, *Die Schrift der linken Hand* (Leipzig: Vieweg, 1917); Robert Heuler, "Ohnhänder, Linkshänder, Gelähmte und Mißwachsene in Schule, Lehre und Leben: Ein Wort zu ihrer Führung," *Die deutsche Sonderschule*, no. 2 (1942); Reprint; Fritz Georg I-wand, *Linksarmer und Linkshänder: Aus der Praxis für die Praxis* (Strasbourg: J. H. Ed. Heitz, 1916); Hans Rederer, *Die Ausbildung der linken Hand: Eine zeitgemäße Studie nebst Anleitung zum Schreiben mit linker Hand* (Hamburg: E. A. Christians' Verlag, 1915); Karl Schlosser, *Das Schreiben mit der linken Hand* (Leipzig: Schimmelwitz, 1916); Othmar Hugo Sterzinger, "Rechts- und Linkshändigkeit bei Amputierten: Eine psychologische Untersuchung," *Untersuchungen zur Psychologie, Philosophie und Pädagogik* 6, no. 1 (1927); Emil Stoltefuß-Elberfeld, *Das Schreiben mit der linken Hand: Ratschläge zusammengestellt von Stoltefuß-Elberfeld* (Düsseldorf: Ausschuß für Kriegsbeschädigtenfürsorge der Rheinprovinz, 1915).

causality" from the Victorian Era to the late twentieth century.[26] Kern demonstrated that causal understanding in science, philosophy, and literature "moved in the direction of increasing specificity, multiplicity, complexity, probability, and uncertainty."[27] This shift was rooted in the division of labor in industry and the academy; the geographical and psychological expansion of cause-effect relations in global capitalism; and new technologies of communication and transportation that increased the temporal and spatial reach of causal explanations for social phenomena.

Given these new ways of understanding and popularizing cause-effect relations, scientists and physicians of the late nineteenth century took up the now pressing problem of left-handedness in unprecedented numbers and with a sense of existential urgency. Whoever could unravel the causes of handedness would prove their own discipline as worthy and contribute to pedagogical, economic, and military advancement.

In line with Kern's findings of increased specificity, multiplicity, complexity, probability, and uncertainty in causal explanations, physicians and scientists of the past one and a half centuries sought to provide ever deeper and more polished explanations for the origin of manual preference. Handedness researchers layered their new ideas on top of existing theories of handedness, and thereby turned handedness research into a complex epistemic endeavor. In the late twentieth century, scientists turned to computerized statistics and probabilistic models to navigate the complex problem of manual preference. With a conclusive causal theory still wanting in the twenty-first century, recent

[26] Stephen Kern, *A Cultural History of Causality: Science, Murder Novels, and Systems of Thought* (Princeton: Princeton University Press, 2004), 24. On the seemingly systemic neuroscientific confusion of correlation and causation, see Fernando Vidal and Francisco Ortega, *Being Brains: Making the Cerebral Subject* (New York: Fordham University Press, 2017), 155–61.
[27] Kern, *A Cultural History of Causality*, 6.

handedness researchers have built uncertainty into their works-in-progress and agreed that non-right-handedness is a "risk" factor for abnormal brain function, cognitive disabilities, and psychiatric illnesses.

Arguments

The Anthropological Machine

This association of handedness with the brain, mind, and character is the focus of my investigation. While successive etiological theories of handedness exemplify vividly Kern's argument on the changing notions of causality, I use handedness research as a window into classification practices in the brain and mind sciences since the late nineteenth century more generally.

In 1865, the French physician, anatomist, and anthropologist P. Paul Broca (1824–1880) postulated that the speech center sits in the left hemisphere of the brain, that the presence of this neural center makes the left half of the brain dominant, and that (most) humans are right-handed because they are "left-brained."[28] Shortly after Broca's proposal, a virtual obsession with the causes of handedness spread throughout Europe and North America. Many scientists of the mind and brain, along with several physicians,

[28] Pierre P. Broca, "Sur le siège de la faculté du langage articulé," *Bulletins et mémoires de la Société d'anthropologie de Paris* 6 (1865). See also the English translation of the report; Ennis A. Berker, Ata H. Berker, and A. Smith, "Translation of Broca's 1865 Report: Localization of Speech in the Third Left Frontal Convolution," *Archives of Neurology* 43, no. 10 (1986). A note on terminology: In Broca's day, scientists believed that the left hemisphere is usually dominant for all cognitive functions. Current-day neuroscientists believe that cerebral dominance is task-specific. The dominant cerebral hemisphere for a particular task is the half of the brain that hosts the major centers needed to carry out this task, e.g., articulate speech, emotional processing, face recognition, or spatial thinking. Here and in the following, I refer to cerebral dominance for articulate language whenever I use the terms "dominant" or "dominance" without further specification. The term "(speech) lateralization" describes this functional and/or structural asymmetry between the two hemispheres. Instead of calling humans "left-brained" or the left hemisphere "dominant" for language, one can say that language is "left-lateralized." In the following, I use these terms interchangeably.

eugenicists, pedagogues, and anthropologists, concerned themselves with the question of handedness. To the best of my knowledge, all handedness researchers after Broca related manual preference to brain asymmetry and/or questions of the mind and character. In the absence of brain imaging methods, the (literally!) manifest quality of handedness served as a welcome proxy for the inaccessible brain and its functions.

By associating manual preference with human cognition, Broca became the first neuroscientist we know of to turn handedness research into what philosopher Giorgio Agamben has called an "anthropological machine": a mechanism to mark the boundary between human and non-human life.[29] In *The Open*, Agamben argued that human identity can only be defined in juxtaposition with what is not human. Since antiquity, Agamben showed, European scholars and artists have relied on the separation of "man" and "animal" to define themselves and the divine, either by positively asserting the existence of superior human qualities or by negatively proclaiming the inferiority of non-human forms of life.

Language and articulate speech were the main components of the anthropological machine during the nineteenth century. Drawing on Broca's contemporaries, German physician and philosopher Ernst H.P.A. Haeckel (1834–1919) as well as German philologist and philosopher C. Heymann Steinthal (1823–1899), Agamben illustrated that the historical debates of when, how, and in whom human language first evolved were a core concern of "man"-making projects in philosophy and natural history.[30] Broca

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[29] Giorgio Agamben, *The Open: Man and Animal* (Stanford: Stanford University Press, 2004), Translated by Kevin Attell.

[30] Agamben, *Open*, 33–38. For more detailed accounts of the obsession with delineating human language from other signifying systems in philosophy, natural history, and the human sciences, see Joanna Bourke, *What It Means to Be Human: Reflections from 1791 to the Present* (London: Virago Press, 2011); Tania Munz, *The Dancing Bees: Karl von Frisch and the Discovery of the Honeybee Language* (Chicago,

cerebralized this question. He crafted a neuro-anatomical model of human superiority over other animals by suggesting that speech lateralization, brain asymmetry, and, by extension, handedness were exclusively human.

It does not seem an obvious choice to take the oddly shaped tail ends of our upper limbs as a proxy for the clump of nerve cells and other tissue hidden in our skull. Still, as I show in the following, physicians and scientists since Broca have advanced theories that handedness is in the brain, notwithstanding the gaps and the inconclusive or sometimes purely speculative nature of such theories. They have formulated anatomical, physiological, genetic, hormonal, mirror-neuron-related, and epigenetic theories of the relationship between hand, brain, mind, and personhood. By the late twentieth century, handedness research had become a seemingly neutral umbrella under which otherwise controversial typologies of sexed, gendered, sexualized, racialized, classed, and dis/abled brains could be constructed.

The Brain Multiple

A *longue durée* history of handedness research shows the interconnectedness of seemingly successive and often incommensurable theories of manual preference. No scientist or physician after Broca built their theory from scratch. Most notably, Broca's idea that handedness is associated with brain asymmetry and "higher" cognitive functions persisted throughout the past one and a half centuries. Furthermore, handedness researchers relied on evolutionary concepts of the origins of physical asymmetries, on previous data sets about the prevalence of handedness and brainedness in different populations, and on

London: University of Chicago Press, 2016); Gregory Radick, *The Simian Tongue: The Long Debate about Animal Language* (Chicago: University of Chicago Press, 2007).

methods of determining physical asymmetries (including questionnaires and behavioral tests). In doing so, generations of handedness researchers built their allegedly novel theories of manual preference on a wide range of concepts from other disciplines, times, and places.

The layering of theories and methodologies in handedness research offers examples of a productive epistemological inconsistency among diverse conceptual and experimental frameworks within the modern neurosciences. Scientists have promoted the results of oftentimes incompatible ways of approaching the brain (as an anatomical, physiological, (epi)genetic, or hormonal organ, to name only a few) as if they were one heterogeneous body of knowledge about "the brain." Moreover, they have based new investigations on a variety of older inquiries, many of which have been conducted within incommensurable frameworks.

The term "brain multiple" can serve as a shorthand for the multi-level conglomerate of different concepts of "the brain."[31] This expression refers to the term "body multiple," which anthropologist Annemarie Mol coined to describe her experience of the diagnosis and treatment of lower-limb atherosclerosis.[32] Mol's body multiple accounts for the many different ways in which physicians conceived of, talked about, measured, and observed atherosclerosis and the human body during Mol's ethnography at a Dutch university hospital. Although the disease had one name, its epistemic structure varied.

Despite this epistemic multiplicity, neither the body multiple nor the brain multiple are "fragmented."[33] The different ways in which the body multiple was "enacted"

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[31] Thanks to John Tresch for allowing me to borrow the term, on which we will expand elsewhere.
[32] Annemarie Mol, *The Body Multiple: Ontology in Medical Practice* (Durham: Duke University Press, 2007).
[33] Mol, *Body*, 55.

during Mol's ethnography did "not align,"[34] but they came together as one multifaceted concept of atherosclerosis and the pathological body. The body multiple persisted even if two concepts of atherosclerosis contradicted one another. A shifting hierarchization within the multiple allowed for successful diagnosis and treatment even if, for example, test results and patient report were inconsistent.[35] Because each of the different perspectives took each other into account, Mol argued, the body multiple was a "patchwork singularity"[36] and a "composite reality"[37] despite its inherent "manyfoldedness [*sic*],"[38] and *not* an instance of ontological or epistemological "pluralism."

Similarly, the brain multiple is not fragmented. It is distributed across different neuroscientific subdisciplines, times, and places, and it derives its cohesion from the neuroscientific self-understanding of being one discipline ("neuroscience" as opposed to "the neurosciences") and of having one object of study: the cerebralized self. In the words of historian of science Fernando Vidal and social scientist Francisco Ortega, "[t]he *neuro* … is not a single entity but the sum of th[e] materializations" of the ideology that personhood is in the brain.[39]

This brain multiple simultaneously poses epistemological problems and endows the neurosciences with unprecedented authority. On the one hand, present-day neuroscience is undermined by inconsistent concepts of the brain and the mind, for instance, the contradictory union of ideas of fixed localization (or nature) and dynamic plasticity (or nurture). With reference to historian of science Hans-Jörg Rheinberger, one can explain

[34] Mol, *Body*, 40.
[35] Mol, *Body*, 53–85.
[36] Mol, *Body*, 72.
[37] Mol, *Body*, 72.
[38] Mol, *Body*, 84.
[39] Vidal and Ortega, *Being*, 229. See below for a historiography of the idea that mind and personhood are in the brain, or that the brain *is* these things.

these contradictions by stating that the brain multiple is made up of distinct “epistemic things.”[40] Rheinberger defined epistemic things as objects of scientific investigation whose existence depends on the conditions of their observation. Even if, hypothetically, scientists investigated the same chunk of matter in two different experimental setups, the two experiments would study different epistemic objects, because the chunk of matter would exhibit distinct features depending on the tools used and the questions asked in the respective experiment. This means that brain-, mind-, and neuroscientists assess different epistemic “brain” things depending on whether they use lesion experiments, behavioral observations, survey forms, or neuroimaging studies. Hence, anatomical, physiological, (epi)genetic, and hormonal brains are distinct epistemic things, and their epistemic features might clash once they are clumped together as “the brain.”

On the other hand, the heterogeneity of neuroscientific subdisciplines and the associated multiplicity of concepts of “the brain” endow the neurosciences with a seemingly all-encompassing expertise. What field if not “neuroscience” (understood as one field by the broader public) can speak to microbiology, cognition, emotions, pathology, and social behavior at once?

Intersectionality

Besides illuminating the ways in which the brain multiple has allowed for the hand to become a proxy for the brain and mind, the history of handedness research exemplifies the idea that the reach of scientific classifications extends far beyond the characteristics that such classifications are supposed to categorize. Through its integration into

[40] Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford: Stanford University Press, 1997), 28–31.

the brain multiple, which seemingly explains all things human, manual preference has become a signifier for mental and physical dis/abilities, sex/gender, sexual behavior, and race/ethnicity. The interaction of all these categories with classifications according to handedness challenges our concept of intersectionality (the idea that individuals who are members of several minority groups at once are exponentially more marginalized than members of only one minority group).[41]

This is precisely why handedness matters. In industrialized societies that have abandoned forced right-hand usage, manual preference seems insignificant. Yet, the history of the science(s) of handedness suggests that the stereotyping of human subpopulations based on manual preference continues to this day, and it demonstrates that even innocuous categories can reproduce hierarchical social structures that impede social justice. No classification is apolitical, and we must include all of them in our considerations of governance, inclusion, and citizenship.

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[41] Lawyer and critical race theorist Kimberlé W. Crenshaw first used the term "intersectionality" to describe the interlocking power systems of race and sex/gender; Kimberlé W. Crenshaw, "Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics," *University of Chicago Legal Forum*, 1989. See also Kimberlé Williams Crenshaw, *On Intersectionality: Essential Writings* (New York: New Press, 2019). Since the late 1980s, other scholars have elaborated on the concept and added more "vectors" (e.g., class, ability, age, faith) to the "matrix" of intersectional oppression, including Michele Tracy Berger and Kathleen Guidroz, *The Intersectional Approach: Transforming the Academy through Race, Class, and Gender* (Chapel Hill: University of North Carolina Press, 2009); Amy L. Brandzel, *Against Citizenship: The Violence of the Normative* (Urbana, Chicago, Springfield: University of Illinois Press, 2016); Patricia Hill Collins, *Black Feminist Thought: Knowledge, Consciousness, and the Politics of Empowerment*, 2nd ed. (New York, London: Taylor & Francis, 2000); Patricia Hill Collins and Sirma Bilge, *Intersectionality* (Cambridge, Malden: Wiley, 2016); Kathy Davis, "Intersectionality as Buzzword: A Sociology of Science Perspective on What Makes a Feminist Theory Successful," *Feminist Theory* 9, no. 1 (2008), https://doi.org/10.1177/1464700108086364; Patrick R. Grzanka, ed., *Intersectionality: A Foundations and Frontiers Reader* (Boulder: Westview Press, 2014). On the history of the term and movement, see Ange-Marie Hancock, *Intersectionality: An Intellectual History* (New York: Oxford University Press, 2016). See also the literature on standpoint theory, which, acknowledging intersectional oppression, suggests that each individual is the best judge of their experience; e.g., Sandra G. Harding, ed., *The Feminist Standpoint Theory Reader: Intellectual and Political Controversies* (New York: Routledge, 2004).

Proto-Ideas

Before Broca turned manual preference into a medical category and a topic for brain research, the hand and its behavior had already been loaded with social and cultural meaning. Scottish anatomist and neurologist Charles Bell (1774–1842), for instance, concluded in his anatomical study, *The Hand*, that this intricate organ could not have developed by chance. Bell believed that the human hand was the result of a purposeful divine creation, and that the hand was a tool of the superior human mind:

> We ought to define the hand as belonging exclusively to man—corresponding in sensibility and motion with that ingenuity which converts the being who is the weakest in natural defence, to the ruler over animate and inanimate nature.[42]
>
> With respect to the superiority of man being in his mind, and not merely in the provisions of his body, it is no doubt true;—but as we proceed, we shall find how the Hand supplies all instruments, and by its correspondence with the intellect gives him universal dominion.[43]

Bell did not mention manual preference in the text of his treatise, but the accompanying illustrations of the 1865 edition make clear the hierarchies between the left and the right hand. One drawing shows a monkey that is reaching for something outside the image with the left paw.[44] In another illustration, the reader sees a scantily dressed dark-skinned male with a dagger hanging from his neck. This person is crawling on the floor

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[42] Charles Bell, *The Hand: Its Mechanism and Vital Endowments, as Evincing Design*, Bridgewater Treatises on the Power, Wisdom, and Goodness of God as Manifested in the Creation 4 (Philadelphia: Carey, Lea & Blanchard, 1833), 26.
[43] Bell, *Hand*, 40.
[44] Charles Bell, *The Hand: Its Mechanism and Vital Endowments, as Evincing Design*, 7th ed., Bridgewater Treatises on the Power, Wisdom, and Goodness of God as Manifested in the Creation 4 (London: Bell & Daldy, 1865), 13. On the futility and offensive politics of human-ape comparisons, see Jonathan Marks, "The Scientific and Cultural Meaning of the Odious Ape-Human Comparison," in Ellison; Goodman, *The Nature of Difference*.

under a white male's bed and reaches for valuables on the night stand—with his left hand.[45]

These illustrations underlined the monograph's function of demarcating superior and inferior groups both among humans and across species.[46] Bell's text expressed his commitment to a hierarchical divine creation, also called the "Great Chain of Being," with white male humans all the way at the top.[47] Because of the presumed close association between the hand and the mind, actions of the hands bore moral valency and seemed apt in distinguishing between "higher" and "lower" groups in the Great Chain of Being. This idea is mirrored in the use of illustrations of the left monkey paw and the black left hand as contrasts to all ostensibly decent and accomplished uses of white right hands in the remaining illustrations in Bell's textbook.

English physiologist and anatomist George M. Humphry (1820–1896) echoed the close association between the mind and the hand in his treatise on *The Human Foot and the Human Hand*. He insisted that "[t]he [h]and [is] the [o]rgan of the [w]ill" and that

45 Bell, *Hand*, 29.

46 On the expression of a similar sentiment in depictions of laboring hands in twentieth-century art, see Gottfried Korff, "From Brotherly Handshake to Militant Clenched Fist: On Political Metaphors for the Worker's Hand," *International Labor and Working-Class History* 42 (1992), https://doi.org/10.1017/S0147547900011236.

47 Arthur O. Lovejoy, *The Great Chain of Being: A Study of the History of an Idea* (New Brunswick: Transaction Publishers, 2009). On the continued importance of the distinction between "higher" and "lower" species, see Mark J. Brandt and Christine Reyna, "The Chain of Being: A Hierarchy of Morality," *Perspectives on Psychological Science* 6, no. 5 (2011), https://doi.org/10.1177/1745691611414587; William F. Bynum, "The Great Chain of Being after Forty Years: An Appraisal," *History of Science* 13, no. 1 (1975), https://doi.org/10.1177/007327537501300101. On the labor involved in a hierarchical classification of living beings, see Harriet Ritvo, *The Platypus and the Mermaid and Other Figments of the Classifying Imagination* (Cambridge: Harvard University Press, 1997); Mary Pickard Winsor, *Starfish, Jellyfish and the Order of Life: Issues in Nineteenth-Century Science*, Yale Studies in the History of Science and Medicine 10 (New Haven, London: Yale University Press, 1976).

“the hand becomes an organ of expression and an index of character” because the mind works through the hand.[48]

Earlier sources bear witness to more heterodox approaches to the hand as a window into human character. For example, some phrenologists believed that hands could be read like skulls and that the size and shape of the hands within one species varied by age, sex, class, race, and ethnicity.[49] Creating a significantly longer-lasting legacy than the hand-phrenologists, Czech anatomist and physiologist Jan E. Purkyně (1787–1869) classified hand- and fingerprints: his research paved the way for the identification of criminals based on their fingerprints and provided a scientific footing for palmistry and dermatoglyphics.[50]

The concept of the hand as a window into the mind and character persisted in the twentieth century within and beyond the mind and brain sciences. The following chapters provide many examples from mainstream science. An example of a non-scientist who adhered to the idea of the mindful hand is French art historian Henri Focillon (1881–1943). He adopted the idea that hands display “style” and have their own “spirit” as well as a

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[48] George Murray Humphry, *The Human Foot and the Human Hand* (Cambridge: Macmillan and Co., 1861), 156–61.

[49] N.N., *The Hand Phrenologically Considered: Being a Glimpse at the Relation of the Mind with the Organisation of the Body* (London: Chapman and Hall, 1848), 51–57. For another phrenological guide to the hand, see Carter Medicine Co., “Mysteries of Our Hands and Faces: Presented by the Makers of Carter’s Little Liver Pills” (New York, 1900).

[50] Daniel Asen, “Secrets in Fingerprints: Clinical Ambitions and Uncertainty in Dermatoglyphics,” *Canadian Medical Association Journal* 190, no. 19 (2018), https://doi.org/10.1503/cmaj.180057; Andrzej Grzybowski and Krzysztof Pietrzak, “Jan Evangelista Purkynje (1787–1869),” *Clinics in Dermatology* 33, no. 1 (2015), https://doi.org/10.1016/j.clindermatol.2014.07.011; Gyula Gyenis, “A Short History and Some Results of the Dermatoglyphic Studies in Hungary,” *Acta Biologica Szegediensis* 44, 1–4 (2000); H. K. Kumbnani, “Dermatoglyphics: A Review,” *Anthropologist Special Volume* 3 (2007); Joseph Louis Julien Leclercq, *Le caractère et la main: Histoire et documents* (Paris: F. Juven, 1900); Robert J. Meier, “Anthropological Dermatoglyphics: A Review,” *American Journal of Physical Anthropology* 23, S1 (1980), https://doi.org/10.1002/ajpa.1330230509; Chris C. Plato and Ralph M. Garruto, “Historical Notes on Dermatoglyphics: From Purkinje to Cummins,” in *Trends in Dermatoglyphic Research*, ed. Norris M. Durham and Chris C. Plato, Studies in Human Biology 1 (Dordrecht: Springer Netherlands, 1990), https://doi.org/10.1007/978-94-009-2137-5_1; Pál Tábori, *The Book of the Hand: A Compendium of Fact and Legend Since the Dawn of History* (Philadelphia: Chilton Compnay, 1962).

particular "physiognomy."[51] However, Focillon did not use this idea to claim human superiority over other animals or superiority of right-handers over left-handers. He did not discuss the former topic at all. As far as the relationship between the left and the right hand are concerned, Focillon asserted that the left hand was equally able as the right to perform all tasks, which it "renounces in order to assist its partner."[52] Furthermore, Focillon resisted the idea that the hand is a tool of the mind. He conceived of mind and body as a non-hierarchical duality whose cooperation induces creativity and transformation and allows for a variety of forms of being.[53]

Histories

Handedness

As historian of medicine Howard Kushner's account of the continued stigmatization of left-handers in science and medicine showed, Focillon's appreciative concept of the left hand was anything but representative for the twentieth century.[54] Tracing theories about and measures against left-handedness from the nineteenth through the twenty-first centuries, Kushner argued that scientists, physicians, and the broader public have framed left-handedness as a disability. Despite the wide-spread abolishment left-hander conversion in European and North-American schools in the twentieth century, scientists continue to conceptualize non-right-handedness as a pathology and/or a risk factor of abnormalities and disorders.[55]

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[51] Henri Focillon, "In Praise of Hands," in *The Life of Forms in Art*, 2nd ed. (New York: George Wittenborn), 65. This is a translation of the French original, which was first published in 1934.
[52] Focillon, "In Praise of Hands" in *The Life of Forms in Art*, 67.
[53] Focillon, "In Praise of Hands" in *The Life of Forms in Art*, 78.
[54] Kushner, *On*.
[55] On the intensifying and increasingly personal "risk" discourse since early modern times, see Robert A. Aronowitz, *Risky Medicine: Our Quest to Cure Fear and Uncertainty* (Chicago, London: University of

Furthermore, Kushner concluded that “the damage produced by [the scientifically sanctioned] discrimination against left-handers was greater than the supposed pathology resulting from left-handedness.”[56] Similar to the forceful retraining practices of the nineteenth and early twentieth centuries, the continued association of left-handedness with learning disabilities, psychiatric illnesses, “homosexuality,” and other anomalies persistently violates the bodies, rights, aspirations, and public image of left-handers.

Handedness research is an excellent example of the survival of what microbiologist Ludwik Fleck has called “proto-ideas” because of the obvious ways in which old preconceptions and vague theories of the sinister left hand and its relationship to the mind have found their way into scientific theories of manual preference.[57] Analogous to Fleck’s description of the integration of pre-scientific religious and philosophical concepts of syphilis into twentieth-century scientific syphilis theories, handedness researchers have reformulated stigmatizing folk knowledge of left-handedness in medical terms rather than done away with the metaphysical meanings of manual preference.

Kushner’s monograph is the first scholarly history of handedness in medicine and the sciences. Kushner’s argument that scientists continue to think of non-right-

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Chicago Press, 2015); Ulrich Beck, *Risk Society: Towards a New Modernity* (London, Thousand Oaks, New Delhi: SAGE Publications, 1992), Translated by Mark Ritter; Daniel B. Bouk, *How Our Days Became Numbered: Risk and the Rise of the Statistical Individual* (Chicago, London: University of Chicago Press, 2015); Deborah Lupton, *Risk*, 2nd ed. (London: Routledge, 2013); Carlos Novas and Nikolas S. Rose, “Genetic Risk and the Birth of the Somatic Individual,” *Economy and Society* 29, no. 4 (2000), https://doi.org/10.1080/03085140050174750; Gerda Reith, “Uncertain Times: The Notion of ‘Risk’ and the Development of Modernity,” *Time & Society* 13, 2–3 (2004), https://doi.org/10.1177/0961463X04045672. See also the below passage on Ne(ur)oliberalism.

56 Kushner, *On*, 151.

57 Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago: University of Chicago Press, 1981). See also Stig Brorson, “Ludwik Fleck on Proto-Ideas in Medicine,” *Medicine, Health Care and Philosophy* 3, no. 2 (2000), https://doi.org/10.1023/A:1009943420053. Connected to the idea of proto-ideas is historian of science Peter Dear’s argument that “science as natural philosophy” (i.e., weaving facts together not only by evidence but based on what makes sense to the scientist and what seems “natural”) has not ceased to exist in modern science; Peter Dear, *The Intelligibility of Nature: How Science Makes Sense of the World* (Chicago, London: University of Chicago Press, 2006) (quote on p. 177).

handedness as an abnormality appears to stand in stark contrast to Bertrand's aforementioned monograph on the history of left-handers in culture and society, which suggests a gradual but successful liberation of left-handers over the course of the first two thirds of the twentieth century.[58] However, the two accounts are only seemingly contradictory. While teachers and parents have stopped converting left-handers in the twentieth century and handedness has become more of an afterthought in daily life in industrialized societies, the scientific understanding of non-right-handedness exhibits various proto-ideas of deviance and abnormality that are no longer visible in the social standing of non-right-handers in Europe and North America.[59]

While Kushner's and Bertrand's monographs are, to the best of my knowledge, the only book-length histories of handedness by historians, several scholars and writers have published on the history and science of handedness. Psychologist I.C. (Chris) McManus has published the most comprehensive collection of scientific theories, cultural attitudes, social conventions, philosophical concepts, and linguistic peculiarities pertaining to asymmetries in hands, in brains, and on the subatomic level.[60] US-American psychologist Clare Porac recently published a concise overview of both state-of-the-art research and older studies describing the connection between manual preference and brain asymmetry.[61] In each chapter, Porac aimed to determine which theories are "*fact*" and

[58] Bertrand, *Histoire*.
[59] This divergence of the contemporary social acceptance of non-right-handers and the continued scientific stigmatization of non-right-handedness might be due to a statistical version of benevolence and "political correctness" in the sciences. For example, if scientists talk/write about the "risks of" pathologies in individuals with abnormal speech lateralization rather than about concrete "pathologies" of the left-handed population, scientists seemingly have no part in the marginalization of all left-handers as deviant.
[60] McManus, *Right*.
[61] Clare Porac, *Laterality: Exploring the Enigma of Left-Handedness* (Amsterdam: Elsevier Academic Press, 2016).

which ones are "*fiction*."[62] More than three decades prior, psychologist Michael C. Corballis had published a thorough overview of folk beliefs about handedness and cerebral asymmetry, scientific theories of the hand-brain-language relationship including related disorders, and scientific methods to assess manual preference.[63] In a similar mindset as Porac, Corballis intended "to set the record straight and to establish the main facts of human laterality as they are currently known,"[64] a desire that also permeates McManus's monograph. Besides the obvious issue of topicality, the main difference between these works is that McManus attended to popular culture and to scientific studies of asymmetry beyond the hand and brain, whereas Porac and Corballis limited themselves to scientific theories about handedness and brainedness and whether these are exceptionally human qualities.[65]

Psychologist Lauren J. Harris has been publishing on the history of scientific handedness research since the 1980s. Particularly noteworthy are Harris's overviews of nineteenth- and twentieth-century theories of handedness, the core ideas of which persist in contemporary research on brain asymmetry and manual preference.[66] The lasting

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[62] E.g., Porac, *Laterality*, 13; 31; 45–46; 81; 113; 119; 129; 149; 172; 194–195. Italics in the original.

[63] Michael C. Corballis, *Human Laterality* (New York, London: Academic Press, 1983).

[64] Corballis, *Human*, ix.

[65] Further book-length sources on the science of manual preference and other physical lateralities include Guy Azémar, *L'homme asymétrique: Gauchers et droitiers face à face* (Paris: CNRS éditions, 2003); Henry Hécaen, *Les gauchers: Étude neuropsychologique* (Paris: Presses Universitaires de France, 1984); Ernst Siegrist, "Zur Händigkeit des Menschen" (Dissertation, Philosophisch-Historische Fakultät, Universität Basel, 1956). Less scholarly accounts of theories about handedness and the treatment of left-handers in culture and society include Michael Barsley, *The Left-Handed Book: An Investigation into the Sinister History of Left-Handedness* (London, Toronto: Souvenir Press, 1966); Dominique Pignon, *La main sauvage: Les gauchers et les autres* (Paris: Editions Ramsay, 1987); Melissa Roth, *The Left Stuff: How the Left-Handed Have Survived and Thrived in a Right-Handed World* (Lanham: M. Evans & Company, 2005); Rik Smits, *The Puzzle of Left-Handedness* (London: Reaktion Books, 2012); Hermann-Josef Zoche, *Ich sehe die Welt auch von der anderen Seite! Die besonderen Talente der Linkshänder* (Kreuzlingen, Munich: Ariston, 2002).

[66] E.g., Lauren J. Harris, "Laterality of Function in the Infant: Historical and Contemporary Trends in Theory and Research," in *Manual Specialization and the Developing Brain*, ed. Gerald Young et al. (New York: Academic Press, 1983); Lauren J. Harris, "Louis Pierre Gratiolet, Paul Broca, et al. on the Question of a Maturational Left-Right Gradient: Some Forerunners of Current-Day Models," *Behavioral and Brain*

commitments of these theories are predominantly conceptual (for example, the idea that asymmetrical brain growth influences speech lateralization and manual preference) and normative (for example, the notion that left-handedness is pathological). In agreement with Kushner's work, Harris argued that "[n]early all" seemingly outdated and stereo-type-laden "theories, facts, and fancies about left-handedness" have lived on "in one form or another."[67]

Neuro-Centrisms

My focus is on integrating this observation of surviving proto-ideas about hands and brains into the larger trajectory of neuroscientific thought and its political stakes. Studying the ways in which permutations of early ideas about the hand-brain connection have persisted in the twentieth and twenty-first centuries leads to a deeper understanding of neuroscientific epistemologies and the sometimes-shaky ground on which the wide-spread faith in brain-based explanations of human behavior and identity rest.

Akin to the ways in which the social stigma of left-handedness has preceded scientific theories of the deviant left-hander, the doctrine that manual preference originates in the brain was based on a metaphysical principle. Neuro-centrism, the idea "that the mind … is what the brain does and that we are essentially (though not exclusively) our

Sciences 7, no. 4 (1984), https://doi.org/10.1017/S0140525X00028338; Lauren J. Harris, "Cultural Influences on Handedness: Historical and Contemporary Theory and Evidence," in Coren, *Left-Handedness*; Lauren J. Harris, "Early Theory and Research on Hemispheric Specialization," *Schizophrenia Bulletin* 25, no. 1 (1999), https://doi.org/10.1093/oxfordjournals.schbul.a033359; Lauren J. Harris, "In Fencing, What Gives Left-Handers the Edge? Views from the Present and the Distant Past," *Laterality* 15, 1-2 (2010), https://doi.org/10.1080/13576500701650430.

[67] Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 68.

brains" has made possible the association of manual preference with the brain, cognition, and character.[68]

Most contemporary scholars in the humanities and social sciences agree that neuro-centrism is (or, in accordance with the observation of a brain multiple, that neuro-centrism*s are*) widespread in industrialized societies.[69] These scholars have also observed that neuroscientific explanations of difference have enormous political power: they tend to marginalize already disenfranchised communities even more, because marginalized individuals are not in the position to decide which brains ought to be considered "normal" and which ones ought to be considered "abnormal" or "pathological."

As Vidal and Ortega have argued, the conviction that everything human can be explained with recourse to the brain was a precursor, and *not* a consequence, of empirical neuroscience.[70] English philosopher and physician John Locke (1632–1704) laid the crucial—and arbitrary—foundations for subsequent neuro-centrisms by locating the self at the intersection of consciousness and memory, placing personhood in the brain. Locke and his followers thereby created the "cerebral subject," that is, a subject that is defined by their brain more than by anything else.[71]

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[68] Vidal and Ortega, *Being*, 9. On the "cerebralization" of numerous other characteristics, behaviors, and emotions over the course of the past three decades, see Vidal and Ortega, *Being*, 58–188.
[69] See, e.g., David W. Bates and Nima Bassiri, eds., *Plasticity and Pathology: On the Formation of the Neural Subject* (Berkeley, New York: Townsend Center for the Humanities, University of California, Berkeley; Fordham University Press, 2016); Francisco Ortega and Fernando Vidal, eds., *Neurocultures: Glimpses into an Expanding Universe* (Frankfurt am Main: Peter Lang, 2011); Martyn Pickersgill and Ira van Keulen, eds., *Sociological Reflections on the Neurosciences* (Bingley: Emerald Group Publishing, 2011); Davi Johnson Thornton, *Brain Culture: Neuroscience and Popular Media* (New Brunswick: Rutgers University Press, 2011); David Wastell and Sue White, *Blinded by Science: The Social Implications of Epigenetics and Neuroscience* (Bristol, Chicago: Policy Press, 2017).
[70] Vidal and Ortega, *Being*.
[71] Vidal and Ortega, *Being*, 13. In the 2000s, Vidal and Ortega popularized the term "cerebral subject"; Francisco Ortega, "The Cerebral Subject and the Challenge of Neurodiversity," *BioSocieties* 4 (2009); Francisco Ortega and Fernando Vidal, "Mapping the Cerebral Subject in Contemporary Culture," *RECIIS* 1, no. 2 (2007), https://doi.org/10.3395/reciis.v1i2.90en; Fernando Vidal, "Le sujet cérébral: Une esquisse historique et conceptuelle," *Psychiatrie, Sciences humaines, Neurosciences* 3, no. 1 (2005),

Without this initial belief in the centrality of the brain, empirical studies of the brain and mind simply would not have made much sense, or at least they would not have found as many adherents.[72] Contemporary neuro-cultures are thus an effect, not the cause, of the faith in the "neuro" in industrialized societies.[73] Notwithstanding the circular relationship between "reinforc[ing]" neuroscientific empirical evidence and the metaphysical justification of neuroscientific investigations,[74] the *a priori* idea of "brainhood" has become a core feature of modernity.[75]

Vidal and Ortega also claimed that the brain-, mind-, and neurosciences have not updated their concepts since the late seventeenth century, no matter how cutting-edge their technologies and experimental paradigms seem: "[a] fundamental ideological continuity" has characterized the brain and mind sciences since Locke's and followers' popularization of the idea that the brain is the organ of the mind.[76]

Biologist and historian of science Olaf Breidbach already observed over two decades ago that there has not been a grand theoretical or methodological revolution in the sciences of the mind and brain since the late eighteenth century, and that contemporary approaches to the brain are merely methodologically refined and do not pose a conceptual

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https://doi.org/10.1007/BF03006830. To my knowledge, this term had rarely been used before that, and mainly in clinical contexts. The concept of the brain-centered human, or "homo cerebralis," however, precedes Vidal's and Ortega's work; Michael Hagner, *Homo cerebralis: Der Wandel vom Seelenorgan zum Gehirn* (Berlin: Berlin Verlag, 1997).

[72] Vidal and Ortega, *Being*, 21–57; 227–231.

[73] Vidal and Ortega, *Being*, 13–21.

[74] Vidal and Ortega, *Being*, 42. On the "strangely self-referential universe" in which in which neuroscientists decide about what the world is, how it should be, and how their research should be used to get there, see also Stephen T. Casper, "History and Neuroscience: An Integrative Legacy," *Isis* 105, no. 1 (2014), https://doi.org/10.1086/675554 (quote on p. 131).

[75] Vidal and Ortega, *Being*, 32. See also Fernando Vidal, "Brainhood, Anthropological Figure of Modernity," *History of the Human Sciences* 22, no. 1 (2009), https://doi.org/10.1177/0952695108099133.

[76] Vidal and Ortega, *Being*, 7.

break with late-nineteenth-century ideas of what the brain is and does.[77] Breidbach traced the "materialization of the self" through the changing questions that brain and mind scientists asked, from the search for the organ of the soul in the late eighteenth century through philosophy of mind in the late twentieth century. These inquiries shifted from the question of *what* the brain is to the question of *how* it works.[78] Breidbach concluded that no coherent theory of the cerebralized self exists, and he doubted the possibility of such a theory because of the metaphysical grounding of the neurosciences.

Several historians have traced conceptual continuities and epistemological shifts in the mind-, brain-, and neurosciences in more detail. Physician and medical historian Robert Martensen, for example, provided insight into the reasons why the concept of cerebral personhood (as opposed to a humoral bodily system) emerged in the second half of the seventeenth century, and why this shift was initiated in England.[79] Martensen argued that the Scientific Revolution and the Reformation instilled a particularly fierce opposition between the church, the monarchy, and natural philosophy. In their quest to rigorously separate themselves from religion and politics, natural philosophers aimed to strip the concepts of life, body, and self of all metaphysical meaning and redefined them in anatomical and physiological terms.[80]

The metaphysical idea of the brain as the seat of the soul lingered until the mid-nineteenth century in the German- and French-speaking world, as historian of science

[77] Olaf Breidbach, *Die Materialisierung des Ichs: Zur Geschichte der Hirnforschung im 19. und 20. Jahrhundert*, Suhrkamp Taschenbuch Wissenschaft 1276 (Frankfurt am Main: Suhrkamp, 1997).
[78] Breidbach, *Materialisierung*, 13.
[79] Robert L. Martensen, *The Brain Takes Shape: An Early History* (Oxford: Oxford University Press, 2004).
[80] On the birth of a scientific mind out of a crisis of religious authority, see also George Makari, *Soul Machine: The Invention of the Modern Mind* (New York: W. W. Norton & Company, 2015).

Michael Hagner illustrated.[81] Through vivisections in the eighteenth century, researchers determined the brain structure(s) that, if destroyed, led to the death of an animal. These findings provided an ideological middle ground between empiricists and metaphysicians: the soul could no longer be understood as entirely immaterial, but scholars could pinpoint a life-providing organ in the brain that could still be defined as the seat of the soul.[82]

Only few decades later, German philosopher Immanuel Kant (1724–1804) and others broke with this intellectual compromise in light of anatomists' inability to derive philosophical insights from their studies of the brain. In Hagner's view, the abandonment of a Cartesian understanding of the brain and soul (that is, the idea that there is a dualism of brain/matter and mind/soul) in favor of a purely materialistic understanding of the brain revolutionized human self-perception over the course of the eighteenth and early nineteenth centuries in a way comparable to later changes in human self-understanding in response to Darwinism and Freudianism.[83]

More than any other epistemological shift, the idea that specific abilities and characteristics can be localized in circumscribed brain areas enabled the materialistic understanding of the brain and the person—and the association of handedness with the brain, mind, and character. After German physician Franz J. Gall's (1758–1828) organology (and its popularization as "phrenology") had taken Europe by storm, anatomists abandoned Gall's and the phrenologists' psychophysiological claims and proposed more

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[81] Hagner, *Homo*. On the ways in which philosophical considerations of the mind and lingering Cartesian ideas might have hindered the "progress" of brain science, see Robert Maxwell Young, *Mind, Brain and Adaptation in the Nineteenth Century: Cerebral Localization and Its Biological Context from Gall to Ferrier* (Oxford: Clarendon Press, 1970).
[82] Hagner, *Homo*, ch. 1.
[83] Hagner, *Homo*, ch. 2. Cf. ch. 5 on Romantic natural philosophers' continued adherence to the idea of the brain as the organ of an immaterial soul. See also Michael Hagner, "The Soul and the Brain between Anatomy and Naturphilosophie in the Early Nineteenth Century," *Medical History* 36, no. 1 (1992), https://doi.org/10.1017/S0025727300054600.

radically material investigation of the brain and the localization of its functions. German Romantic physiologists, including Karl F. Burdach (1776–1847) and Carl G. Carus (1789–1869), divided the brain into fewer larger sections to balance phrenological ideas with equipotentiality (that is, the theory that any part of the brain can theoretically fulfill any function and that there are no strictly localized brain centers).[84]

These investigations marked the transition from inductive brain research to the late-nineteenth-century tradition of experimental physiological brain localization. Hagner identified the unsuccessful European revolutions of 1848 as a crucial turning point in physiological concepts towards the complete abandonment of the search for the soul. Under a new materialistic paradigm, physiologists and clinicians investigated the electrical excitability of the brain and its connection with reflexes, mental functions, and pathologies.[85]

The success of physiological brain localization heavily rested on the increasing collaboration between psychiatrists, physiologists, and anatomists towards the later nineteenth century. The combination of individual case studies and galvanic experiments allowed for the conceptualization of the brain as a conglomerate of centers of localized brain functions. This merger of disciplines allowed for a redefinition of the categories of "normality" and "abnormality": instead of the medical categories of health and disease, physicians and scientists henceforth relied on notions of the "normal function" or

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[84] Hagner, *Homo*, chs. 3 and 4.
[85] Hagner, *Homo*, ch. 7. See also Michael Hagner, "The Electrical Excitability of the Brain: Toward the Emergence of an Experiment," *Journal of the History of the Neurosciences* 21, no. 3 (2012), https://doi.org/10.1080/0964704X.2011.595634. On the electrical brain, see also Cornelius Borck and Ann Hentschel, *Brainwaves: A Cultural History of Electroencephalography* (London: Routledge, 2018), Translated by Ann M. Hentschel.

"dysfunction" of the brain.[86] Although none of these inquiries disproved the existence of an organ of the soul, the obsession with how the brain works and where brain functions are localized led to a thorough cerebralization of personhood by the late nineteenth century.[87]

Localization

The faith in brain asymmetry and the localization of cognitive functions has been foundational to forging a connection between the brain and the hand.[88] Scholars besides Hagner have traced the history of localization theory and its usefulness in establishing human hierarchies, the latter of which became an integral commitment of handedness research. Most notably, historian of medicine and science Anne Harrington has argued that the idea of a "double brain" (that is, both brain hemispheres are fully functional and could execute all necessary functions by themselves and compensate for one another in case of a pathology) initially seemed to explain human agency and morality.[89] Very soon, Broca turned the study of brain asymmetry into an inquiry into human exceptionalism, and his successors proceeded to link brain laterality with gender identity, sexual orientation, intellectual abilities, criminal tendencies, mental disturbances, and psychiatric illnesses.

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[86] Hagner, *Homo*, ch. 8. See also Breidbach, *Materialisierung*, chs. 8 and 9; Michael Hagner, "Cultivating the Cortex in German Neuroanatomy," *Science in Context* 14, no. 4 (2001), https://doi.org/10.1017/S0269889701000242.
[87] Michael Hagner, *Der Geist bei der Arbeit: Historische Untersuchungen zur Hirnforschung* (Göttingen: Wallstein Verlag, 2006).
[88] On the early history of localization, see Young, *Mind*. For a critique of the continued reliance on rigid localization, see Geert-Jan Rutten, *The Broca-Wernicke Doctrine: A Historical and Clinical Perspective on Localization of Language Functions* (New York: Springer, 2017).
[89] Anne Harrington, *Medicine, Mind, and the Double Brain: A Study in Nineteenth-Century Thought* (Princeton: Princeton University Press, 1987).

Sociologist Susan L. Star has shown that the success of localizationism over alternative theories was itself a consequence of social hierarchies.[90] From Broca's day until 1906, when "the map [of the brain and its functions] and its underlying premises had become an unquestioned fact," localizationism competed with and was often virtually indistinguishable from alternative theories of brain function.[91] Localizationism triumphed despite evidence against the rigid localization of function because the proponents of localizationism had more institutional leverage and managed to integrate clinical with physiological research.[92]

Historian of science and medicine Katja Guenther traced the influence of the localizationist doctrine through the twentieth century and illustrated that nineteenth-century doctrines of the localization of brain function have conceptually shaped psychoanalysis and neurology.[93] In fact, Guenther argued that the fields of neuropsychiatry, psychoanalysis, and neurology share their roots in localizationism, and that their histories cannot be fully comprehended separately from one another. Most of the perceived breaks and oppositions between the fields in the twentieth century, she argued, were in fact "internal reformulations" that aimed to escape too-rigid localizationist doctrines in different ways.[94]

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[90] Susan Leigh Star, *Regions of the Mind: Brain Research and the Quest for Scientific Certainty* (Stanford: Stanford University Press, 1989).
[91] Star, *Regions*, 4. The major event in 1906 that (almost) brought closure to the debate surrounding localizationism was the publication of English physiologist Charles S. Sherrington's (1857–1952) *The Integrative Action of the Nervous System*. On lingering controversies in North America, see Tabea Cornel, "Something Old, Something New, Something Pseudo, Something True: Pejorative and Deferential References to Phrenology since 1840," *Proceedings of the American Philosophical Society* 161, no. 4 (2017).
[92] On the flaws of the localizationist doctrine from a scientific perspective, see Rutten, *The Broca-Wernicke Doctrine*.
[93] Katja M. Guenther, *Localization and Its Discontents: A Genealogy of Psychoanalysis and the Neuro Disciplines* (Chicago: University of Chicago Press, 2015).
[94] Guenther, *Localization*, 14.

Continuity

In line with Breidbach, Guenther, Ortega, and Vidal, who all argued that there has not been a radical paradigm shift in the neurosciences for the past few centuries, Hagner also insisted on the importance of conceptual continuities in the sciences of the brain and mind. New technologies and new data have not caused a break with the concept of the brain as the cerebralized mind; instead, methodological shifts have been and continue to be subordinate to old frameworks.[95] Some of these interpretative "traditions" are specific to distinct subfields within the sciences of the mind and brain, and they can disappear and reappear as alleged innovations.[96] Covered up by a pervasive "revolutionary rhetoric" surrounding new methods and ways of storing or handling data,[97] Hagner contended that there is a "poverty of theory" at the core of the brain-, mind-, and neurosciences that prevents true paradigmatic changes.[98]

One of the most politically problematic concepts that has persisted since the early nineteenth century is the idea that exceptional human qualities derive from exceptional brains. Based on this assumption, researchers have constructed the elite brain, the male brain and the female brain, the criminal brain, and not least the left-handed brain and the right-handed brain. These categories can overlap (for example, the male brain and the elite brain have been defined with much overlap) or remain distinct.[99]

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[95] Hagner, *Geist*.
[96] Hagner, *Geist*, 8.
[97] German original: "Revolutionsrhetorik"; Hagner, *Geist*, 22.
[98] German original: "Theoriearmut"; Hagner, *Geist*, 16.
[99] On "elite brains" and their intersections with other brain types, see Michael Hagner, *Geniale Gehirne: Zur Geschichte der Elitegehirnforschung* (Göttingen: Wallstein Verlag, 2004); Michael Hagner, "Genius, Gender, and Elite in the History of the Neurosciences," in Karafyllis; Ulshöfer, *Sexualized Brains*. On the "criminal brain," see David G. Horn, *The Criminal Body: Lombroso and the Anatomy of Deviance* (New York, London: Routledge, 2003); Jarkko Jalava, Stephanie Griffiths and Michael Maraun, *The Myth of the Born Criminal: Psychopathy, Neurobiology, and the Creation of the Modern Degenerate* (Toronto, Buffalo, London: University of Toronto Press, 2015); R. F. Wetzell, *Inventing the Criminal: A History of*

Caught within centuries-old conceptual bounds, the modern "brain" has an unavoidable and inevitable "double character"[100] as "a simultaneously natural and cultural object" because it originated at the intersection of matter and a designation as *the* organ of the mind and personhood.[101] Vidal and Ortega supported the insight that the brain is much more than matter by suggesting that "[t]he *neuro* … ends up serving a multiplicity of interests in contexts ruled more by economic or political considerations … than by the ideals of logic, verifiability, and objectivity."[102]

Social scientist Nikolas Rose and historian of science Joelle Abi-Rached would object to the view that the neurosciences are first and foremost characterized by conceptual continuity.[103] Their optimistic account of the history of neuroscience proper suggests that neuroscientists of the twentieth century have broken radically with older notions of the

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German Criminology, 1880–1945 (Chapel Hill: University of North Carolina Press, 2003). On the sexed/gendered brain in the nineteenth century and its uptake in the popular discourse, see, e.g., Tabea Cornel, "Matters of Sex and Gender in F.J. Gall's Organology: A Primary Approach," *Journal of the History of the Neurosciences* 23, no. 4 (2014), https://doi.org/10.1080/0964704X.2014.885097; Rachel Ann Malane, *Sex in Mind: The Gendered Brain in Nineteenth-Century Literature and Mental Sciences*, Studies in Nineteenth-Century British Literature 22 (New York: Peter Lang, 2005); Cynthia Russett, *Sexual Science: The Victorian Construction of Womanhood* (Cambridge: Harvard University Press, 1991); Alison Winter, *Mesmerized: Powers of Mind in Victorian Britain* (Chicago: University of Chicago Press, 2000). On the related obsession with the images and measurements related to certain types of brains, see Hagner, *Geist*, 165–222; Michael Hagner, "Skulls, Brains, and Memorial Culture: On Cerebral Biographies of Scientists in the Nineteenth Century," *Science in Context* 16, no. 1 (2003), https://doi.org/10.1017/S0269889703000784. On contemporary neuroimaging methods and the political power of brain scans, see Morana Alač, *Handling Digital Brains: A Laboratory Study of Multimodal Semiotic Interaction in the Age of Computers* (Cambridge: MIT Press, 2011); Anne Beaulieu, "Images Are Not the (Only) Truth: Brain Mapping, Visual Knowledge, and Iconoclasm," *Science, Technology, & Human Values* 27, no. 1 (2002), https://doi.org/10.1177/016224390202700103; Joseph Dumit, *Picturing Personhood: Brain Scans and Biomedical Identity* (Princeton, Woodstock: Princeton University Press, 2004); Kelly A. Joyce, *Magnetic Appeal: MRI and the Myth of Transparency*, Cornell Paperbacks (Ithaca: Cornell University Press, 2008); Jan de Vos, "The Iconographic Brain: A Critical Philosophical Inquiry into (the Resistance of) the Image," *Frontiers in Human Neuroscience* 8 (2014), https://doi.org/10.3389/fnhum.2014.00300; Deena S. Weisberg et al., "The Seductive Allure of Neuroscience Explanations," *Journal of Cognitive Neuroscience* 20, no. 3 (2008), https://doi.org/10.1162/jocn.2008.20040.

[100] German original: "Doppelcharakter"; Hagner, *Geist*, 163.

[101] German original: "ein zugleich natürliches und kulturelles Objekt"; Hagner, *Geist*, 9.

[102] Vidal and Ortega, *Being*, 11.

[103] Nikolas S. Rose and Joelle M. Abi-Rached, *Neuro: The New Brain Sciences and the Management of the Mind* (Princeton, Oxford: Princeton University Press, 2013).

brain and mind. By "neuroscience proper," I mean the mechanistically oriented interdisciplinary conglomerate of the sciences of the mind and brain, mathematics, physics, chemistry, and computer science whose institutionalization in the 1960s Rose and Abi-Rached connected with the birth of a novel "thought style," to borrow Fleck's terminology once more.[104]

Rose and Abi-Rached recounted the "key mutations" that make up modern neuroscience at the conceptual, technological, economic, and biopolitical levels.[105] They specified four "imaginaries" that have reshaped the interaction of the neurosciences with humans in the twentieth century:[106] the psychopharmacologically mediated "neuromolecular gaze" that encompasses a chemical and cellular understanding of personhood and pathology[107]; the application of genetic principles within brain science; the concepts of neural plasticity and a malleable brain; and the visual accessibility of the brain and its functions through imaging methods.

In contrast to the aforementioned historical arguments that the concept of the cerebralized mind and personhood go back to Locke, Rose and Abi-Rached argued that the innovative neuromolecular gaze has completely supplanted previous psychological concepts of the brain and pulled the mental into the realm of the physical. Moreover, they suggested that the neuromolecular gaze has done away with traditional "notions of human beings as individualized, discrete, autonomous, coherent subjects, free to choose."[108]

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[104] Rose and Abi-Rached, *Neuro*, 43.
[105] Rose and Abi-Rached, *Neuro*, 9.
[106] Rose and Abi-Rached, *Neuro*, 9.
[107] Rose and Abi-Rached, *Neuro*, 38; 44.
[108] Rose and Abi-Rached, *Neuro*, 24. However, Rose and Abi-Rached saw this radical shift only in the neuroscientific realm and assume that human self-understanding as conscious agents will not change. Instead, they suggested that the neurobiological understanding of the self might get added on to the individual self-understanding; Rose and Abi-Rached, *Neuro*, 223.

Instead, human thoughts, emotions, characteristics, and behaviors can now be understood as genetically-dependent neuronally-mediated physical entities that are open to pharmacological intervention.[109]

Neurological Humanity

As anthropologist Tobias Rees argued, the neuromolecular gaze, like any doctrine about the brain and its functions, brought with it certain ethical commitments. Thus, we can consider theories of the brain to have both intellectual and moral content. Rees termed these intellectual-moral hybrids ways of "being neurologically human."[110] Beginning with Spanish anatomist Santiago Ramón y Cajal's (1852–1934) staining of the neuron and ending with French neurobiologist Alain Prochiantz's (b. 1948) work on adult neurogenesis (that is, the continuous birth of neurons in the mature brain), Rees illustrated the freedom and limitations that each way of knowing "the brain" imposed on our view of the individual and social interaction. Ramón y Cajal, for instance, saw the neurological human as "an exquisite forest" of individual neurons that required "cultivation."[111] The idea of the brain as "a chemical, synaptic machine," which originated in the 1950s and was a prerequisite to the neuromolecular gaze, implied that human brains and selves were fixed and could be altered only through neurochemical (that is, psychopharmacological) intervention.[112] Finally, the view of a cellular, plastic brain freed neurological humanity from determinism and allowed for neural and cognitive self-determination.

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[109] Rose and Abi-Rached, *Neuro*, 152.
[110] Tobias Rees, "Being Neurologically Human Today: Life and Science and Adult Cerebral Plasticity (an Ethical Analysis)," *American Ethnologist* 37, no. 1 (2010), https://doi.org/10.1111/j.1548-1425.2010.01247.x; Tobias Rees, *Plastic Reason: An Anthropology of Brain Science in Embryogenetic Terms* (Oakland: University of California Press, 2016), 198–218.
[111] Rees, *Plastic*, 199–200.
[112] Rees, *Plastic*, 211.

Because of the sometimes-opposing ethical commitments of different ways of being neurologically human, it is crucial to recognize the past and present co-existence of concepts of "the brain" since the nineteenth century. Historians of medicine and science Stephen T. Casper and Delia Gavrus, for instance, provided insight into the conceptual diversity on "the margins of the mind and brain sciences" as a conscious push-back against positivistic and teleological grand narratives of the brain and mind sciences.[113] Casper and Gavrus's edited volume shows clearly the heterogeneity of meanings of "the brain" that have fueled the rise of the brain and mind sciences since the nineteenth century.[114] Various and often incommensurable ways of looking at the brain—from the recording of animal behavior[115] to human neurosurgery[116] and from the measurement of electrical charges of single brain cells[117] to psychopharmaceutical interventions[118]—have made possible the far and wide reach of neuroscience in industrialized societies. Hiding behind the words "the brain," these various understandings have become manifest in photographs and textbooks, which scientists have transported between continents and across disciplinary boundaries.[119]

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113 Delia Gavrus and Stephen T. Casper, "Technique, Technology, and Therapy in the Brain and Mind Sciences," in Casper; Gavrus, *The History of the Brain and Mind Sciences*, 7.
114 Stephen T. Casper and Delia Gavrus, eds., *The History of the Brain and Mind Sciences: Technique, Technology, Therapy* (University of Rochester Press: Rochester, 2017).
115 L. S. Jacyna, "'We Are Veritable Animals': The Nineteenth-Century Paris Menagerie as a Site for the Science of Intelligence," in Casper; Gavrus, *The History of the Brain and Mind Sciences*.
116 Thomas Schlich, "'Physiological Surgery': Laboratory Science as the Epistemic Basis of Modern Surgery (and Neurosurgery)," in Casper; Gavrus, *The History of the Brain and Mind Sciences*.
117 Max Stadler, "Circuits, Algae, and Whipped Cream: The Biophysics of Nerve, ca. 1930," in Casper; Gavrus, *The History of the Brain and Mind Sciences*.
118 Brian P. Casey, "Salvation through Reductionism: The National Institute of mental Health and the Return to Biological Psychiatry," in Casper; Gavrus, *The History of the Brain and Mind Sciences*.
119 Frank W. Stahnisch, "'What Was in Their Luggage?': German Refugee Neuroscientists, Migrating Technologies, and the Emergence of Interdisciplinary Research Networks in North America, 1933 to 1963," in Casper; Gavrus, *The History of the Brain and Mind Sciences*.

The same holds true for the late twentieth century. Anthropologist Tanya Luhrmann suggested that the neuromolecular gaze did not supplant but complement older concepts of "the brain" in clinical psychiatry.[120] Based on ethnographic research in the late 1980s and early 1990s, Luhrmann argued that the field exhibited a parallelism of diagnosis-focused pharmacological and dynamic psychotherapy-oriented approaches.[121] Instead of regarding both approaches "different tools in a common toolbox," medical practitioners consciously labored to reconcile the two models of patients and their brains.[122]

Ne(ur)oliberalism

Handedness researchers of the past one and a half centuries have struggled with the question of how plastic the brain is, and whether manual behavior leaves a lasting impact on neural function or the other way around. Rees described the doctrine of structural brain plasticity (in particular adult neurogenesis) as a "radically novel" way of being neurologically human,[123] and Rose and Abi-Rached identified plasticity as a central concept in neuroscience proper.[124] Other scholars have pointed to the dangers of the seemingly groundbreaking concept. Philosopher Catherine Malabou, for example, inquired into the extent to which the knowledge of a malleable brain can subjugate individuals to the

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[120] Tanya M. Luhrmann, *Of Two Minds: An Anthropologist Looks at American Psychiatry* (New York: Vintage Books, 2001).

[121] On the rise of psychopharmacology, see also David Healy, *The Antidepressant Era* (Cambridge, London: Harvard University Press, 1997); David Healy, *Let Them Eat Prozac: The Unhealthy Relationship between the Pharmaceutical Industry and Depression* (New York, London: New York University Press, 2004); David Healy, *The Creation of Psychopharmacology* (Cambridge, London: Harvard University Press, 2002).

[122] Luhrmann, *Of*, 7.

[123] Rees, *Plastic*, 218. On recent doubts whether adult neurogenesis actually exists in humans, see Jason S. Snyder, "Questioning Human Neurogenesis," *Nature* 555, no. 7696 (2018), https://doi.org/10.1038/d41586-018-02629-3.

[124] On the differing concepts of "plasticity" in Rees's resp. Rose and Abi-Rached's work, see Rees, *Plastic*, 259–61. On more plasticities, see Bates and Bassiri, *Plasticity*.

demands of capitalism and neoliberal flexibility rather than liberate them to have brains of their own making.[125] Malabou suggested that a lack of engagement with neuroscientific doctrines about selfhood leads to a habit of letting the political and economic system dictate what one's brain and self should be like. In a neoliberal corporation-oriented economy that has embraced the idea of a malleable brain, the brain is transformed into "personal capital," which needs to be molded and enhanced in the interest of "employability" and "flexibility."[126]

Malabou was not alone in connecting the neoliberal idea of individual responsibility to be healthy and productive (which also left its mark on late-twentieth- and twenty-first-century handedness research) with the neurosciences. Sociologist Victoria Pitts-Taylor has validated Malabou's perception that brain plasticity is a powerful trope in the neoliberal work environment by juxtaposing the celebration of brain plasticity as creative malleability with a rhetoric of biological determinism and governmentality.[127] The false promise of empowerment through a neuroscientific model of the brain is strongly normative and blames the non-conforming and the allegedly un-self-disciplined. Concepts such as self-care, responsibility, enhancement, risk-aversion, and flexibility all come with the popular plasticity package.

Moving beyond this critique of the normative power of the concept of brain plasticity, Pitts-Taylor also showed that neuroscientists themselves are rarely committed to

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[125] Catherine Malabou, *What Should We Do with Our Brain?* (New York: Fordham University Press, 2008), Translated by Sebastian Rand. On neoliberalism, see also Nikolas S. Rose, "Governing 'Advanced' Liberal Democracies," in *Foucault and Political Reason: Liberalism, Neo-Liberalism, and Rationalities of Government*, ed. Andrew Barry, Thomas Osborne and Nikolas S. Rose (Chicago: University of Chicago Press, 1996); Gilles Deleuze, "Postscript on the Societies of Control," *October* 59 (1992).
[126] Malabou, *What*, 46.
[127] Victoria Pitts-Taylor, "The Plastic Brain: Neoliberalism and the Neuronal Self," *Health* 14, no. 6 (2010), https://doi.org/10.1177/1363459309360796.

malleability and environmental effects.[128] Instead of treating the brain as an embodied organ that is shaped by individual experience and the social structures in which selfhood is embedded, neuroscientists often treat the brain as an isolated entity and fall back on biological determinism.[129]

Nature vs. Nurture

The call for a more embodied treatment of the brain that accounts for experience-dependent plasticity is most pervasive in feminist critiques of the contemporary neurosciences. A growing number of scholars from the humanities, social sciences, and neurosciences have argued that cognition, mind, and personhood cannot be reduced to the brain and that, in particular, dichotomous understandings of femininity/femaleness and masculinity/maleness cannot be mapped onto the brain.[130] Psychologist and science communicator Cordelia Fine has coined the term "neurosexism" to describe both stereotypically

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[128] Victoria Pitts-Taylor, *The Brain's Body: Neuroscience and Corporeal Politics* (Durham: Duke University Press, 2016).

[129] On the lack of commitment to environmentally shaped brains, see also Cordelia Fine et al., "Plasticity, Plasticity, Plasticity … and the Rigid Problem of Sex," *Trends in Cognitive Sciences* 17, no. 11 (2013), https://doi.org/10.1016/j.tics.2013.08.010. On the importance of lay concepts that make possible the success of scientific concepts of plasticity, see Martyn Pickersgill, Paul Martin, and Sarah Cunningham-Burley, "The Changing Brain: Neuroscience and the Enduring Import of Everyday Experience," *Public Understanding of Science* 24, no. 7 (2015), https://doi.org/10.1177/0963662514521550. On the bias inherent in biological explanations of social categories, see also Gisela T. Kaplan and Lesley J. Rogers, *Gene Worship: Moving beyond the Nature/Nurture Debate over Genes, Brain, and Gender* (New York: Other Press, 2003).

[130] E.g., Robyn Bluhm, Anne J. Jacobson and Heidi L. Maibom, eds., *Neurofeminism: Issues at the Intersection of Feminist Theory and Cognitive Science* (New York: Palgrave Macmillan, 2012); Anne Fausto-Sterling, *Sexing the Body: Gender Politics and the Construction of Sexuality* (New York: Basic Books, 2000); Janet S. Hyde et al., "The Future of Sex and Gender in Psychology: Five Challenges to the Gender Binary," *American Psychologist* 74, no. 2 (2018), https://doi.org/10.1037/amp0000307; Rebecca M. Jordan-Young, *Brain Storm: The Flaws in the Science of Sex Differences* (Cambridge: Harvard University Press, 2011); Nicole C. Karafyllis and Gotlind Ulshöfer, eds., *Sexualized Brains: Scientific Modeling of Emotional Intelligence from a Cultural Perspective* (Cambridge: MIT Press, 2008); Sigrid Schmitz and Grit Höppner, eds., *Gendered Neurocultures: Feminist and Queer Perspectives on Current Brain Discourses,* Contemporary Challenges of_within Gender Theory 2 (Vienna: Zaglossus, 2014).

laden investigations of alleged male and female brains and the ways in which neuroscientific accounts of “hardwired” sex/gender reinforce existing social hierarchies.[131]

Many feminist critiques of hardwiredness as well as the “female brain” and the “male brain” challenge the alleged binary of nature (that is, innateness, biology, brain, sex) and nurture (that is, malleability, experience, mind, gender). In recent years, even scientists have discredited the idea of innateness as “folk wisdom” and questioned the usefulness of rigidly separating nature and nurture, because reducing complex phenomena to simplified binaries poses obstacles to better understanding cognition and behavior.[132] Nonetheless, the idea that science can delineate nature from nurture *and* that nature determines nurture or culture have persisted.

The adherence to this faulty dichotomy is rooted in a tradition of (male) scientists’ attempts to dominate (female-coded) nature and thereby assert their own superior culture.[133] Anthropologists and historians have shown that this dichotomous concept of

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[131] Fine, *Delusions* (quote on p. xxvii). On the problem of concepts of “hardwired” differences, see also Giordana Grossi, “Hardwiring: Innateness in the Age of the Brain,” *Biology & Philosophy* 32, no. 6 (2017), https://doi.org/10.1007/s10539-017-9591-1.

[132] Patrick Bateson and Matteo Mameli, “Has the Innateness Concept Helped or Hindered the Understanding of Behavioural and Cognitive Development?” accessed March 15, 2019, http://neurofuture.ru/_mozg/archive/content2006/september14bateson/Innate-Cognition.pdf; Patrick Bateson and Matteo Mameli, “The Innate and the Acquired: Useful Clusters or a Residual Distinction from Folk Biology?” *Developmental Psychobiology* 49, no. 8 (2007), https://doi.org/10.1002/dev.20277; Matteo Mameli and Patrick Bateson, “Innateness and the Sciences,” *Biology & Philosophy* 21, no. 2 (2006), https://doi.org/10.1007/s10539-005-5144-0; Matteo Mameli and Patrick Bateson, “An Evaluation of the Concept of Innateness,” *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* 366, no. 1563 (2011), https://doi.org/10.1098/rstb.2010.0174. For proposals to integrate nature/culture in a systems-approach, see Susan Oyama, *Evolution’s Eye: A Systems View of the Biology-Culture Divide* (Durham: Duke University Press, 2000). See also Dale Goldhaber, *The Nature-Nurture Debates: Bridging the Gap* (Cambridge: Cambridge University Press, 2012).

[133] Ludmilla J. Jordanova, “Nature Unveiling Before Science,” in *Sexual Visions: Images of Gender in Science and Medicine between the Eighteenth and Twentieth Centuries*, ed. Ludmilla J. Jordanova (Madison: University of Wisconsin Press, 1989); Sherry B. Ortner, “Is Female to Male as Nature Is to Culture?” *Feminist Studies* 1, no. 2 (1972), https://doi.org/10.2307/3177638; Katharine Park, “Nature in Person: Medieval and Renaissance Allegories and Emblems,” in Daston; Vidal, *The Moral Authority of Nature*; Robert J. Richards, “The Erotic Authority of Nature: Science, Art, and the Female during Goethe’s Italian Journey,” in Daston; Vidal, *The Moral Authority of Nature*. For an example of scientific attempts to make emotions “natural” and thereby turn nurture into a biological need, see Marga Vicedo, *The Nature and Nurture*

nature and culture, and its mapping onto femaleness/femininity and maleness/masculinity, is not as inevitable as it might seem to scientists in the industrial world: it is a relatively recent—or "modern"—development in the so-called "Western" world.[134]

Historian and philosopher of science Donna J. Haraway described the ways in which the distinction between nature and culture allows for the creation of "origin stories" that naturalize existing social hierarchies.[135] Focusing on primatology, Haraway traced teleological tales of how the current world order has come into being. In these primatological origin stories of how humans left the jungle to become a superior species, different classification systems—sex/gender, race/ethnicity, nature vs. culture, etc.—are entangled. Primatologists have projected these constructed binaries onto non-human primates to stabilize the grounds on which "Western" human society stands. Primatological theories reframe—in an allegedly objective way—the metaphysical tales and moral myths that make up the history of modern civilization.

Anthropologist Elizabeth D. Whitaker provided a more extensive cultural and historical counter-narrative to evolutionary origin stories that naturalize social hierarchies and global inequities.[136] She offered an alternative account of hominids' diet and social

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of Love: From Imprinting to Attachment in Cold War America (Chicago, London: University of Chicago Press, 2013).

[134] Philippe Descola, *Beyond Nature and Culture* (Chicago, London: University of Chicago Press, 2014); K. R. Howe, *Nature, Culture, and History: The "Knowing" of Oceania* (Honolulu: University of Hawaií Press, 2000); Cheryl A. Logan and Timothy D. Johnston, "Synthesis and Separation in the History Of 'Nature' And 'Nurture'," *Developmental Psychobiology* 49, no. 8 (2007), https://doi.org/10.1002/dev.20274; Carol P. MacCormack and Marilyn Strathern, eds., *Nature, Culture and Gender* (New York: Cambridge University Press, 1980); Martin S. Staum, *Nature and Nurture in French Social Sciences, 1859–1914 and Beyond*, McGill-Queen's Studies in the History of Ideas 53 (Montréal, Québec: McGill-Queen's University Press, 2011).

[135] Donna J. Haraway, "Primatology is Politics by Other Means," *Proceedings of the Biennial Meeting of the Philosophy of Science Association* 1984, no. 2 (1984), https://doi.org/10.1086/psaprocbienmeetp.1984.2.192523. See also Donna Jeanne Haraway, *Primate Visions: Gender, Race, and Nature in the World of Modern Science* (New York: Routledge, 1989).

[136] Elizabeth Dixon Whitaker, *The Trouble with Human Nature: Health, Conflict, and Difference in Biocultural Perspective* (Oxon, New York: Routledge, 2017). On the problems of and push-backs against similar

life, arguing that gender roles, racial inequalities, health disparities, and other forms of violence and injustice are not part of human nature. Rather than having biological roots, these structures have evolved from human behavior. Natural scientists retroactively essentialized these hierarchies by crafting theories of sex/gender, sexuality, race/ethnicity, and dis/ability whose rigid constructs often contradicted evolutionary processes.[137]

Classification

The feminist push-back against the idea of distinct male and female brains (which have frequently overlapped with concepts of right-handed and left-handed brains) resonates with a broader body of literature on the practical, ethical, and epistemological ramifications of classification in the life sciences. Historian and philosopher of science Geoffrey C. Bowker and sociologist S. Leigh Star provided a far-reaching collection of empirical studies of various standards and classifications pertaining to health, labor, and racial segregation.[138] They illuminated the roles that these systems of ordering played in everyday-societies in the twentieth century, who made them functional and how, and "[w]hat happen[ed] to the cases that d[id] not fit."[139] In doing so, Bowker and Star illustrated that

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nature-making in genetics and allied biological sciences, see Alan H. Goodman, Deborah Heath and Mary Susan Lindee, *Genetic Nature/Culture: Anthropology and Science beyond the Two-Culture Divide* (Berkeley: University of California Press, 2003); Evelyn F. Keller, "Nature, Nurture, and the Human Genome Project," in Kevles; Hood, *The Code of Codes*; Richard C. Lewontin, Steven Peter Russell Rose and Leon J. Kamin, *Not in Our Genes: Biology, Ideology, and Human Nature* (New York: Pantheon Books, 1984); Cheryl A. Logan, *Hormones, Heredity, and Race: Spectacular Failure in Interwar Vienna* (Rutgers University Press, 2013); Oyama, *Evolution*; Robert Plomin and G. E. McClearn, *Nature, Nurture & Psychology* (Washington, D. C., London: American Psychological Association, 1993).

[137] On the futility of genetic theories of race and ethnicity, see Alan H. Goodman, "Seeing Culture in Biology," in Ellison; Goodman, *The Nature of Difference*; Simon M. Outram and George T. H. Ellison, "The Truth Will Out: Scientific Pragmatism and the Geneticization of Race and Ethnicity," in Ellison; Goodman, *The Nature of Difference*. On the recent return of biology as a marker of racial and ethnic difference in the United States, see Rogers Brubaker, *Grounds for Difference* (Cambridge: Harvard University Press, 2015).

[138] Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge: MIT Press, 1999).

[139] Bowker and Star, *Sorting*, 9.

classifications are ubiquitous in modern societies and that acts of classification *per se* are ethically and politically charged. While some witty individuals used the vagueness of existing classification practices to their benefit, for example by moving in between racial categories during apartheid in South Africa, the usually rigid and politically charged systems of ordering facilitated neoliberal governance and citizen surveillance.

Classifications of handedness and brainedness were no less political. They took on sexed/gendered, sexualized, classed, and racialized meanings because scientists connected laterality with entities that already carried these connotations. In the sciences of hormones and heredity, the political ramifications of "natural" classifications became particularly obvious. Public health scientist George T.H. Ellison and anthropologist Alan H. Goodman's edited volume, for instance, makes clear "the tautological tendencies" of scientific classification and differentiation,[140] which essentialize social realities and fuel lay ontologies of a hierarchical world order.[141] Focusing on the history of genetics (broadly conceived), the contributors shed light on the ways in which social categories permeated and continue to permeate every aspect of the scientific understanding of difference and imaginary biological types. In particular, the contributions show that the media are not to blame for discriminatory and exclusionary employments of science. This runs contrary to the claims of many scientists who deny the intrinsic value-ladenness of

[140] George T. H. Ellison and Alan H. Goodman, eds., *The Nature of Difference: Science, Society and Human Biology,* Society for the Study of Human Biology Series 45 (Boca Raton: Taylor & Francis, 2006), xxxviii.
[141] On lay ontologies of racial difference, see especially Kevin Durrheim and John Dixon, "Everyday Explanations of Diversity and Difference: The Role of Lay Ontologizing," in Ellison; Goodman, *The Nature of Difference*.

science and try to shift responsibility away from knowledge producers and onto popularizers.[142]

Historical monographs have provided even deeper insight into the value-ladenness of molecular science. For example, historian of science Helga Satzinger has shown that scientists of the late nineteenth and early twentieth centuries ascribed (with varying success) ideas of a sex/gender binary, heteronormativity, and racial inequalities to hormones, gametes, genes, and chromosomes.[143] Similarly, historian of science Sarah S. Richardson illustrated that gendered ideas preceded the definition of the X and Y chromosomes as "sex chromosomes."[144] These *a priori* assumptions about the differences between men and women influenced the acquisition of empirical evidence, theoretical frameworks, experimental setups, and the language used to communicate chromosomal research. Making the socio-political impact of molecular research even clearer, historian of science Cheryl Logan suggested that some progressive endocrinologists deliberately tried (without success) to blur alleged racial boundaries in the early twentieth century by emphasizing the transformative power of hormones over hereditary orders.[145]

The power of scientific order lies not only in the potential to classify individuals according to their sex/gender, sexuality, or race/ethnicity, but also in the authority to draw the line between the "normal" and the "abnormal" or the "pathological."

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[142] See especially Jenny Kitzinger, "Constructing and Deconstructing the 'Gay Gene': Media Reporting of Genetics, Sexual Diversity, and 'Deviance'," in Ellison; Goodman, *The Nature of Difference;* Alice Wexler, "Inventing the History of a Genetic Disorder: The Case of Huntington's Disease," in Ellison; Goodman, *The Nature of Difference*.
[143] Helga Satzinger, *Differenz und Vererbung: Geschlechterordnungen in der Genetik und Hormonforschung 1890–1950* (Cologne: Böhlau Verlag & Cie, 2009).
[144] Sarah S. Richardson, *Sex Itself: The Search for Male and Female in the Human Genome* (Chicago: University of Chicago Press, 2015), 2. A similar argument holds for the science of "sex hormones"; Nelly Oudshoorn, *Beyond the Natural Body: An Archeology of Sex Hormones* (London: Routledge, 2005).
[145] Logan, *Hormones*.

Philosopher and physician Georges Canguilhem analyzed the rise of biology in the nineteenth century and its interaction with new concepts of health and disease.[146] He argued that scientists had no objective measure to delineate the normal from the pathological, and that the classification of a certain state as pathological was based on (aesthetically, politically, and economically influenced) *a priori* concepts of what the healthy norm should be. In Canguilhem's words: "[T]here is no biological science of the normal. There is a science of biological situations and conditions *called* normal."[147]

Historians Peter Cryle and Elizabeth Stephens recently argued that our concept of normality is a construct of the mid-twentieth century, which is neither "timeless" nor "ubiquit[ous]."[148] Tracing the stabilization and the rising influence of the concept of normality as well as normative and normalizing practices from early nineteenth to the mid-twentieth centuries, the two historians showed that the term "normal" carried various contextually specific meanings. The current version of "normal," the authors proposed, is not a scientific result of the rise of statistics around 1900, but a socio-cultural feature of "the emergent self-improvement and consumer cultures of the mid-twentieth century."[149]

Cryle and Stephen's argument that "normal" is not primarily descriptive but also prescriptive rests heavily on Canguilhem's distinction between the normal and the pathological.[150] Deviating from Canguilhem, the authors explained that a conflation of qualitative and quantitative understandings of the normal have lain at the heart of the concept.

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[146] Georges Canguilhem, *The Normal and the Pathological* (New York: Zone Books, 1991). This is a translation of the French original from 1966; a shorter French version was published in 1943.
[147] Canguilhem, *Normal*, 228. Italics in the original.
[148] Peter Maxwell Cryle and Elizabeth Stephens, *Normality: A Critical Genealogy* (Chicago, London: University of Chicago Press, 2017), 3.
[149] Cryle and Stephens, *Normality*, 14.
[150] On the ableism inherent in concepts of the "normal," see, e.g., Elizabeth Barnes, *The Minority Body: A Theory of Disability* (Oxford: Oxford University Press, 2016); Lennard J. Davis, *Enforcing Normalcy: Disability, Deafness, and the Body* (London: Verso, 1995).

Similarly, physicians and scientists developed concepts of normality both to include and exclude alleged others. Furthermore, the authors drew on historian and philosopher of science Ian Hacking's studies on the history of statistics as means of social control.[151] In particular, they supported Hacking's view that medical and mathematical normality have not emerged simultaneously, but that statistical averages were constructed based on already existing social understandings of what should be normal. The influential population-level term of "normality" has found access to the individual through regulations and comparisons (also known as Foucaultian biopolitics) and thereby created new bodies and new forms of relating to oneself.[152]

There is some scholarship that tackles classification specifically within the brain and mind sciences. Historian Jan E. Goldstein, for instance, analyzed the unprecedented authority of French psychiatrists, the *aliénistes*, during the nineteenth century, when France underwent substantial political, administrative, and cultural reforms.[153] Goldstein argued that nineteenth-century French psychiatry stood (and understood itself) in the tradition of the clergy. At the same time, psychiatrists competed against the clergy for authority in asylums. They derived their authority from scientific methods to refine, correct, and develop classifications of psychiatric pathologies, which redefined hitherto spiritual, legal, and moral categories. For example, they transformed alleged demonic possessions into

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[151] E.g., Ian Hacking, *The Taming of Chance* (Cambridge: Cambridge University Press, 1990); Ian Hacking, "Making Up People," in *Reconstructing Individualism: Autonomy, Individuality, and the Self in Western Thought*, ed. Thomas C. Heller and Christine Brooke-Rose (Stanford: Stanford University Press, 1986); Ian Hacking, *The Emergence of Probability: A Philosophical Study of Early Ideas about Probability, Induction and Statistical Inference*, 2nd ed. (Cambridge, New York: Cambridge University Press, 2006).
[152] According to philosopher Michel Foucault, the term "biopolitics" captures the state's power over life, i.e., the ways in which government and society (have) control(led) corporeality, behavior, and identity in the interest of economic gain and political stability; Michel Foucault, *Discipline and Punish: The Birth of the Prison* (New York: Pantheon Books, 1977).
[153] Jan Ellen Goldstein, *Console and Classify: The French Psychiatric Profession in the Nineteenth Century* (Chicago: University of Chicago Press, 2001).

"hysteria," pathologized suicide as the outcome of a neural disease, and attributed criminal behavior to "monomania."[154] The authority of the *aliénistes*' classifications derived in part from their bureaucratic role, namely the recording of disease cases in the interest of national insanity control starting in the mid-nineteenth century.

Paleontologist and historian of science Stephen J. Gould attended more closely to the measurements that have underlain classifications of brains and minds since the nineteenth century.[155] Gould argued that racial science was not objective and that its data were not neutral by exposing the scientific racism that has driven the quantification of allegedly innate human intellectual capacity from US-American physician Samuel G. Morton's (1799–1851) measurement of cranial volumes; to Broca's assessment of brain weight and volume; to twentieth-century theories about "general intelligence."[156] Gould made visible both the ways in which nineteenth-century notions of white male human superiority persisted in the sciences of intelligence and the concrete consequences that marginalized populations had to suffer from this bias (for example, the denial of immigration in the 1920s based on IQ tests).[157]

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[154] Goldstein, *Console*, 383.
[155] Stephen Jay Gould, *The Mismeasure of Man* (New York: W.W. Norton & Company, 1996). On measurement in psychology, see also Gail A. Hornstein, "Quantifying Psychological Phenomena: Debates, Dilemmas, and Implications," in *The Rise of Experimentation in American Psychology*, ed. Jill G. Morawski (New Haven: Yale University Press, 1988); Joel Michell, *Measurement in Psychology: Critical History of a Methodological Concept* (New York: Cambridge University Press, 1999).
[156] Charles Spearman, "'General Intelligence', Objectively Determined and Measured," *American Journal of Psychology* 15, no. 2 (1904), https://doi.org/10.2307/1412107.
[157] See also John Carson, *The Measure of Merit: Talents, Intelligence, and Inequality in the French and American Republics, 1750–1940* (Princeton: Princeton University Press, 2007).

Overview

These works provide important insight into the ways in which mind and personhood were cerebralized in the past; how neuro-centrisms play out in contemporary neuroscience; the biases inherent in scientific systems of ordering; and what the potential consequences are of classifying individuals based on their brain and its functions. Still wanting is an account of how human characteristics and behaviors *that seemingly have nothing to do with the brain* have become firmly integrated into the neurosciences, and the ways in which these non-brain characteristics can stand in for one another whenever one of them is under scientific scrutiny.

This study offers one answer to these open questions. By tracing the history of handedness research, it uncovers the epistemological labor that is necessary to cerebralize the hand and manual behavior, and it illustrates the multiple understandings of the brain, the mind, and the person that have enabled this tenuous connection. Furthermore, it navigates the intersectional quagmire of handedness and more obviously politically charged categories. More broadly, this is an over-150-year history of the ways in which traditions, stereotypes, and social inequities have informed research in the human sciences and how, in turn, scientists have found scientific explanations for these socio-cultural realities.

Each of the following chapters advances this goal with slightly different methods and illuminates one subsection of the brain multiple. Chapter 2 focuses on anatomical and physiological theories of brain asymmetry and manual preference from Broca until World War I. Drawing on scientific textbooks, monographs, and journal articles in English, German, and French, the chapter shows that the earliest theories of handedness and brainedness echoed the wide-spread fear of degeneration during the Second Industrial

Revolution. Physicians, scientists, and educators in Europe and North America disagreed on how to combat human decline, but they shared the concern that manual behavior might harm the brain, mind, and character. These researchers also promoted the idea that right-handedness and left-brainedness are exceptional human qualities that are markers of superiority among humans and across species. This concept of the superior hand and brain hemisphere resonated with the colonial mindset, which divided the globe into allegedly superior/advanced and inferior/subhuman halves.

Chapter 3 explores the continuing association between handedness and hierarchical thinking in the second half of the twentieth century, when three generations of British psychologists turned handedness research into a science of big data. Their research rested heavily on questionnaires, computerized statistics, and hypothetical (that is, *not* genetically confirmed) sex-linked genes for brainedness and handedness.[158] R.C. (Carolus) Oldfield (1909–1972) developed the still popular Edinburgh Handedness Inventory and speculated that handedness might be coded for on the so-called sex chromosomes. Marian Annett (b. 1931) and I.C. (Chris) McManus (b. 1951) tried to refine the measurement of manual preference in the interest of obtaining large data sets to help determine possible parameters for their genetic models of laterality, which included chance

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[158] To this day, brain-, mind-, and neuroscientists employ hypothetical genes and statistical methods to draw a boundary between nature and nurture. One current example at the shoreline of psychiatry, genetics, and social policy is the negotiation of causal factors that may or may not connect schizophrenia and low socio-economic status; see, e.g., A. Sariaslan et al., “Schizophrenia and Subsequent Neighborhood Deprivation: Revisiting the Social Drift Hypothesis Using Population, Twin and Molecular Genetic Data,” *Translational Psychiatry* 6 (2016), https://doi.org/10.1038/tp.2016.62. A slightly less deterministic counterproposal is a “mediated causal relationship” between low socio-economic status and genetic risk for schizophrenia. According to this theory, the genetic factors that underlie schizophrenia cause certain traits in individuals that in turn impact their social position. Living in a certain neighborhood is thus not understood as a direct consequence of a genetic predisposition for schizophrenia, but as an effect of behaviors and experiences that are themselves caused by one’s individual genetic make-up; see, e.g., S. H. Gage, George Davey Smith, and M. R. Munafo, “Schizophrenia and Neighbourhood Deprivation,” *Translational Psychiatry* 6, no. 12 (2016), https://doi.org/10.1038/tp.2016.244.

elements. Complementing close reading of scientific journal articles with oral histories, the chapter traces the deeply gendered competition between Annett and McManus, who nonetheless formulated very similar models. These genetic models reiterated the idea that handedness is exclusively human, and Annett furthermore associated left-handedness with the "risk" of learning disabilities and psychiatric illnesses.

Chapter 4 analyzes a hormonal model of handedness, which three neurologists from Harvard University and the University of Glasgow introduced around 1980.[159]

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[159] The sequence of etiological theories of handedness—anatomical, genetic, hormonal—might surprise the reader who is familiar with the history of the life sciences. Although the terms "gene" and "hormone" were coined in the 1900s, endocrinology advanced to a well-respected international science between the World Wars, while (molecular) genetics only took on momentum after the description of the double helix in 1953. In handedness research, however, genes preceded hormones. For a pointed summary of different concepts of the "gene" and competing terms, see Petter Portin, "The Concept of the Gene: Short History and Present Status," *Quarterly Review of Biology* 68, no. 2 (1993), https://doi.org/10.1086/418039. On the history of genetics, see, e.g., Nathaniel Comfort, *The Science of Human Perfection: How Genes Became the Heart of American Medicine* (New Haven: Yale University Press, 2012); Stephen Hilgartner, *Reordering Life: Knowledge and Control in the Genomics Revolution* (Cambridge: MIT Press, 2017); Lily E. Kay, *Who Wrote the Book of Life? A History of the Genetic Code* (Stanford: Stanford University Press, 2000); Daniel J. Kevles and Leroy E. Hood, eds., *The Code of Codes: Human and Social Issues in the Human Genome Project* (Cambridge: Harvard University Press, 1992); Mary Susan Lindee, *Moments of Truth in Genetic Medicine* (Baltimore: Johns Hopkins University Press, 2005); Staffan Müller-Wille and Christina Brandt, *Heredity Explored: Between Public Domain and Experimental Science, 1850–1930* (Cambridge: MIT Press, 2016); Aaron Panofsky, *Misbehaving Science: Controversy and the Development of Behavior Genetics* (Chicago: University of Chicago Press, 2014). On the history of endocrinology and the commercialization of hormones, see Merriley E. Borell, "Organotherapy, British Physiology, and Discovery of the Internal Secretions," *Journal of the History of Biology* 9, no. 2 (1976), https://doi.org/10.1007/BF00209884; Merriley E. Borell, "Setting the Standards for a New Science: Edward Schäfer and Endocrinology," *Medical History* 22, no. 3 (1978); Merriley E. Borell, "Organotherapy and the Emergence of Reproductive Endocrinology," *Journal of the History of Biology* 18, no. 1 (1985), https://doi.org/10.1007/BF00127955; Adele E. Clarke, *Disciplining Reproduction: Modernity, American Life Sciences, and "The Problems of Sex"* (Berkeley: University of California Press, 1998); John M. Hoberman, *Testosterone Dreams: Rejuvenation, Aphrodisia, Doping* (Berkeley: University of California Press, 2005); Logan, *Hormones*; C. Nordlund, *Hormones of Life: Endocrinology, the Pharmaceutical Industry, and the Dream of a Remedy for Sterility, 1930–1970* (Cambridge: Science History Publications, 2011); Bob Ostertag, *Sex Science Self: A Social History of Estrogen, Testosterone, and Identity* (Amherst, Boston: University of Massachusetts Press, 2016); Oudshoorn, *Beyond*; Christina Ratmoko, *Damit die Chemie stimmt: Die Anfänge der industriellen Herstellung von weiblichen und männlichen Sexualhormonen, 1914–1938*, Interferenzen 16 (Zurich: Chronos Verlag, 2010); Satzinger, *Differenz*; Chandak Sengoopta, *The Most Secret Quintessence of Life: Sex, Glands, and Hormones, 1850–1950* (Chicago: University of Chicago Press, 2006); Heiko Stoff, *Wirkstoffe: Eine Wissenschaftsgeschichte der Hormone, Vitamine und Enzyme, 1920–1970*, Studien zur Geschichte der Deutschen Forschungsgemeinschaft 9 (Stuttgart: Franz Steiner Verlag, 2012). On the ways in which endocrinology stimulated the cultural imagination and shifted views of physiological and emotional causality, see Kern, *A Cultural History of Causality*, 157–67.

Norman Geschwind (1926–1984) took the lead in developing this theory, which postulated excessive exposure to prenatal testosterone as the cause of right-brainedness, left-handedness, and numerous anomalies on the anatomical, physiological, mental, and behavioral levels. Drawing on archival records, oral history interviews, and scientific publications, the chapter suggests that Geschwind's Grand Unified Theory of human deviance was born out of an inadvertent reliance on an unwieldy brain multiple. The neurologists did *not* perform experimental research. They derived their data from a literature review of hundreds of publications from disciplines ranging from anatomy to zoology and dating from the 1860s to the 1980s. This distance from actual brains and the reliance on multiple epistemic "brain" things in this heterogeneous mass of literature allowed Geschwind and colleagues to connect widely disparate phenomena. The consequence of taking as one the different epistemic versions of "the brain" was a racist, sexist, and homophobic theory that reiterated the idea of the inferior left-hander.

Chapter 5 takes the story from the 1980s to the twenty-first century. A review of recent publications on the origins of handedness in the mirror-neuron system and in epigenetics illustrates that the link between brainedness and handedness is still firm. Based on large-scale digital text mining in the programming language R in a corpus of over one thousand recent publications on laterality, I show that the idea of the deviant left-hander has also persisted. One consequence of this assumption is the continued exclusion of left-handers from many neuroimaging studies, because neuroscientists consider left-handedness a potential confounding factor that might pose an obstacle to the generalizability of their findings. Finally, the understanding of left-handedness as a "risk" factor has aligned manual preference with neoliberal frameworks of prevention and optimization. Several psychologists and educators offer handedness testing, consulting, and self-help books that promise to assist left-handers to function more efficiently in a right-handed world. I close with some remarks on the “truth” about handedness, fully aware that there is no such truth, or at least “not yet,” as handedness researchers hopefully assured me.

CHAPTER 2

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FILLING THE GAP BETWEEN THE BRAIN AND THE WRITING HAND: DEGENERATION AND HUMAN EXCEPTIONALISM IN ANATOMICO-PHYSIOLOGICAL THEORIES OF HANDEDNESS AROUND 1900

> [A]s man advances in civilization and culture, he shows an always greater right-sidedness as compared to savages, the masculine in this way outnumbering the feminine and adults outnumbering children. Thus women and savage races, even when they are not properly left handed, have certain gestures and movements which are a species of left-handedness.[160]

Introduction

A drawing in English physiologist Henry C. Bastian's (1837–1915) *Treatise on Aphasia* epitomizes the room there was for scholars of the past one and a half centuries to position multiple entities and metaphysical concepts between the brain and the hand.[161] The drawing shows the left profile of a hair-less and body-less head and neck with a cut-

[160] Cesare Lombroso, "Left-Handedness and Left-Sidedness," *North America Review* 177, no. 562 (1903): 442.
[161] Henry Charlton Bastian, *A Treatise on Aphasia and Other Speech Defects* (London: H. K. Lewis, 1898), frontispiece. See also "File:H. C. Bastian, a Treatise on Aphasia and Other Speech Defects Wellcome L0028659.Jpg," accessed March 15, 2019, https://commons.wikimedia.org/wiki/File:H._C._Bastian,_A_treatise_on_aphasia_and_other_speech_defects_Wellcome_L0028659.jpg.

open skull. Inside the skull, various brain centers are designated with obscure letters. Underneath the head and detached from it, in a place where one would expect the gut in an anatomically realistic drawing, is the person's right hand, holding a pen and writing on a piece of paper. Lines with directional arrows lead from the brain centers to/from one another, and to/from the ear, mouth, and writing hand of the person, right where the fingers touch the pen. While all of the brain centers are connected by these lines, each organ connects to only one distinct brain center.

The apparent gap between the floating head and the detached hand exemplifies the vagueness of most anatomico-physiological theories of the relationship between handedness and brain asymmetry. The lines and arrows between the brain, mouth, ears, and writing hand highlight the elusive nature of anatomical or physiological connections between these organs, whose obscurity made room for numerous interwoven ideological biases and preconceptions in explanatory models of how the hand relates to the brain. Most researchers believed that the writing hand was physiologically and anatomically connected to the contralateral brain hemisphere, but the concrete conceptions of the brain, the hand, and their relation to a person's character and mental life were controversial.

There were various interconnected ways in which medical and social scientists in Europe and North America approached the brain in the late nineteenth and early twentieth centuries. Mostly white, male, educated, and right-handed, these scholars hypothesized that cerebral laterality was intricately interwoven with handedness. Their theories went far beyond concrete anatomical descriptions and exact neurophysiological processes. In fact, after French anatomist and anthropologist P. Paul Broca (1824–1880) had speculated about the connection between brain asymmetry and manual preference, other scholars took this relationship for granted and mostly refrained from studying the concrete mechanisms of this hypothetical connection in more detail. They developed etiological theories of handedness that were saturated with an existential fear of degeneration and a firm belief in a hierarchical natural order, rooted in the social struggles during the Second Industrial Revolution and the colonial imaginary of the late nineteenth century. Assuming that physical asymmetries underlie the superiority of (educated, able-bodied, white, male) humans over other animals, the scholars elevated right-handedness to a criterion of evolutionary success.

As illustrated in the previous chapter, the idea that one's hand can provide insight into one's character preceded research on brain asymmetry. However, late-nineteenth- and early-twentieth-century handedness researchers added a novel twist on the more traditional hand-character connections. They understood the brain as *the* vital source for anything the hand does or can do. The relatively new idea that personhood is in the brain, in conjunction with Broca's postulate that handedness and brain laterality are closely entwined, gave rise to a new hand-brain-character triad in which either one seemed an appropriate proxy for the other two.

Deeply affected by Broca's ideas, three clusters of scholars, which I group according to shared intellectual commitments, left their mark on the turn-of-the-century discourse surrounding handedness and the brain. I call the first group Exceptionalist-Degenerationists. The major players in this cluster were anatomists and physicians who concerned themselves with evolutionary hierarchies. Following Broca and other localizationists, these researchers investigated lateralized speech centers in the brain to establish a link between handedness and cerebral asymmetry. Their resulting theories established causal connections between manual preference, mental ability, and moral worth, thereby using handedness research as an anthropological machine.[162] The members of this group were united by their search for the causes of human superiority and their conviction that left-handedness is an atavism or a sign of degeneration.

The concrete theories through which these scholars reached their conclusions, however, differed. Some were content to suggest that the left brain hemisphere matures earlier and more fully than the right one, while others advanced theories of asymmetric blood flow, which allegedly preceded a stronger left hemisphere and right-hand preference. Notwithstanding the differences in explanations, the anatomico-physiological concept of the causes of handedness led to the scientific justification of the marginalization of left-handers in Europe and in the colonies.

Despite the pathologizing tendencies of Broca's postulates, a second group, which I call the Brain-Centric Reformers, interpreted them in favor of left-handedness and/or ambidexterity. Mostly physicians and pedagogues, these scholars built on the Exceptionalist-Degenerationists' idea that cerebral asymmetries underlie manual preference. The Brain-Centric Reformers argued that right-handers could be considered morally or physically superior because handedness was innate and left-handers or ambidexters frequently acquired considerable skills with both hands. Despite advocating for the liberation of left-handers and/or population-wide ambidexterity training, the Brain-Centric Reformers employed a similar degenerationist rhetoric as the Exceptionalist-Degenerationists. Rather than advocating for individual well-being, they suggested harnessing the power of hands

[162] Agamben, *Open*.

and brains for national moral, economic, and military gain, and they warned that the careless use of the hands would lead to mental and physical decline.

There was a third contestant in the debate surrounding innate cerebralized handedness. Several European researchers questioned the habit of seeing the hand as a proxy for the brain. I call this third, and comparably very small, group of one physician and one sociologist the Brain-Centrism Opponents.[163] These scholars did not entirely oppose the idea of an association between manual preference and cerebral asymmetry, but they asked for an embodied theory of hand preference that integrated societal conventions and spiritual traditions. The Brain-Centrism Opponents emphasized that attention to broader physical asymmetries and binary thinking was crucial for explaining the phenomenon of handedness. Despite the Brain-Centrism Opponents' efforts to the contrary, they did not entirely break with the vernacular conception of left-handers as deviant. In fact, the Brain-Centrism Opponents reaffirmed the dichotomous conception of the left brain and the right brain, and thereby sustained the Exceptionalist-Degenerationists' rhetoric of innate asymmetries and their purported physical, cognitive, and cultural effects.

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[163] As my research continues, I might be able to add more members to this group. Psychoanalysts seem to have supported the neuro-centric view of handedness; e.g., Blau and Abram, *The Master Hand: A Study of the Origin and Meaning of Right and Left Sidedness and Its Relation to Personality and Language,* Research Monographs 5 (American Orthopsychiatric Association, Inc., 1946); Arthur Kronfeld, "Die Individualpsychologie als Wissenschaft: Ihre Formen und ihre Beziehungen zur Psychologie der Gegenwart," in Wexberg, *Handbuch der Individualpsychologie*; Max Reis, "Die Minderwertigkeit von Organen," in Wexberg, *Handbuch der Individualpsychologie*. Some female experimental and developmental psychologists have offered more embodied approaches to manual preferences, but they did not provide etiological theories of handedness, and so I excluded them from this discussion; e.g., Rosemarie Brann, "Untersuchungen zur Frage der Rechts- und Linkshändigkeit und zum Gestalterkennen aus der Bewegung bei Kindern," *Archiv für Psychiatrie und Nervenkrankheiten* 86, no. 2 (1929); Margaret Macdonald Clark, *Left-Handedness: Laterality Characteristics and Their Educational Implications,* Publications of the Scottish Council for Research in Education 39 (London: University of London Press, 1957); June Etta Downey, "Laterality of Function," *Psychological Bulletin* 30, no. 2 (1933), https://doi.org/10.1037/h0073574; Helen Bradford Thompson Woolley, "The Development of Right-Handedness in a Normal Infant," *Psychological Review* 17, no. 1 (1910), https://doi.org/10.1037/h0074110.

A tension between concepts of fixity and plasticity cuts across all three groups of handedness researchers. To the Exceptionalist-Degenerationists, brain plasticity was a convenient tool to reaffirm the anatomical doctrine of the law of symmetry of paired organs in "higher" species. These scholars employed functional plasticity (the idea that our habits shape the actions of our brains, though not their morphological structure) as an explanation for why the two hands and the two brain hemispheres respectively look alike and yet one dominates over the other in each pair. At the same time, the Exceptionalist-Degenerationists believed that handedness and brainedness were innate, unchangeable, and that they determined the cognitive and cultural abilities of an individual or a group of people.

The Brain-Centric Reformers were on board with the idea of functional plasticity. Many of them argued that ambidexterity would result in the simultaneous stimulation of both cerebral hemispheres and allow for higher cognitive achievements than one-handedness. Simultaneously, several Brain-Centric Reformers promoted the inheritance of acquired characteristics, suggesting that a one-time plastic change would be a lasting fix for the social and physical problems of generations to come.

The Brain-Centrism Opponents depended most heavily on a theory of cerebral plasticity: if handedness had cultural origins, and if our brains functioned asymmetrically, then brainedness would have to be a functional adaptation of the brain to the asymmetric use of our hands. However, even cultures who do not value the right hand as the "right" hand show marked right-handedness. Hence, the Brain-Centrism Opponents suggested, right-handedness might have some innate core after all.

A note on sources and methods seems warranted at this point. The content of this chapter relies on published primary sources, mainly monographs and short treatises. These publications were often cheaply produced, with no or very few illustrations and brief methods sections (if any). Most of these publications contain lengthy reviews of other people's views on handedness plus the author's own theory, but no clues as to the authors' personal stakes regarding the matter. Furthermore, there is a vast historiographical asymmetry in the treatment of individual actors. Broca, physician Cesare Lombroso (1835–1909), and to a lesser extent sociologist Robert W. Hertz (1881–1915) have been figures of historical interest. Many other handedness researchers are virtually unknown today, making it hard to determine details of their biography, let alone provide insight into animosities, collaborations, or great research failures in the early history of handedness research.

For these reasons, my account of anatomical and physiological theories of manual preference might at times read like a history of dead white men's ideas, detached from actual research practice and only loosely anchored in time and space. Luckily, many works of relatively unknown authors contain the author's profession or institutional affiliation on the title page, providing a sense of the circles wherein manual preference was a hot topic. That is enough for my purposes. I cannot claim that all these individuals thought about handedness in terms of speech lateralization, human exceptionalism, and degeneration, but I know that *some* of them did, and that these ideas directly reflected the socio-political environment during industrialization, colonialism, and nationalism. This means that the earliest theories of handedness and the brain, which contemporary neuroscientists still (partially) rely on, were historically contingent and culturally situated.

Consequently, they might not be the best bases for twenty-first-century theories and practices surrounding manual preference.

The Exceptionalist-Degenerationists

Broca's Legacy

The idea that hands and brains are closely connected through physical asymmetry goes back to Broca's studies on aphasia.[164] There, the French anatomist and anthropologist reported his observations of patients with lesions to the left cortical frontal lobe who exhibited aphasia and symptoms of paralysis in the right half of their bodies. Extrapolating from these observations, Broca claimed in 1865 that most acts of articulate speech derived from a cerebral center in the left frontal lobe (nowadays called "Broca's area"), and that the left hemisphere dominated over the right one in all right-handed individuals.[165]

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164 For Broca's biography and bibliography, see Francis Schiller, *Paul Broca: Founder of French Anthropology, Explorer of the Brain* (Berkeley: Oxford University Press, 1992).

165 Broca, "Sur," 383; 387. For a translation of the report, see Berker, Berker and Smith, "Translation". For a more detailed account of Broca's work in the early 1860s and the controversies surrounding it, including the question of whether French neurologist Marc Dax (1770–1837) had anticipated Broca's findings regarding speech lateralization (though not regarding its connection with handedness), see Breidbach, *Materialisierung*, 125–28; Catherina Gere, "Curating Aphasia: Pierre Paul Broca's Museological Science," *Interdisciplinary Science Reviews* 38, no. 3 (2013), https://doi.org/10.1179/0308018813Z.00000000047; Harrington, *Medicine*, 35–69; Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 19–21; Richard Leblanc, 62–86; 97–108; 125–136; J. M. S. Pearce, "Broca's Aphasiacs," *European Neurology* 61, no. 3 (2009), https://doi.org/10.1159/000189272; Schiller, *Paul*, 165–211. For primary-source critiques of Broca's work on localization, see particularly Constantin von Monakow, *Die Lokalisation im Grosshirn und der Abbau der Funktion durch kortikale Herde* (Wiesbaden: J. F. Bergmann, 1914), 575–873; François Moutier, *L'aphasie de Broca* (Paris: G. Steinheil, 1908). For an overview of earlier research on cerebral localization, which was instrumental to the broad acceptance of Broca's theory, see Jason W. Brown and Karen L. Chobor, "Phrenological Studies of Aphasia before Broca: Broca's Aphasia or Gall's Aphasia?" *Brain and Language* 43 (1992); Edwin Clarke and L. Stephen Jacyna, *Nineteenth-Century Origins of Neuroscientific Concepts* (Berkeley, Los Angeles: University of California Press, 1987), 302–7; Harrington, *Medicine*, 6–34; Harris, "Early"; Leblanc, *Fearful*, 3–61; Carmela Morabito, "Cortical Localization of Language and the 'Birth' of Cognitive Neurosciences," *Rivista internazionale di Filosofia e Psicologia* 4, no. 2 (2013), https://doi.org/10.4453/rifp.2013.0013; Jürgen Tesak, *Die Geschichte der Aphasie* (Idstein: Schulz-Kirchner-Verlag, 2001), 11–69. For a critique of the adherence to Broca's theory of speech localization, see Rutten, *The Broca-Wernicke Doctrine*.

Broca built on the claims of his fellow countrymen anatomist Louis P. Gratiolet (1815–1865) and physician Jean-Baptiste Bouillaud (1796–1881) to establish this close connection between handedness and brain laterality.[166] Bouillaud had maintained that a circumscribed cerebral center underlay word memory and speech-related motor action; in agreement with physician and father of phrenology Franz J. Gall (1758–1828) from the Grand Duchy of Baden, Bouillaud had located this center in the frontal lobe.[167] Bouillaud's claims were in line with Broca's own findings in aphasic patients, who had suffered lesions to the frontal lobe. Gratiolet had suggested that the embryonic development of the left hemisphere preceded that of the right hemisphere.[168] Building on Gratiolet's findings, Broca assumed that skills acquired in early development would mainly be guided by the left hemisphere. Because of the contralateral connection between the motor nerves in the brain and the rest of the body (that is, the notion that the right half of the brain directs the left half of the body and vice versa), infants would execute most early

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[166] Some scholars have erroneously attributed the idea that handedness follows speech dominance to Bouillaud or French neurologist Jules G.F. Baillarger (1809–1890); Harrington, *Medicine*, 54–60. On a rivaling exchange between Bouillaud and Broca regarding the origin of this idea, see Leblanc, *Fearful*, 158–161.

[167] J. Bouillaud, "Recherches cliniques propres à démontrer que la perte de la parole correspond à la lésion des lobules antérieurs du cerveau, et à confirmer l'opinion de M. Gall, sur le siège de l'organe du langage articulé," *Archives générales de médecine* 8 (1825). See also Leblanc, *Fearful*, 24–45. On Gall's work on a cerebral center for language, see Brown and Chobor, "Phrenological"; Macdonald Critchley, "Neurology's debt to F.J. Gall (1758–1828)," *British Medical Journal* 2, no. 5465 (1965), https://doi.org/10.1136/bmj.2.5465.775; Paul Eling, ed., *Reader in the History of Aphasia: From (Franz) Gall to (Norman) Geschwind*, Amsterdam Studies in the Theory and History of Linguistic Science, Series II 4 (Amsterdam, Philadelphia: J. Benjamins, 1994); Helmut Heintel, *Leben und Werk von Franz Joseph Gall: Eine Chronik* (Würzburg: Richard Mayr, 1986); Leblanc, *Fearful*, 13-23; Donald Simpson, "Phrenology and the Neurosciences: Contributions of F.J. Gall and J.G. Spurzheim," *ANZ Journal of Surgery* 75, no. 6 (2005), https://doi.org/10.1111/j.1445-2197.2005.03426.x; Peter-Christian Wegner, *Franz Joseph Gall, 1758-1828: Studien zu Leben, Werk und Wirkung*, ed. Peter-Christian Wegner (Hildesheim: Georg Olms Verlag, 1991); John van Wyhe, "The Authority of Human Nature: The *Schädellehre* of Franz Joseph Gall," *British Journal for the History of Science* 35, no. 1 (2002), https://doi.org/10.1017/S0007087401004599; Robert M. Young, "The Functions of the Brain: Gall to Ferrier (1808–1886)," *Isis* 59, no. 3 (1968); Young, *Mind*.

[168] Leblanc, *Fearful*, 49–61. Gratiolet himself, however, did *not* support the idea language localization in the brain; Leblanc, *Fearful*, 62–73; 87–96. For a review of inconclusive studies on developmental differences between the two hemispheres after Gratiolet, see Michael C. Corballis, *The Lopsided Ape: Evolution of the Generative Mind* (New York: Oxford University Press, 1991), 292–301.

movements with the right half of their bodies, reinforcing the already existing developmental advantage of the motor centers in the left brain hemisphere.[169]

Articulate language is a particularly striking example of a skill acquired in early development. Because it is much more complex than simple motor actions, Broca assumed that the preeminence of the speech center in the left frontal lobe would be substantial. While an underdeveloped right cerebral hemisphere might be sufficient to induce some crude movements of the left hand, a complex cognitive and motor action like articulate speech would have to rely on the advanced hemisphere. Hence, he concluded that normally developing humans executed the neural mechanisms related to articulate speech with the help of the left half of their brains.[170]

This theory did not explain all cases that Broca had treated. Some of his patients were left-handed and did not show speech defects after a lesion to the left side of their brains. Consequently, Broca reasoned that their leading speech centers did not sit in the left hemisphere. He suggested that *some* left-handers *might* have brains that mirror the supposedly normal brains of right-handers. That is, the leading speech center *might* sit in the right cerebral hemisphere in *some* left-handers and provide superior strength and skill to the left half of their bodies.[171] Broca called those individuals "*droitiers du cerveau*" ("right-handers of the brain," commonly translated as "right-brained").[172]

Broca phrased this hypothesis carefully and remarked later that the incidence of right-brainedness was lower than that of left-handedness. This would mean that there had to be left-handers whose speech center was located in the left hemisphere, just like in

169 Broca, "Sur," 383.
170 Broca, "Sur," 384–86.
171 Broca, "Sur," 386–87.
172 Broca, "Sur," 383; 386.

right-handers. Nonetheless, Broca's followers interpreted manual preference as a reliable indicator of brain anatomy. Despite evidence to the contrary, they promoted "Broca's Rule," the doctrine that left-handers' brains are mirror images of the brains of right-handers.[173]

Ambidextrous individuals came off even worse. Broca and his followers believed that the absence of a clear manual preference derived from a virtually symmetrical brain. This quality was associated with the brains of "lower" animals.[174] According to Broca's theory, functional brain asymmetry was *the* exceptional human quality, a consequence of articulate speech and other acquired "higher" cognitive functions.[175]

Broca and many of his contemporaries, regardless of their religious or political orientation, believed that articulate speech was the characteristic that most distinctly separated humans from non-human animals.[176] In this context, claiming that a center for

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[173] For a summary of Broca's 1865 report and an overview of the long history of the idea of Broca's Rule, which is a twentieth-century misattribution to Broca, see Paul Eling, "Broca on the Relation between Handedness and Cerebral Speech Dominance," *Brain and Language* 22, no. 1 (1984), https://doi.org/10.1016/0093-934X(84)90085-3; Paul Eling, "Broca's *faculté du langage articulé*: Language or Praxis?" *Journal of the History of the Neurosciences* 25, no. 2 (2016), https://doi.org/10.1080/0964704X.2015.1041347; Harrington, *Medicine*, 58–69; Lauren J. Harris, "Cerebral Control for Speech in Right-Handers and Left-Handers: An Analysis of the Views of Paul Broca, His Contemporaries, and His Successors," *Brain and Language* 40, no. 1 (1991), https://doi.org/10.1016/0093-934X(91)90115-H; Lauren J. Harris, "Broca on Cerebral Control for Speech in Right-Handers and Left-Handers: A Note on Translation and Some Further Comments," *Brain and Language* 45, no. 1 (1993), https://doi.org/10.1006/brln.1993.1037; Lauren J. Harris, "Right-Handers Speak with the Left Hemisphere, Left-Handers with the Right: The Rise and Fall of a Neuropsychological Hypothesis," accessed March 15, 2019, http://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199765683.001.0001/oxfordhb-9780199765683-e-5. On the continuously strong adherence to Broca's Rule in twenty-first-century neuroscience, see Nathalie Tzourio-Mazoyer and Cyril Courtin, "Brain Lateralization and the Emergence of Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*.

[174] On the history of hierarchical classifications of living beings, see footnote 47.

[175] Broca's argument that cerebral asymmetry is a consequence of "man['s efforts] ... to civilize or 'perfect' himself to a higher level than any other animal" contrasted with earlier ideas that articulate speech was an innate human skill; Harrington, *Medicine*, 64–65 (quote on p. 65). On the sex(ualiz)ed and racialized aspects of this hypothesis, see Harrington, *Medicine*, 49–51; 63–104. On more recent discussions regarding the relationship between speech, handedness, and human exceptionalism, see Kushner, *On*, ch. 9.

[176] On the long history of the idea that articulate language clearly divides the human and non-human world, see Sylvain Auroux, "The Origin of Language as Seen by 18th-Century Philosophy," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*; Henri Cohen, "Historical, Darwinian, and Current Perspectives on the Origin(s) of Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins*

articulate speech could be mapped on the cortex was a secularizing political act. The cerebral speech center provided a material substitute for the formerly theologically conceived ability of language, the idea that speech is a divine endowment. Broca and his followers naturalized articulate speech by grounding it in the brain.[177] According to their theory, human superiority over non-human animals was no longer a matter of a hierarchical divine Creation but of the evolution of distinct brain centers.

There was one more heretical aspect to Broca's theory, which, according to neurosurgeon Richard Leblanc, "must have been jarring to his audience":[178] In proposing that right-handedness was a consequence of left-brainedness, Broca connected manual behavior to one of the "highest" human intellectual functions. At the time, motor functions were thought to stem from the basal ganglia, a structure that lies in the center of the brain. To Broca's contemporaries, no matter their stance towards the localization of cognition, the cortex was reserved for advanced intellectual functions. Broca's association between handedness and a center for articulate speech in the frontal lobe deprived the cortex of its pure intellectual glow.[179]

of Language. On the storms of controversy and taxonomic debates aroused by claims of talking animals since the seventeenth century, see Agamben, *Open*, 23–27. On uncertainty about whether language is a sufficient marker for the superiority of humans over non-human animals since the late eighteenth century, see Hagner, *Geist*, 38–58. For more detailed accounts of the obsession with delineating human language from other signifying systems in philosophy, natural history, and the human sciences, see Bourke, *What*; Munz, *Dancing*; Radick, *Simian*. On nineteenth-century Parisian attempts to delineate human intelligence from non-human intelligence beyond questions of language, see L. S. Jacyna, "'We Are Veritable Animals': The Nineteenth-Century Paris Menagerie as a Site for the Science of Intelligence," in Casper; Gavrus, *The History of the Brain and Mind Sciences*. On the marginality of non-human animals in investigations of human superiority, see Katja M. Guenther, "Technique, Marginality, and History," in Casper; Gavrus, *The History of the Brain and Mind Sciences*, 258–60. On the importance of language in the cultural imagination around the turn of the twentieth century and its relationship with the linguistic turn in philosophy, see Kern, *A Cultural History of Causality*, 108–46.

[177] Harrington, *Medicine*.

[178] Leblanc, *Fearful*, 153.

[179] Harris, "Right," 12–13; Leblanc, *Fearful*, 149-161.

Broca was known for his liberal political views, which he defended with "intransigence and rebelliousness."[180] A member of a Huguenot family of "several non-conformists," he intentionally launched this brain-based attack on conservative Catholicism.[181] Nonetheless, Broca formulated his theory of a cerebral speech center with caution. Broca emphasized that not every human ability might be localizable in the brain; this was a concession to more conservative views of the brain. Throughout his academic and political careers, Broca navigated the pragmatic space between the conservatives and the liberals.[182]

Plasticity was a useful tool to partially satisfy both camps. French left-wing scientists concurred that it was the asymmetric brain that made humans exceptional, but they disagreed about whether humans were born with an asymmetric brain or if brain laterality was a consequence of an innate human ability of intellectual learning.[183] Broca supported the latter view. He adhered to French anatomist M.F. Xavier Bichat's (1771–1802) postulation that paired organs are symmetrical regarding their basic anatomy and functional potential.[184] He consequently suggested that both frontal lobes could theoretically house a center for articulate speech, but that the non-simultaneous development and differing training of the plastic cerebral hemispheres caused the leading speech center to develop in the left frontal lobe in most humans.[185]

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180 Schiller, *Paul*, 37.
181 Schiller, *Paul*, 10.
182 Schiller, *Paul*, 170–92. On Broca's diplomacy regarding the question of polygenism vs. monogenism, see Richard McMahon, *The Races of Europe: Construction of National Identities in the Social Sciences, 1839–1939* (London: Palgrave Macmillan, 2016), 106–10. On Broca's significant political investments, see Schiller, *Paul*, especially chs. 4, 6, and 15.
183 Harrington, *Medicine*, 35–69.
184 Leblanc, *Fearful*, xiii–xvii. On the importance of Bichat's law of symmetry in late-nineteenth-century anatomy, see also Harris, "Right," 5–15.
185 Leblanc, *Fearful*, 150–153; see also xiii–xvii; 30–33; 87–96; 109–121.

Despite all his caution, Broca deemed right-brainers abnormal. He asserted that the leading speech center sat in the left hemisphere of ostensibly normal humans because the left hemisphere matured faster than the right one during normal fetal development.[186] Although he assumed that *not* all left-handers were right-brained, he did not doubt that *only* left-handers were in the abnormally right-brained group. Broca had furthermore inferred that the widespread human preference to use the right hand was a by-product of the left-localized speech center, which caused the relative superiority of the alleged normal left brain hemisphere. In this way, Broca complemented the widespread idea of left-handedness as an atypical manual preference with a declaration of left-handers' potentially abnormal brain anatomy. Overall, Broca suggested that left-handers were abnormal regarding *the* quality that defined humans: articulate speech.[187]

Yet, not all of Broca's ideas were new; his research fueled scholars' existing preoccupation with establishing hierarchies between human subpopulations in the nineteenth century. Anthropologists' attempts to distinguish different human races are most infamous in this connection. Technological innovation, industrial capitalism, and aggressive colonialism widened the social gaps in Europe and made global disparities visible like never before. Broca and his anti-religious colleagues across Europe seized the chance to provide materialistic explanations for these inequalities in an allegedly objective, but in fact highly political and nationalistic, manner. Theories of physical differences between human races, sexes/genders, and manual preferences were intrinsically linked in this

[186] For other followers of this theory of brain growth gradients, see Harris, "Laterality," 182–86; Harris, "Louis".

[187] On the racist, sexist, and in other ways discriminatory potential of Broca's craniology and related anthropological work, see Gould, *Mismeasure*, 105–41.

positivistic endeavor to naturalize social hierarchies and situate one's own group at the top of the imagined evolutionary hierarchy.[188]

Historian Tamara P. Thornton has aptly summarized this quagmire of handedness, brainedness, and imperialistic ideology in the late nineteenth century:

> For if handedness was a matter of specialization, and specialization was what made Western civilization superior to savagery, then certainly handedness would prove to be a matter of one "hemisphere" dominating the other by virtue of its greater "complexity." It had to be that the brain, like the globe, could be analyzed into its superior and inferior halves and that these, like human societies, would prove to be complex and simple, respectively.[189]

Broca's theory of the superior right-handed and left-brained human brain also mirrored the widespread fear of degeneration in the later nineteenth and early twentieth centuries.[190] During the Second Industrial Revolution, large numbers of laborers from various regional and social backgrounds poured into the cities, where they lived in overcrowded quarters. Workers and their families were often malnourished and exposed to a wide range of pests and diseases. Cities became hectic, dirty, and noisy environments. In addition, the population growth contributed to an increase of the heterogeneity of people in urban centers. The moral, mental, and physical condition of these masses worried

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188 McMahon, *Races*, 19–167.

189 Tamara P. Thornton, "Deviance, Dominance, and the Construction of Handedness in Turn-of-the-Century Anglo-America," in *Moral Problems in American Life: New Perspectives on Cultural History*, ed. Karen Halttunen and Lewis Perry (Ithaca: Cornell University Press, 1998), 93.

190 On the degeneration discourse in Europe and the United States, see Bertrand, *Histoire*, 74–85; Jalava, Griffiths and Maraun, *myth*; Kern, *A Cultural History of Causality*, 27–63; Daniel Pick, *Faces of Degeneration: A European Disorder, c.1848–c.1918* (Cambridge: Cambridge University Press, 1989); Joachim Radkau, *Das Zeitalter der Nervosität: Deutschland zwischen Bismarck und Hitler* (Munich: Carl Hanser Verlag, 1998). On the mobilization of "degeneration" as a justification for enslavement, see Evelynn M. Hammonds and Rebecca M. Herzig, "Introduction," in *The Nature of Difference: Sciences of Race in the United States from Jefferson to Genomics*, ed. Evelynn M. Hammonds and Rebecca M. Herzig (Cambridge: MIT Press, 2008).

scholars and policy makers. Immorality, "nervosity," disease, and other signs of evolutionary regression—or "degeneration"—seemed to threaten the acquired superiority of humankind.[191]

By the time Broca's theory of handedness and brainedness was published in the mid-1860s, Charles R. Darwin's (1809–1882) *Origin of Species* was available in Dutch, German, French, and Italian translations.[192] With the idea of heredity firmly ingrained in the scientific consciousness, Broca's contemporaries and successors elevated degeneration to the central tropic of scientific and anthropological investigation. French psychiatrist Bénédict A. Morel (1809–1873) was one of the earliest and most vocal defenders of degeneration prevention in continental Europe, but writers and speakers of various disciplinary backgrounds supported the medicalization of social problems and non-conformity until well into the twentieth century.

Darwinism was grist for the mills of believers in degeneracy.[193] It seemed to confirm their notion that life is hierarchically organized and that "lower" humans threaten the superiority of humanity over other animals: if evolution is forceful enough to transform us from apes into humans, then it would also be able to take us backwards, so they thought.[194] Instead of singling out individuals with deteriorating mental, physical, or

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[191] On the idea of a hierarchical order of different forms of life, see footnote 174.

[192] "Darwin Online: On the Origin of Species," accessed March 15, 2019, http://darwin-online.org.uk/EditorialIntroductions/Freeman_OntheOriginofSpecies.html.

[193] On the continued impact of evolutionary theories on the sciences of the mind and brain, particularly in the form of sexed/gendered and sexualized interpretations, see Pieter R. Adriaens and Andreas de Block, "The Evolutionary Turn in Psychiatry: A Historical Overview," *History of Psychiatry* 21, no. 82 (2010), https://doi.org/10.1177/0957154X10370632; H. G. Cocks, "The History of Sexuality Meets Evolutionary Psychology," *Contemporary British History* 24, no. 1 (2010), https://doi.org/10.1080/13619460903553826; Robert John Richards, *Darwin and the Emergence of Evolutionary Theories of Mind and Behavior* (Chicago: University of Chicago Press, 1987); Richard J. Siegert and Tony Ward, "Evolutionary Psychology: Origins and Criticisms," *Australian Psychologist* 37, no. 1 (2002), https://doi.org/10.1080/00050060210001706636.

[194] On monogenism, the pre-Darwinistic scientific concept that paved the way for a theory of degeneration, see the Gould, *Mismeasure*, 62–104; 401–412.

moral capacities, the degenerationists diagnosed entire groups as defective and potentially threatening to the progress of humankind. This alleged group-specific degeneration could manifest, for instance, as criminal behavior, physical decline, interracial desire, substance abuse—or left-handedness.

Lombroso's Aggravation

Cesare Lombroso, one of the founders of criminology, was one of the most vocal defenders of the idea that left-handedness is a visible sign of degeneration. Lombroso was born in the Italian city of Verona, which at the time was part of the Austrian Empire. He was a socialist and appeared to be a progressive figure in his time. Yet, utilizing craniology and physiognomy, he formulated a theory that identified crime, prostitution, mental disability, and other non-conforming conditions as "atavisms," that is, relapses to an earlier stage of evolution.[195]

In contrast to the French degenerationists, Lombroso had a positivistic view of the battle against degeneration. Morel and other scholars of a conservative Catholic mindset believed that degeneration would progress infinitely. In Lombroso's understanding, evolution was a mostly linear progression, but degeneration in certain lineages was natural. He was convinced that unnatural counter-evolutionary forms of degeneration could be stopped by scientifically guided political reforms and rigid institutionalization.[196]

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[195] On the afterlife of the concept of atavism in twentieth-century genetics, see Robert Dingwall, Brigitte Nerlich, and Samantha Hillyard, "Biological Determinism and Its Critics: Some Lessons from History," in Ellison; Goodman, *The Nature of Difference*.

[196] Pick, *Faces*, 109–52. On Lombroso's life and work, see also Cryle and Stephens, *Normality*, 180–211; Mary Gibson, *Born to Crime: Cesare Lombroso and the Origins of Biological Criminology* (Westport: Praeger, 2002); Gould, *Mismeasure*, 151–73; Horn, *Criminal*; Hans G. Kurella, "Cesare Lombroso und die Naturgeschichte des Verbrechers," *Sammlung gemeinverständlicher wissenschaftlicher Vorträge* Neue Folge VII, no. 147 (1893); Hans Georg Kurella, *Cesare Lombroso als Mensch und Forscher,* Grenzfragen des Nerven- und Seelenlebens 73 (Wiesbaden: J.F. Bergmann, 1910); Kushner, *On*, 16–29; Karl Ruehl,

Lombroso was eleven years younger than Broca and his work stretched well into the twentieth century, long after Broca had passed away. Lombroso upheld that left-handedness originated from brain asymmetry, but he did not cite Broca in this context.[197] According to Lombroso, "[n]ormal" individuals were right-handed and had a larger left cerebral hemisphere.[198] Lombroso assumed that a heightened blood supply to the left half of the brain made this the default hemisphere with which "honest person[s]" think.[199] He was unsuccessful at proving an association between asymmetric blood pressure and hand preference, but blood flow remained a key explanation in his own and his contemporaries' studies on the physiology and anatomy of deviance.[200]

Where Broca had retreated to a concept of plasticity to satisfy conservatives (who believed in human superiority by divine endowment) and liberals (who believed in evolutionarily acquired human superiority), Lombroso inconsistently employed ideas of malleability and fatalism in his theory. Like Broca, Lombroso believed that the relationship between the hand and the brain was plastic: left-brainedness preceded right-handedness, and the predominant use of the right hand made the left brain hemisphere even stronger.[201] While Broca had suggested that *some* left-handers might have abnormal brains and had foregone detailed speculations on the potential inheritance of left-handedness, Lombroso

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Cesare Lombroso, geboren 10. Januar 1836, gestorben 19. Oktober 1909 (Halle an der Saale: Carl Marhold Verlagsbuchhandlung, 1910).

[197] There is no reference to Broca in Lombroso, "Left". I did not consult, however, Lombroso's untranslated Italian works, some of which are referenced in Horn, *Criminal*, 72.

[198] Lombroso, "Left," 441; 443.

[199] Horn, *Criminal*, 72.

[200] On Lombroso's failed attempt to prove this theory, see Horn, *Criminal*, 173, n. 73. On Lombroso's theory of how blood circulation influences the body, mind, and character, see, e.g., Cesare Lombroso, *Genie und Irrsinn in ihren Beziehungen zum Gesetz, zur Kritik und zur Geschichte*, Reclams Universal-Bibliothek (Leipzig: Philipp Reclam jun., 1887), Translated by A. Courth, 7–34. See also a summary on Lombroso's work on blushing in Horn, *Criminal*, 107–31.

[201] Lombroso, "Left," 442.

maintained that left-handedness—or "mancinism"—was an atavism *per se*, that is, an innate and visible sign of mental and moral underdevelopment.[202] Ambidexterity, Lombroso suggested, was also inborn and might go back to an even earlier state in human ancestry than left-handedness.[203] This concept of pre-determined fixity defies the description of handedness as a plastic characteristic.

Lombroso found support for his theory that left-handedness is an atavism in population statistics on manual preference. Marginalized ethnic or regional groups had proportionally more left-handers than allegedly culturally advanced white Italians.[204] Furthermore, Lombroso observed a very high ratio of left-handers and ambidexters among criminals and the mentally ill.[205] He even reported that some animal species who share important characteristics with humans, including parrots and lions, were more likely to exhibit right-handedness than less "perfect" animals, which are not equally "near ... [to] man."[206] Manual preference, according to Lombroso, was neither a cause nor consequence of moral and intellectual inferiority. He considered left-handedness, criminal

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[202] Cesare Lombroso, *Der Verbrecher (Homo delinquens) in anthropologischer, ärztlicher und juristischer Beziehung: Erster Band* (Hamburg: J.F. Richter, 1887), Translated by M. O. Fraenkel, 280–281; 298–301; 533–35. Quote from Cesare Lombroso, *Entartung und Genie: Neue Studien* (Leipzig: Wiegands Verlag, 1894), Edited and translated by Hans G. Kurella, 57. Kushner pointed to a similar contradiction: Lombroso assumed that left-handers are biologically predisposed to commit crimes, but he interpreted criminal behavior among the Jewish population as cultural circumstance rather than an innate tendency; Kushner, *On*, 20–21.

[203] Cesare Lombroso, *Neue Verbrecherstudien* (Halle an der Saale: Carl Marhold Verlagsbuchhandlung, 1907), Translated by Ernst Jentsch, 111.

[204] Cesare Lombroso, *Neue Fortschritte in den Verbrecherstudien*, 2nd ed. (Gera: C.B. Griesbach, 1896), Translated by Hans Merian, 191–92. On Lombroso's racialized concept of atavisms, see also Gibson, *Born*, 97–126; Horn, *Criminal*, 12–16; 33–51; 70–73.

[205] Lombroso, *Verbrecher*, 280–281; 298–301; 530; Cesare Lombroso, *Der Verbrecher (Homo delinquens) in anthropologischer, ärztlicher und juristischer Beziehung: Zweiter Band* (Hamburg: Verlagsanstalt und Druckerei A. G., 1890), Translated by M. O. Fraenkel, 343–44.

[206] Lombroso did not provide an example for what he meant by less "perfect" animals; Lombroso, "Left," 441.

tendencies, mental illness, and cognitive problems to be visible symptoms of an underlying atavism in a particular individual, family, or population.[207]

Lombroso also employed his theory of physical asymmetries to explain purported intellectual differences between women and men, and he took the old idea of a developmental hierarchy so far as to elevate socially recognized sex/gender differences to a marker of evolutionary progress.[208] He counted more left-handers among women (5 to 8 percent) than men (4 percent), most notably among female criminals (22 percent).[209] This finding indicated to him a higher rate of atavism in women than men, and hence an evolutionary inferiority of women. However, in "low-standing races," that is, allegedly underdeveloped human subpopulations, Lombroso saw less of a difference between men and women.[210] He inferred that only advanced human races had pronounced physical sex/gender differences, and that only highly developed cultures had designated male and female social roles.[211]

Lombroso's definition of handedness oscillated between "anatomical" and "functional" handedness.[212] Anatomical left-handers exhibited superior sensory capacities in their left hands and/or displayed more strength in their right arm and hand when assessed with a dynamometer. Functional left-handedness designated a preference and/or habit to

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[207] Lombroso thought that genius is just as much a form of degeneration as criminality or mental illness; Cesare Lombroso, *L'homme de génie* (Paris: Félix Alcan, 1889), Translated by Fr. Colonna d'Istria, 6–7; 17–18; 459–460.
[208] For more extensive treatments of Lombroso's views on women as criminals and inferior human types, see Gibson, *Born*, 53–95; Horn, *Criminal*, 52–57; 140–143.
[209] Cesare Lombroso and Guglielmo Ferrero, *Das Weib als Verbrecherin und Prostituirte: Anthropologische Studien gegründet auf einer Darstellung der Biologie und Psychologie des normalen Weibes* (Hamburg: Verlagsanstalt und Druckerei A. G., 1894), Translated by Hans G. Kurella, 44; 371. Later studies almost exclusively found an excess of left-handers in men, or equal ratios of left-handedness in women and men (Chapter 3).
[210] German original: "tiefstehenden Rassen"; Lombroso and Ferrero, *Weib*, 44–45 (quote on p. 45).
[211] Lombroso and Ferrero, *Weib*, 44–45.
[212] Lombroso and Ferrero, *Weib*, 513.

use the left hand over the right. Even if individuals with anatomical left-handedness did not display any functional left-handedness, Lombroso counted them as left-handers proper.

Lombroso's connection between right-handedness, intellectual abilities, and cultural superiority is reminiscent of Broca's argument that only "higher" species have asymmetric brains. By linking handedness with human intellect, Broca's aphasia studies enabled Lombroso's and others' theories of left-handedness as a sign of degeneration and weak character. The Second Industrial Revolution and its allegedly unphysiological (that is, unhealthy and unnatural) forms of "progress" scared not only Lombroso but also his European colleagues.[213] Around 1900, a considerable number of additional European academics, educators, and writers supported the view of the abnormal, if not sinister, left-hander, and Lombroso's work was quoted widely and favorably.[214] When other scholars challenged Lombroso, they mostly did so on the grounds of his definition of left-handedness.[215] The fact that they did not criticize Lombroso for his claim that left-handedness was an atavism exemplifies the firm belief in the doctrine of degeneration at the time. Broca's cautionary remarks that not all left-handers might have abnormal brains had given way to more simplistic approaches to brain asymmetry and manual preference.

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[213] German original: "Fortschritt"; Cesare Lombroso and Rodolfo Laschi, *Der politische Verbrecher und die Revolutionen in anthropologischer, juristischer und staatswissenschaftlicher Beziehung: Erster Band* (Hamburg: Verlagsanstalt und Druckerei A. G., 1891), Edited and translated by Hans G. Kurella, 1–3; 39–46 (quote on p. 1).

[214] Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 53–54.

[215] Scholars who have criticized Lombroso for this definition of handedness include Hasseroth, "Rechts," 85; Arthur Kronfeld, "Die Individualpsychologie als Wissenschaft: Ihre Formen und ihre Beziehungen zur Psychologie der Gegenwart," in Wexberg, *Handbuch der Individualpsychologie*, 22; Walter Scharnke, "Epilepsie und Linkshändigkeit" (Inaugural-Dissertation, Medizinische Fakultät, Friedrich-Wilhelms-Universität, 1920), 6; 8; Ewald Stier, *Untersuchungen über Linkshändigkeit und die funktionellen Differenzen der Hirnhälften* (Jena: Gustav Fischer, 1911), Nebst einem Anhang: „Über Linkshändigkeit in der deutschen Armee," 3.

Blood as the Material Cause

Some scholars were not content with Broca's assertion that right-handedness originated from left-brainedness; they set out to investigate the causes of left-brainedness itself. Lombroso hinted at the importance of blood supply for the activity of specific brain centers. Other scholars explained the entire doctrine of left-hemispheric dominance with asymmetric blood flow and/or blood pressure. Ironically, none of these scholars tried to unravel the causes of asymmetric blood flow itself. Blood seems to have been a scientific frontier in anatomico-physiological handedness research around 1900.

Moritz Alsberg (1840–1937), for instance, a Jewish physician and anthropologist born in Hesse-Kassel, upheld Gratiolet's and Broca's propositions that the key to left-brainedness lay in the early maturation of the left brain hemisphere.[216] He intended to strengthen their theories by providing an explanation for the lop-sided development of the brain, building on an analysis of the blood vessels that provided the brain hemispheres with necessary nutrients.[217]

When Alsberg addressed the *Deutsche Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* (German Society for Anthropology, Ethnology, and Prehistory) in 1893, he summarized the contemporary knowledge about brain physiology as follows:

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[216] Moritz Alsberg, "Rechtshändigkeit und Linkshändigkeit, sowie deren muthmaßliche Ursachen: Vortrag, gehalten auf dem XXIV. Kongreß der Deutschen Gesellschaft für Anthropologie, Ethnologie und Urgeschichte zu Hannover am 8. August 1893," *Sammlung gemeinverständlicher wissenschaftlicher Vorträge* IX, no. 205 (1895): 493–501.

[217] Alsberg was not the originator of this theory. According to Ernst Weber's literature review, it was first mentioned in the Encyclopædia Britannica in 1810; Ernst Weber, *Ursachen und Folgen der Rechtshändigkeit* (Halle an der Saale: Carl Marhold, 1905), 32. Several decades later, William Ogle popularized the idea; William Ogle, "On Dextral Pre-Eminence," *Medico-Chirurgical Transactions* 54 (1871). Alsberg, Ludwig Liersch, and F.K.A. "Fritz" Lueddeckens presented the idea as if it were their own, and later scholars, including Ewald Stier and Weber, referred to Lueddeckens as the first German promoter of the idea.

The view is currently unchallenged that the nervous processes in the brain, which we call "feelings," "consciousness," and "will," are rooted in particular in the cerebral ganglia (neural cells) occurring physical-chemical changes; it can also hardly be questioned that the activity of the cerebral ganglia, depending on their nutrition, i.e., depending on the differing degrees of blood supply, will be more or less lively and energetic.[218]

The concrete presumed physical and chemical mechanisms by which nutrients in the blood created "feelings," "consciousness," and "will" were beyond Alsberg's investigative abilities. Nevertheless, he could trace the blood flow by means of anatomical descriptions, drawing from Austrian-Hungarian anatomist Josef Hyrtl's standard works (1810–1894).[219] Alsberg explained that the left common carotid artery led directly from the aortic arch (which he saw as an extension of the left heart) to the head, while the right common carotid artery was not directly connected with the aortic arch. Instead, he assumed that it grew out of a branching of the brachiocephalic artery, which was itself connected to the aortic arch.

[218] German original: "Daß die im Gehirn sich abspielenden Nervenprozesse, die wir als ‚Empfindung', ‚Bewußtsein', und ‚Willen' bezeichnen, auf gewissen in den Hirnganglien (Nervenzellen) vor sich gehenden physikalisch-chemischen Veränderungen beruhen, diese Anschauung ist gegenwärtig unbestritten; auch kann es wohl kaum bezweifelt werden, daß die Thätigkeit der Hirnganglien je nach der Ernährung derselben, d. i. je nach den verschiedenen Graden der Blutzufuhr eine mehr oder weniger lebhaftere und energischere sein wird"; Alsberg, "Rechtshändigkeit," 501.
[219] Joseph Hyrtl, *Lehrbuch der Anatomie des Menschen, mit Rücksicht auf physiologische Begründung und praktische Anwendung*, 3rd ed. (Vienna: Wilhelm Braumüller, 1853). Although Alsberg did not attribute the idea to Hyrtl, Hyrtl suggested in another widely-read textbook that asymmetric blood flow to the arms might be the cause for muscular asymmetries in favor of the right side of the body; Joseph Hyrtl, *Lehrbuch der Anatomie des Menschen mit Rücksicht auf physiologische Begründung und praktische Anwendung*, 6th ed. (Vienna: Wilhelm Braumüller, 1859), 821. Hyrtl had suggested in previous editions of the latter textbook that this muscular asymmetry underlies right-handedness; Joseph Hyrtl, *Handbuch der topographischen Anatomie, und ihrer praktisch medizinisch-chirurgischen Anwendungen: Zweiter Band* (Vienna: Johann Baptist Wallishausser, 1847), 178–79; Joseph Hyrtl, *Handbuch der topographischen Anatomie, und ihrer praktisch medicinisch-chirurgischen Anwendungen: Zweiter Band*, 3rd ed. (Vienna: Wilhelm Braumüller, 1857), 228–29. Hyrtl denied any relationship between handedness and the mind or character; Hyrtl, *Handbuch*, 267–68; Hyrtl, *Handbuch*, 332–33.

Alsberg explained that the left heart pumped nutrient-rich blood in a relatively straight line from the aortic arch through the left common carotid artery and into the left half of the brain.[220] The blood from the left heart that was supposed to supply the right half of the brain with nutrients, however, would "bump into" the fork between the right common carotid artery and the right subclavian artery.[221] Alsberg believed that this would increase friction, causing lower blood pressure, fewer nutrients, less metabolism, and hence less "energy of the nervous current" in the right brain hemisphere as compared to the left.[222] Consequently, the left half of the brain would become dominant over the right in all motor tasks, leading to right-handedness in what he considered normal people.[223] If the blood vessels that connect the heart and the head were arranged in a different way and friction was stronger on the left (or equally strong on both sides), Alsberg suggested, individuals could become left-handed (or ambidextrous).[224]

Prussian-German anatomist Ernst W.T. Gaupp (1865–1916) moved the focus of the blood-vessel theory of handedness from the heart to the brain. He firmly believed in the association between brain asymmetry and manual preference and built his argument with direct reference to Broca.[225] Following Broca, but disagreeing with many other anatomists around 1900, Gaupp assumed that cerebral asymmetry was mainly functional, not structural. Because of the functional superiority of one of the two hemispheres (usually the left one), most humans preferred the contralateral hand (usually the right one), and as a consequence of this habit, the symmetrically existing speech centers were unevenly

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[220] Alsberg, "Rechtshändigkeit," 502.
[221] German original: "anschl[a]g[en]"; Alsberg, "Rechtshändigkeit," 502.
[222] German original: "Energie des Nervenstromes"; Alsberg, "Rechtshändigkeit," 503.
[223] Alsberg, "Rechtshändigkeit," 502–3.
[224] Alsberg, "Rechtshändigkeit," 504–5.
[225] Ernst W. T. Gaupp, "Über die Rechtshändigkeit des Menschen," *Sammlung anatomischer und physiologischer Vorträge und Aufsätze* 1, no. 1 (1909): 17–19.

used. Hence, whatever caused functional brain asymmetry also determined manual preference, which in turn molded the brain by stimulating only one of its two speech centers.[226]

Gaupp did not take brain asymmetry as a satisfactory explanation for handedness. In his view, Broca had only shifted the etiological problem from the hand to the brain, and now Gaupp set out to solve the mystery of brainedness.[227] Feeding the anthropological machine that Broca had set into motion, Gaupp assumed that cerebral dominance was rooted in an exceptionally human quality. Trying to reach farther back into evolution than Broca, who had fallen back upon articulate speech, Gaupp thought it possible that erect posture is the key to the problem of cerebral dominance. Drawing on Dutch anatomist Lodewijk "Louis" Bolk (1866–1930), Gaupp deliberated if upright carriage might have caused the heart and major blood vessels to shift to the left side of the human body. If this was the case, then asymmetric blood circulation might be an important factor in explaining cerebral dominance and handedness, Gaupp suggested.[228]

There was a problem with the theory that asymmetric blood circulation causes handedness: it seemed disproven by cases of the transposition of the viscera. This condition leads to the reversal of the common position of all interior organs and, before Broca, used to be a leading contender to explain the origins of handedness. With increasing research on the topic, however, it became clear that most individuals with transposed viscera were right-handed, and that there existed many left-handers without this condition. This observation also challenged Alsberg's theory of blood circulation. If the position of

[226] Gaupp, "Über," 20.
[227] Gaupp, "Über," 20.
[228] Gaupp, "Über," 21–24.

the heart and all connected blood vessels were reversed, then the individual should be left-handed, but the statistics did not support this view.[229]

Thus, Gaupp invented a transposition that did not contradict the previous findings. He suggested that left-handedness derived from a condition he called "*Transpositio cerebralis*"—a transposition of the cerebral hemispheres.[230] Gaupp defined *Transpositio cerebralis* as a—potentially minimal—abnormality of the position of the blood vessels that lead to the brain. If the asymmetry was significant, then the functional difference between the brain hemispheres would be substantial, and the individual would have a pronounced hand preference. Most people would have only minor blood flow asymmetries, and hence only slight hemispheric dominance and a mild manual preference. In these individuals, Gaupp asserted, education determined handedness, not biology.[231]

Despite his belief in prevalence of nearly symmetrical plastic brains and culturally acquired handedness, Gaupp suggested in agreement with Broca that brain asymmetry *per se* is a characteristic of higher development. He accepted left-handedness as a natural variation but considered ambidexterity dangerous for one's intellectual abilities and for the development of a species. Trying to undo the dominance of one brain hemisphere might interfere with natural development, so Gaupp echoed Broca's theory of cerebral asymmetry as the highest evolutionary achievement to date.[232] In Gaupp's work, the fear of degeneration seems much more visceral than his admiration for the achievements of evolution.

[229] Gaupp, "Über," 22–24.
[230] Gaupp, "Über," 20.
[231] Gaupp, "Über," 28.
[232] Gaupp, "Über," 29–32.

The Brain-Centric Reformers

Physical, Intellectual, and Economic Gain for Germany

Notwithstanding the Exceptionalist-Degenerationists' tendencies to pathologize left-handedness, they served the liberation of left-handers to some extent. Some reformers shifted the research focus from unraveling human nature to concrete biopolitics and to economic gain, but the rhetoric of human exceptionalism and degeneration clearly persisted. A good example for this is the work of Ludwig Liersch (1830–1904), a physician and health officer in Cottbus. Liersch wrote his tract on handedness as a guidance for insurance companies, particularly to help them assess the handedness of workers who claimed high compensations for injuries to their alleged dominant hand.[233]

Inspired by Hyrtl's assertion of the importance of blood flow to the extremities, Liersch believed that handedness was caused by asymmetric blood circulation (and not, as Hyrtl had claimed, by muscular asymmetry).[234] Liersch also maintained that left-handedness was a deviance and that right-handedness was "obligatory" for human development.[235] Nonetheless, he advocated for the permissibility of left-handedness in the interest of economic and national(istic) gain. Most of all, Liersch encouraged ambidexterity in all manual labor because he feared the detrimental effects of the strictly right-sided use of the body. These included loss of strength and sensation in the neglected extremities, scoliosis, visual impairments, constipation, and heart disease.[236] After drawing this alarming picture of one-sidedness, Liersch suggested that widespread ambidexterity would prevent all of these ailments. Furthermore, workers would be more efficient if they were

[233] Liersch, *linke*, 36–39.
[234] Liersch, *linke*, 13. On Hyrtl's work, see footnote 219.
[235] German original: "obligatorisch(e)"; Liersch, *linke*, 1; 12 (quote on p. 12).
[236] Liersch, *linke*, 15–28.

ambidextrous, since they could continue working in spite of one-sided fatigue or an injury to one side of their bodies.[237]

It is important to note that Liersch's hopes for ambidexterity extended only to the better use of the extremities. Many reformers were more brain-centric; they assumed that ambidexterity, in addition to making laboring bodies more efficient, would prove beneficial for language and the intellect of individuals as well as entire populations.[238] German pedagogue Anton Hasseroth (1858–?) was on board with two-handedness. He judged Germany's state of ambidexterity education unfavorably in 1911: the United States, Britain, and Japan had more advanced programs for two-handed schooling despite German schools' outstanding curricula in physical education.[239] Hasseroth had direct access to students and could experiment on them himself, for instance, by determining the (insignificant) correlation between students' hand preference and the side from which they drew a profile.[240]

Hasseroth was familiar with Lombroso's and Morel's theories of degeneration. He was not entirely certain if left-handedness was a sign of degeneration, but he considered left-handedness a "*Stigma*."[241] Maintaining that the superior strength of the right hand preceded its preferred use within the human race, he rejected Gaupp's theory of acquired functional dexterity.[242] Hasseroth was convinced that education only played a small role compared to an innate tendency to use one hand.[243] This inborn predominance

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[237] Liersch, *linke*, 39–47.
[238] Cf. the interpretation of nineteenth-century ambidexterity movements as a form of "neuroascesis," i.e., attempts to discipline oneself in the interest of increasing brain-health; Vidal and Ortega, *Being*, 43–47.
[239] Hasseroth, "Rechts," 90–91.
[240] Hasseroth, "Rechts," 82.
[241] Hasseroth, "Rechts," 85.
[242] Hasseroth, "Rechts," 86.
[243] Hasseroth, "Rechts," 86.

of one hand was a person's "true nature" and could not be reversed by training, hypnosis, or other means.[244]

A fear of brain damage lay at the heart of Hasseroth's advocacy for the increased use of the left hand in right- and left-handers. Although his suggestions concerning the precise connection between the brain and the hand were as vague as Broca's, Hasseroth assumed that our manual behavior could hurt our brains. He cited evidence that the dominant hemisphere slept more deeply than the non-dominant one. To him, this indicated an overexertion of the left half of the brain in right-handed individuals, a condition that might have (unspecified) detrimental consequences.[245] Thus, right-handers should frequently give their left hemispheres some rest by using their left hands, and hence prevent the potential brain damage that a fixation on one hand might cause.[246]

Another Brain-Centric Reformer who encouraged ambidexterity in terms of the brain was physician F.K.A. "Fritz" Lueddeckens. He worked at the "Asylum for Deaf-Mutes and Idiots" in the Silesian city of Legnica (now Poland) and was more explicit about the ways in which ambidexterity might lead to economic gain.[247]

Lueddeckens's understanding of handedness was, in accordance with Lombroso and Hyrtl, a quite mechanical one. He assumed that manual preference appeared on the stronger side of the body as a secondary effect.[248] The fact that one side of the body was usually stronger than the other was already a developmental error to Lueddeckens. A firm believer in Bichat's law of symmetry, he suggested that every individual in the "realm of

[244] German original: "wahre Natur"; Hasseroth, "Rechts," 86–87.
[245] Hasseroth, "Rechts," 89.
[246] Hasseroth, "Rechts," 88–89.
[247] German name of the institution: "Taubstummen- und ... Idioten-Anstalt"; Friedrich Karl August Lueddeckens, *Rechts- und Linkshändigkeit* (Leipzig: Wilhelm Engelmann, 1900), I.
[248] Lueddeckens, *Rechts*, v.

higher animals" was perfectly symmetrical in the early embryonic stage.[249] During development, slight asymmetries could lead to the asymmetric growth of blood vessels. This could, in turn, cause more significant anatomical and functional asymmetries, including handedness.[250]

According to Lueddeckens, increased blood flow in one half of the body did *not* lead to stronger extremities on the same side. Instead, left-handedness and superior strength in the left half of the body manifested as a "compensatory moment" in response to lower blood pressure on the right side of the body and vice versa.[251] The asymmetrical blood flow's impact on the brain was much more direct than that on the muscles, Lueddeckens thought. Where there is more blood, there is more cognition. He divided humanity into "three groups" according to the strength of the blood flow to the sides of the brain: the majority with left-dominant brains, a large minority with right-dominant brains, and a tiny minority with almost symmetrical brains.[252]

The distinction between these brain types mattered not only to science but was a concern of daily life. In the interest of good brain care, Lueddeckens advised right-handers (that is, in his view, left-brainers) to sleep on their right side. He argued that a crucial prerequisite for healthy sleep was elevating the dominant left hemisphere and allowing the blood to easily vacate it, as well as saving it from unnecessary compression.[253] Left-handers had more options when it came to sleeping. They might lie on their left side to help with the blood flow from their dominant right hemisphere, but the might just as

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[249] German original: "höheren Tierwelt"; Lueddeckens, *Rechts*, 1.
[250] Lueddeckens, *Rechts*, 1–12.
[251] German original: "kompensatorisches Moment"; Lueddeckens, *Rechts*, 12.
[252] German original: "drei Gruppen"; Lueddeckens, *Rechts*, 12. For more detailed descriptions of the right-brained group, see Lueddeckens, *Rechts*, 12–58.
[253] Lueddeckens, *Rechts*, 58.

well decide not to compress their heart and stomach, and instead sleep on the right side.[254] These recommendations suggested that knowing one's handedness empowers one to take good care of one's brain and be a more productive citizen.

From a statistical perspective, Lueddeckens considered right-brainedness (and left-handedness) as "something unusual,"[255] but he was strictly against the conversion of left-handers.[256] He denied that any postulated inferiorities of left-handers (or right-brainers) had been convincingly established, and hence considered the cruel retraining methods to turn left-handers into right-handers unjustified.[257] More importantly, he hoped that the skillfulness and stamina of German laborers might be increased by encouraging them to use both of their hands.[258] Even one of the greatest dangers to the industrial worker, the loss of a limb, could be ameliorated if only laborers trained both of their hands equally.[259] What a comfort this argument must have been to industrialists and insurance companies!

Military and Moral Gain for Germany

Much more explicitly than Lueddeckens, German physician Manfred Fränkel's (b. 1877) claim that ambidexterity benefits the brain and the body supported a strongly nationalistic and militaristic agenda. Fränkel's focus on the body mirrored the trend of holistic "*Lebensreform*" ("life reform") in Germany around 1900, which emphasized physical education as an antidote to the rising number of alleged degenerates and

[254] Lueddeckens, *Rechts*, 60–81.
[255] German original: "etwas Ungewöhnliches"; Lueddeckens, *Rechts*, 70.
[256] Lueddeckens, *Rechts*, 75.
[257] Lueddeckens, *Rechts*, 70–75.
[258] Lueddeckens, *Rechts*, 75–76.
[259] Lueddeckens, *Rechts*, 75.

"*vergeistisgte Schwächlinge*" ("learned weaklings") in the industrial age.[260] Fränkel's tract *Value of Two-Handed Education for School and State with Regard to the Advantages of Non-Cursive Writing* was first published in 1910.[261] A corrected second edition was published in 1915, when World War I was already raging.

In his preface to the second edition, Fränkel reported that German teachers had launched ambidexterity experiments in response to his suggestions. Furthermore, he saw his insistent calls for ambidexterity justified by the struggles and injuries of soldiers at the front.[262] Fränkel reasoned that if Germans wanted to leave "*ein mächtiges, unbesiegbares Deutschland*" ("a strong, invincible Germany") to the next generation, they would have to train their children in ambidexterity.[263] That way, they could strengthen Germany and its economy even further and show their enemies "*nicht nur eine Faust, nein! zwei gleichkräftige Arme zur Abwehr*" ("not only one fist, no! two equally strong arms to our defense").[264] Drawing heavily on the Darwinist theory of the struggle for existence, Fränkel argued in the final chapter of both editions that enemies might kill off the German

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[260] Michael Hagner, *Der Hauslehrer: Die Geschichte eines Kriminalfalls – Erziehung, Sexualität und Medien um 1900* (Frankfurt am Main: Suhrkamp, 2010), 22. As Hagner showed, the focus on physical health did not rule out (at times even deadly) corporal punishment, which was an integral part of the "black pedagogy" in the long nineteenth century. See also Johannes Bilstein et al., eds., *Bildung und Gewalt* (Wiesbaden: Springer Verlag, 2015); Benno Hafeneger, *Strafen, prügeln, missbrauchen: Gewalt in der Pädagogik* (Frankfurt am Main: Brandes & Apsel Verlag, 2012); Jacob Middleton, "The Experience of Corporal Punishment in Schools, 1890–1940," *History of Education* 37, no. 2 (2008), https://doi.org/10.1080/00467600701607882; Katharina Rutschky, *Schwarze Pädagogik: Quellen zur Naturgeschichte der bürgerlichen Erziehung* (Frankfurt am Main: Ullstein, 1977).

[261] This is my translation of the title. Manfred Fränkel, *Wert der doppelhändigen Ausbildung für Schule und Staat mit Berücksichtigung der Vorteile der Steilschrift* (Berlin: Richard Schoetz, 1910), Nebst einem praktisch-didaktischen Teil „Zur doppelhändigen Ausbildung" von Stadt- und Kreisschulinspektor F. Tromnau, Königsberg.

[262] Manfred Fränkel, *Die doppelhändige Ausbildung und ihr Wert für Schule und Staat: Mit Berücksichtigung der Vorteile der Steilschrift*, 2nd ed. (Berlin: Richard Schoetz, 1915), Nebst einem praktisch-didaktischen Teil „Zur doppelhändigen Ausbildung" von Stadt- und Kreisschulinspektor F. Tromnau, Königsberg, V.

[263] Fränkel, *doppelhändige*, VI.

[264] Fränkel, *doppelhändige*, VI.

people soon unless German soldiers gained additional military prowess from strengthening both hands and brain hemispheres.[265]

Fränkel based his concerns with one-handedness and cursive writing on the observation that fewer and fewer young Germans were fit for military service. Instead, numerous school-aged children were affected by scoliosis, eye problems, lung defects, heart problems, general weakness and unfitness, among other ailments. If furniture in schools were improved, more physical education provided, cursive writing abolished, and both hands educated in all manual tasks, then both halves of the body and brain would be equally well-trained and the above complaints would vanish.[266]

Fränkel agreed with Gaupp that handedness was predominantly functional, that is, a matter of skill rather than strength, and due to some innate preponderance of the right side.[267] Maybe this agreement is why Fränkel massively borrowed (not to say "plagiarized") from Gaupp's study on handedness.[268] Just like Gaupp, Broca, and others, Fränkel agreed that handedness was a matter of plasticity. He did, however, not settle on functional plasticity and instead suggested that the predominant use of the stronger hand would increase the anatomically-based lop-sidedness of humans by means of *structural* plasticity.[269] The relatively high ratio of ambidexters among women, who tended to use both hands a lot during housekeeping, crafts, or playing the piano, seemed to support this opinion.[270]

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[265] Fränkel, *doppelhändige*, 121–129.
[266] Fränkel, *doppelhändige*, 1–19.
[267] Fränkel, *doppelhändige*, 42.
[268] E.g., Fränkel, *doppelhändige*, 34–44. Cf. Gaupp, "Über," 1, 14, 17–20, 30. Gaupp himself "borrowed" from Liersch without acknowledging his doing so; Gaupp, "Über," 14. Cf. Liersch, *linke*, 13.
[269] Fränkel, *doppelhändige*, 41.
[270] Fränkel, *doppelhändige*, 67.

Uncertain if the presumed innate dominance of the right hand derived from left-brainedness, Fränkel at least considered it the best available explanation. Again, in agreement with Gaupp, he insisted that the causes of manual preference could only be determined if the causes of brain asymmetry could be revealed.[271] He supported Liersch, Alsberg, and Gaupp in their opinion that the relatively high supply of nutrient-rich blood to the left hemisphere caused left-brainedness, that right-handedness was a secondary effect of this asymmetry, and that this marked right-handedness as an exceptionally human quality, most likely connected to erect posture.[272]

Even in the absence of a firm theory of the causes of handedness, Fränkel encouraged ambidextrous education. Just like eyes, ears, and feet needed simultaneous training, the non-dominant hand should not be neglected.[273] This plea might seem surprising considering that Fränkel subscribed to the idea of brainedness as a characteristic of human superiority. However, he argued that ambidextrous training did not reverse handedness or brainedness; it empowered the right brain and the left hand to exercise "*Nebenstudien*" ("side studies"), and to rise from its supporting role as soon as the dominant hand or brain needed subbing.[274]

In addition to the fear of political enemies, the "*nervöse(s) Zeitalter*" ("nervous age") around 1900, that is, the perceived age of mental, moral, and physical degeneration, concerned Fränkel.[275] In such frail and uncertain times, he thought it best to train the left hand and right brain hemisphere so they could potentially replace their injured better half.

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[271] Fränkel, *doppelhändige*, 43–44.
[272] Fränkel, *doppelhändige*, 47.
[273] Fränkel, *doppelhändige*, 50.
[274] Fränkel, *doppelhändige*, 57–58 (quote on p. 58). See also Fränkel, *doppelhändige*, 87–89.
[275] Fränkel, *doppelhändige*, 111. On the German "nervous age" in the late nineteenth and early twentieth centuries, see Radkau, *Zeitalter*. See also footnote 190.

Fränkel focused on advocating for right-handers to also use their left hand, presumably in the assumption that left-handers already knew the importance of training their right hand. Besides the promise of military strength, Fränkel saw in this two-handed education a cure for intellectual and moral inferiority:

> The conclusion is justified that we can, this way, reduce the shockingly high numbers of the mentally ill and feeble-minded, the army of mentally abnormal individuals including all deviancies of those with a perverted bent, the legions of criminals that stem from mental anomaly.[276]

All Gains for English-Speaking Countries

Advocacy for ambidexterity in the interest of physical, intellectual, economic, moral, and military gain was not an exclusively German concern. Scottish-Canadian anthropologist Daniel Wilson (1816–1892), who later became the President of the University of Toronto, had anticipated many of the above arguments already in 1891. A left-hander himself, he intended to change the tone of handedness research from stigma towards opportunity. He sought to uncover the "true source" of left-handedness and to expose "the folly of persistently striving to suppress an innate faculty of exceptional aptitude."[277]

Wilson based his argument on archeological and physiological evidence. Although he conceded that right-handedness was prevalent "not only among cultured and civilised races," but also among the "uncultured and savage ... man," he maintained that

[276] German original: "[E]s ist … der Schluß berechtigt, daß wir so die erschreckend große Zahl Geisteskranker und Schwachsinniger, das Heer der geistig Anormalen mit all den Abarten der pervers Veranlagten, die Legion von Verbrechern infolge geistiger Abnormität vermindern können"; Fränkel, *doppelhändige*, 111. The entire quote is boldened in the original.
[277] Wilson, *Right*, vii–viii.

left-handedness nonetheless existed in all of these groups.[278] Consequently, there had to be an underlying biological mechanism that lead to left-handedness.[279]

Like other Brain-Centric Reformers, Wilson interpreted his evidence through the lens of theories that assumed a causal relationship between strong handedness and marked brain asymmetry.[280] Wilson assumed—as Gaupp did almost two decades later—that most humans had only weak laterality in their hands and brain and could easily adapt to the cultural pressure of right-handedness. The rest of the population had strong biological tendencies to use either the left or the right hand.[281] In the absence of a satisfactory explanation for this phenomenon, Wilson suggested studies of "lower animals," which had not been culturally pressured to use their right hands, but who would—in accordance with the idea of evolutionary hierarchies—show ancestral features of human handedness.[282] Furthermore, he volunteered his own brain to be examined upon his death, and wished for more samples of individuals with strong manual preferences to assess the degree of their brain asymmetry.[283]

For decades, Wilson's call for comparative anatomy and animal experiments to destigmatize non-right-handedness remained unheard. Until well into the twentieth century, experimental and anatomical studies were unpopular among handedness researchers who made statements about the etiology of the manual preference.[284] Luckily, to Wilson,

[278] Wilson, *Right*, 115–116; 120.
[279] Wilson, *Right*, 118.
[280] Wilson, *Right*, 131.
[281] Wilson, *Right*, 127–128; 190–191.
[282] Wilson, *Right*, 198–201; 207.
[283] Wilson, *Right*, 212–15.
[284] Scholars who performed experimental handedness studies usually did not provide overarching etiological theories. Instead, they focused on tests to determine manual preference, manual skill, and their correlation with mirror writing, speech defects, and other disorders; e.g., J. M. Baldwin, "Origin of Right or Left Handedness," *Science* 16, no. 404 (1890), https://doi.org/10.1126/science.ns-16.404.247; Arthur L. Beeley, *An Experimental Study in Left-Handedness: With Practical Suggestions for Schoolroom Tests,*

knowing the concrete cause of cerebral asymmetry was not necessary to advocate for population-wide ambidextrous training. Whereas the degenerationists were afraid to lose the allegedly exceptionally human advantage of brain asymmetry, Wilson argued that the stimulation of both hands and hemispheres would increase human abilities. He agreed with anatomists that most humans have morphologically symmetrical brain hemispheres and were hence born to be "bimanous."[285] Giving up on the cultural pressure to be right-handed, he suggested, would provide individuals with more freedom and strength, increase population health, and economically serve human societies.[286]

After several unsuccessful attempts to launch a potent ambidexterity movement in Britain in the late nineteenth century, the British Ambidexterity Culture Society (ACS), established in 1903, became the institutionalized voice of individuals who assumed that ambidexterity strengthened the hands *and* the brain.[287] By 1905, the ACS comprised around three dozen members, including some prominent ones, such as army general and Boy Scouts founder Robert S.S. Baden-Powell (1857–1941).[288] Thornton found most impressive the "liberal sprinklings of initials and abbreviations indicating the acquisition of scholarly degrees [oftentimes in medicine and/or education], the honor of knighthood,

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Supplementary Educational Monographs 8 (Chicago: University of Chicago Press, 1918). See also Lauren J. Harris, "James Mark Baldwin on the Origins of Right- and Left-Handedness: The Story of an Experiment That Mattered," *Monographs of the Society for Research in Child Development* 50, 4/5 (1985), https://doi.org/10.2307/3333863.

[285] Wilson, *Right*, 206.

[286] Wilson, *Right*, 203–207.

[287] Unless otherwise noted, this and following paragraph draw from Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 45-51; Harris, "Laterality," 192; Lauren J. Harris, "The Ambidextral Culture Society and The 'Duality of Mind'," *Behavioral and Brain Sciences* 8, no. 4 (1985), https://doi.org/10.1017/S0140525X00045404; Kushner, *On*, 25–26; Thornton, "Deviance, Dominance, and the Construction of Handedness in Turn-of-the-Century Anglo-America," 93–98. The founding date of the ACS is taken from John Jackson, *Ambidexterity or Two-Handedness and Two-Brainedness: An Argument for Natural Development and Rational Education* (London: Kegan Paul, Trench, Trübner & Co., 1905), 120. Thornton suggested that the Society was founded in 1904.

[288] Jackson, *Ambidexterity*, 247–48.

and fellowship in handfuls of learned societies," but it is also worth noting that several unmarried women were on the ACS members' list.[289]

Scottish educator John Jackson's monograph *Ambidexterity* summarized and widely spread the idea of the advantages of two-handedness in Britain.[290] Jackson also provided concrete guides on how to instruct one's children, students, and oneself in the art of two-handed writing, drawing, etc., a course of learning best commenced in very early childhood.[291] He assumed, similar to Gaupp, that only a minority of humans had a strong innate manual preference. If left to their own devices, Jackson argued, only around 3 percent of the British population would be left-handed, 17 percent right-handed, and the rest ambidextrous.[292] Most right-handedness as well as the uneven ratios of handedness types among women and men respectively were due to cultural expectations and social roles.[293]

Jackson turned the exceptionalism arguments of Gaupp, Broca, and Lombroso upside down. The Exceptionalist-Degenerationists believed that ambidexterity was detrimental to cognitive skills and/or a sign of underdevelopment because only humans had asymmetrical brains and showed a marked manual preference, but Jackson asserted that one-handedness was unnatural since it cannot be found in any animals other than humans.[294]

The British ambidexterity advocates mobilized the brain in this ideological battle with high pedagogical stakes. Jackson posed the question of the first hen and the first egg

[289] Thornton, "Deviance, Dominance, and the Construction of Handedness in Turn-of-the-Century Anglo-America," 94.
[290] Jackson, *Ambidexterity*.
[291] Jackson, *Ambidexterity*, 195–246.
[292] Jackson, *Ambidexterity*, 97–98.
[293] Jackson, *Ambidexterity*, 191.
[294] Jackson, *Ambidexterity*, 20–40.

with regard to handedness and brainedness.[295] If it was not true, he suggested, that right-handedness derived from left-brainedness, but the other way around, then parents would hurt their children's brains whenever they suggested to use one hand habitually. Notwithstanding the causal relationship between brainedness and handedness, however, Jackson firmly believed in plasticity and argued that the use of both hands benefitted the entire brain.[296]

Although explicitly against one-handedness, Jackson used similar concepts and rhetorical strategies as the defenders of right-handedness.[297] For instance, after providing a thorough and well-structured account of previous etiological theories of handedness as well as their argumentative pitfalls, Jackson concluded that ambidexterity was indeed a characteristic of early hominoids, just like Lombroso, Alsberg, Gaupp, and others had suggested. Jackson maintained that ambidexterity was not a sign of evolutionary backwardness and instead was "intended to be by the Creator the rightful heritage of mankind."[298]

Furthermore, even though Jackson did not employ the term "degeneration" in his tract, the rhetoric in his description of one-handedness was strikingly similar to the Exceptionalist-Degenerationists' accounts of left-handedness and ambidexterity. He recounted the ways in which one-handedness made humans clumsy and inefficient as athletes and workers, caused writer's cramp, left individuals entirely debilitated after the loss

[295] Jackson, *Ambidexterity*, xii.
[296] Jackson, *Ambidexterity*, 11–12.
[297] The same observation was made in Thornton, "Deviance, Dominance, and the Construction of Handedness in Turn-of-the-Century Anglo-America," 96–97.
[298] Jackson, *Ambidexterity*, 41–98 (quote on p. 97).

of one hand, and lead to "permanent Dextrocerebral Atrophy, with an inseparable accompanying mental inferiority."[299]

In contrast, ambidexterity could prevent aphasia, agraphia, the loss of the ability to work after an accident to one hand, the overexertion of one hand, and posture problems.[300] It would also reduce the rate of "nervous and mental disease" due to feelings of "helplessness," for instance in the case of hemiplegia or after debilitating accidents.[301] Because ambidextrous workers would be less tired, they would "live longer and more happily" and their work would be "more effective ... and profitable."[302] Ambidexterity, by virtue of its beneficial impact on both hemispheres, would also improve memory function and facilitate learning, and it would strengthen the British Army strategically as well as physically.[303] Above all, the "moral sense [would] be perceptibly, if not proportionately raised" and the moral problems of the British would be a thing of the past.[304]

These calls to train both hemispheres were rooted in nineteenth-century beliefs in the double brain and a double consciousness. Several phrenologists and physicians, most notably Englishmen Henry Holland (1788–1873) and Arthur Ladbroke Wigan (baptized 1785, died 1847), suggested that each of the two hemispheres was a full-functioning brain. By deliberately stimulating both hemispheres individually, one might double one's mental and moral powers and prevent the loss of particular functions after damage to one of the two brains.[305]

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299 Jackson, *Ambidexterity*, 99–107 (quote on p. 106).
300 This paragraph draws on Jackson, *Ambidexterity*, 120–149.
301 Jackson, *Ambidexterity*, 126.
302 Jackson, *Ambidexterity*, 134; 244.
303 Jackson, *Ambidexterity*, 244.
304 Jackson, *Ambidexterity*, 129.
305 Harrington, *Medicine*, 6–34; Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 49–50.

Jackson relied on these old ideas and added ambidexterity as a concrete way of achieving equally trained double brains. Despite the liberating and revolutionary tone of Jackson's monograph, then, economic, nationalistic, and biopolitical interests were at the core of the ACS's values. It was therefore certainly no coincidence that the accomplished officer Baden-Powell wrote in his preface to Jackson's monograph:

> [T]he value of Ambidexterity from a military point of view is immense. I do not consider a man is a thoroughly trained soldier unless he can mount equally well on either side of his horse, use the sword, pistol, and lance, equally well with both hands, and shoot off the left shoulder as rapidly and accurately as from the right.[306]

Baden-Powell added emphasis to his statement by providing his handwritten signature twice: once with his right hand and once with his left. The signatures are virtually indistinguishable.

Irish physician Henry Macnaughton-Jones (1844–1918) was one of Jackson's biggest fans, and he dedicated his monograph on ambidexterity to Jackson.[307] Macnaughton-Jones was convinced that ambidexterity increased an individual's intelligence and moral sense, though only when acquired in the absence of coercion.[308] Because ambidexterity was hard to attain, he argued, it endowed a person with surplus stamina and cognitive stimulation, thereby enhancing human memory, perception, as well as the abilities to speak and converse.[309]

Macnaughton Jones took it for granted that the brain housed neural centers that underlay speech and writing.[310] As opposed to Hasseroth and other supporters of

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[306] Jackson, *Ambidexterity*, xi–xii.
[307] Henry Macnaughton-Jones, *Ambidexterity and Mental Culture* (London: William Heinemann, 1914), 5.
[308] Macnaughton-Jones, *Ambidexterity*, 35–39.
[309] Macnaughton-Jones, *Ambidexterity*, 32; 47–58.
[310] Macnaughton-Jones, *Ambidexterity*, 26; 32.

anatomical theories of brain asymmetry, Macnaughton-Jones insisted that brain asymmetry was exclusively functional and hence manual behavior could not harm the brain in any way. The only way in which manual behavior influenced the brain was on a functional level. Two-handed writing, so Macnaughton-Jones hoped, would reverse the functional "differentiation" in the brain, which he saw as no more than "a consequence of educational neglect."[311] The human habit of training only one hand has led to a relative loss in half of our "intellectual centres" which lay in the non-dominant cerebral hemisphere.[312]

Macnaughton-Jones left open how exactly the superior cognitive skills and the discipline acquired through ambidexterity training could enhance morality, but he suggested that numerous successful educated white males from the past have demonstrated this point:

> Intelligence and moral excellence are not at all times handmaidens, and we often find moral depravity linked with intellectual power. ... Still, looking back on history, we find that the intelligences which have generally contributed to the building up of the moral precepts and tone of the social edifice have been those of men to whom the race is most indebted for its scientific discoveries and social advances.[313]

Most likely, it never occurred to Macnaughton-Jones that the privileged men who contributed "scientific discoveries and social advances" were also in charge of the mores. It would hence be surprising if those men had *not* exhibited outstanding compliance with the moral customs of their time.

[311] Macnaughton-Jones, *Ambidexterity*, 27–28.
[312] Macnaughton-Jones, *Ambidexterity*, 32.
[313] Macnaughton-Jones, *Ambidexterity*, 44–45.

Anti-Ambidexterity, Eye Dominance, and a Combat-Theory of Handedness

Not all Brain-Centric Reformers thought that ambidexterity was a good idea. Philadelphia physician and lexicographer George M. Gould (1848–1922), for instance, clearly cannot be counted as one of Jackson's supporters in the United States.[314] "The 'ambidexterity' crank," he wrote, "is deserving of a more severe punishment than any other of our many criminally insane."[315] With this attitude, Gould represented a group of scholars who argued for the liberation of left-handers but opposed ambidexterity. The idea of eye dominance and the concept of limited brain plasticity lay at the core of his model.

Gould assumed in agreement with English physician and physiologist Philip H. Pye-Smith (1839–1914) that handedness was an evolutionary consequence of the location of the heart and the use of weapons during early human warfare.[316] Once the early hominoids assumed erect posture, they learned to use increasingly elaborate tools. To maximize productivity, each hominoid perfected tool usage with one hand only. In turn, each hominoid invested significant effort in shaping the tool such that it would fit precisely into this chosen hand. Over the course of time, tool-sharing communities agreed on the same tool-using hand for reasons of efficiency. At this point, there were as many left- as right-handed groups, but with growing competition among humans, fighting increased.

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[314] For a bibliography of Gould's work from 1886 through 1909, particularly the numerous reprints of excerpts of his book-length treatise on handedness, see George M. Gould, *Bibliography of the Contributions of George M. Gould, M.D., to Ophthalmology, General Medicine, Literature, Etc.* (Ithaca: Andrus & Church, 1909).

[315] George M. Gould, *Righthandedness and Lefthandedness: With Chapters Treating of the Writing Posture, the Rule of the Road, Etc.* (Philadelphia, London: J.B. Lippincott Company, 1908), 20.

[316] Gould, *Righthandedness*, 22–25, 40. Cf. Philip H. Pye-Smith, "On Left-Handedness," *Guy's Hospital Reports* 16 (1871): 144–46. According to Bertrand, the "undoubtedly" first person to suggest this theory was French physician M.F. Xavier Bichat (1771–1802); Bertrand, *Histoire*, 14. On other proponents of the warfare theory in the late nineteenth and early twentieth centuries, see Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 40–41.

Communities that had not perfected one hand were killed off relatively quickly, because they were inferior in battle. Eventually, the left-handed and the right-handed communities engaged in battle, during which right-handers carried their weapon in the right and a shield or similar device in the left hand, protecting their hearts. Left-handers carried their weapon and protective device in reverse positions, which left left-handers' hearts exposed in battle and left them with lower chances of survival.

In industrializing societies, Gould believed, this evolutionary advantage of right-handedness was no longer meaningful. Instead, the retraining of left-handers was "a crime" and futile, because the child's brain centers for speaking, writing, and counting have already adapted to left-hand usage.[317] Although the brain was plastic in early childhood and *almost* akin to a "*tabula rasa*," motor habits would become firmly inscribed in the brain and would be harder to reverse with increasing age.[318]

Gould neither accepted brain asymmetry as a causal explanation for handedness nor fancied the blood-circulation-related theories that Alsberg and Liersch had proposed before him.[319] Instead, Gould suggested that "ocular dominance" preceded handedness because the stronger eye would determine the writing hand, and this habit would shape the brain.[320] In most cases, handedness, eyedness, earedness, and footedness would be on

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[317] Gould, *Righthandedness*, 44.
[318] Gould, *Righthandedness*, 11, 25–34, 42 (quote on p. 114).
[319] Gould was not the first scholar to suggest a connection between eyedness and handedness. In a postscript to his chapter on eyedness, Gould acknowledged that Peter N. Callan had previously conceptualized a similar model and published his findings in the *Medical Record*, April 2, 1881. Apparently, Callan informed Gould about this when Gould read his paper in Atlantic City; Gould, *Righthandedness*, 193–194. On other theories on the connection between vision and manual preference, see Georg Herrmann and Otto Pötzl, *Über die Agraphie und ihre lokaldiagnostischen Beziehungen,* Abhandlungen aus der Neurologie, Psychiatrie, Psychologie und ihren Grenzgebieten 35 (Berlin: S. Karger, 1926), 139–190. See also Harris, "Laterality," 187–88.
[320] Gould, *Righthandedness*, 45–60.

the same side of an individual's body; this coordination had served as an advantage in early human history and still endowed them with efficiency, Gould claimed.[321]

Contradicting himself to a significant degree, Gould suggested in the same monograph that brain asymmetry was the primary cause of eyedness and handedness. Once the speech center has established itself in one cerebral hemisphere (in whichever undisclosed way), efficiency and evolutionary pressure required that the motor centers of the dominant limbs and organs sit in the same half of the brain.[322] Gould consistently claimed that handedness followed eyedness, but it is unclear from his writings if cerebral laterality was supposed to be a consequence of the plastic brain's adaption to eyedness and handedness, or whether brain asymmetry was primary and facilitated eyedness, thereby reinforcing handedness.

Gould kept the anthropological machine running on eyedness. Paralleling the ways in which the Exceptionalist-Degenerationists had singled out brain asymmetry as an exceptional human quality, Gould suspected that only human animals (including "the lowest human savages all over the world") experienced eye dominance.[323] Just as his predecessors had framed language as the basis of superior human intellect, Gould established vision as the basis of human speech *and* reason, and hence as an anthropological machine: "Intellect is, in fact, the product of vision, and all mental symbols, the letters of the alphabet themselves, are but modified visual images."[324]

Ewald Stier (1874–1962), a German physician and psychiatrist, most visibly connected degenerationism with the fear of ambidexterity and a call for left-hander

[321] Gould, *Righthandedness*, 182–83.
[322] Gould, *Righthandedness*, 17–20; 193.
[323] Gould, *Righthandedness*, 121.
[324] Gould, *Righthandedness*, 184.

liberation. He borrowed from Broca's model of the connection between speech laterality and handedness as well as from Pye-Smith's evolutionary model of handedness. Furthermore, Stier was among Lombroso's aforementioned methodological critics who at the same time firmly believed that left-handedness was a remnant from an early stage of human evolution.

In the 1900s, Stier held appointments as captain in the German medical corps as well as lecturer at the Kaiser Wilhelms-Akademie, a German military academy. In these capacities, he examined approximately 400 soldiers, their families, students, and prisoners of war by subjecting them to detailed behavioral tests and physical measurements. Among other tasks, bread cutting, needle threading, mixing cards, waxing shoes, and pushing a dynamometer belonged to Stier's experimental repertoire.[325] For a simple survey to estimate the prevalence of left-handedness among the German troops, Stier drew on a sample of almost 5,000 soldiers.[326]

Pushing back against Lombroso's overly inclusive conceptualization of left-handedness, Stier provided a more rigid definition. He suggested that individuals who were forced to use their left hand, for instance because they have lost their right hand, could not be called left-handers. Stier identified innate preference for the left hand, which manifested early in life, and the potential to quickly acquire high skills with the left hand as the core components of "*echte(r) Linkshändigkeit*" ("true left-handedness"), discounting habit and Lombroso's anatomical criteria as hardly important.[327] Stier acknowledged the importance of education on hand usage, but he believed that education could rarely

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[325] Stier, *Untersuchungen*, 31–33.
[326] Stier, *Untersuchungen*, 152. On Stier's survey methods and questionnaire, prepared for a follow-up survey of 266,270 soldiers in 1909, see Stier, *Untersuchungen*, 355–63.
[327] Stier, *Untersuchungen*, 1–5 (quote on p. 2).

overwrite someone's innate handedness completely.[328] In his positivism, he assumed that scientific research on left-handedness would be able to provide age- and sex/gender-specific tests with which to penetrate the veil of habit and unveil someone's supposedly true handedness.[329]

Stier agreed with Lombroso and Broca that brain asymmetry underlay handedness.[330] Nevertheless, like Lombroso and many handedness researchers after him, Stier asserted this causal relationship without providing concrete anatomical or physiological evidence. Although he devoted several pages to a review of aphasia studies, Stier uncritically accepted Broca's proposal that the center for articulate speech made the left hemisphere (and, as a consequence, the right body half) the dominant one.[331]

The unquestioned cerebralization of the hand in the decades after Broca is epitomized in Stier's framing of handedness as a form of manual cognition. Stier dubbed handedness a specific form of "*motorische Intelligenz*" ("motor intelligence") and compared it to cognitive abilities: just like some individuals found it easy or hard to read, some individuals effortlessly learned a task with their preferred hand, or with both, or with none.[332] In Stier's own words, left-handedness was "a psychomotoric, that is, cerebrally caused peculiarity, which is rooted in an early-manifesting better disposition of the right brain to learn and repeat fine complicated movements with the left hand."[333]

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[328] Stier, *Untersuchungen*, 8–16.
[329] Stier, *Untersuchungen*, 31–33.
[330] Stier, *Untersuchungen*, 205–6.
[331] Stier, *Untersuchungen*, 206–15.
[332] Stier, *Untersuchungen*, 4–8 (quote on p. 4).
[333] German original: "eine psychomotorische, also cerebral bedingte Eigentümlichkeit, die auf einer früh zutage tretenden besseren Disposition des rechten Hirns zur Erlernung und Wiederholung feiner komplizierter Bewegungen der linken Hand beruht"; Stier, *Untersuchungen*, 33.

Because Stier saw handedness as an innate characteristic, he tried to describe a hereditary mechanism for this asymmetry. Drawing on Mendelism and eugenic theories of "racial crossing," Stier insisted that every left-hander would need to have some left-handed ancestry.[334] Stier employed the term "*Atavismus*" ("atavism") for cases in which a left-handed ancestor was several generations removed.[335] Due to the "*Kompliziertheit der Verhältnisse beim Menschen*" ("complexity of the circumstance in humans"), he failed to describe the concrete mechanisms of the inheritance of left-handedness.[336]

Unsuccessful at formulating a genetic model of handedness, Stier adopted Pye-Smith's evolutionary theory.[337] According to Stier, the evolutionary advantage of right-handedness continued through early historic times, when the "*überragende(n) Bedeutung des Kampfes Mann gegen Mann*" ("the supreme importance of hand-to-hand combat") decreased and enough disposable tools were available in order for left-handers not to starve or be killed after losing theirs.[338] Despite the increased chances of survival for left-handers in modern times, Stier made it clear that: "Consequently, we must understand left-handers today as a *variety* of homo sapiens that is in the process of dying out."[339] Therefore, left-handers exhibited twice as much "*Degenerationszeichen*" ("signs of de-generation") as right-handers.[340] Stier chose not to disclose what exactly he meant by "*Degenerationszeichen*" as he did not want to jeopardize his analysis by means of providing a controversial definition of the term.[341]

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[334] Stier, *Untersuchungen*, 108–124; 382–385.
[335] Stier, *Untersuchungen*, 112.
[336] Stier, *Untersuchungen*, 153.
[337] Stier, *Untersuchungen*, 142–49. On Pye-Smith's theory, see above and footnote 316.
[338] Stier, *Untersuchungen*, 144.
[339] German original: "Die heutigen Linkshänder müssen wir also ansehen als den Rest einer im Aussterben begriffenen Varietät der Gattung homo sapiens"; Stier, *Untersuchungen*, 154. Italics in the original.
[340] Stier, *Untersuchungen*, 347; 386–391.
[341] Stier, *Untersuchungen*, 387.

The belief that ontogenesis mirrors phylogenesis (or "recapitulation theory," that is, the theory that each being, during their development, repeats the evolution of their entire species) was crucial to Stier's acceptance of the doctrine that pervasive right-handedness is an outcome of the struggle for existence. Stier trusted evidence that human newborns were ambidextrous and that children developed handedness in the first few years of their life. Likewise, he assumed that apes were evolutionary predecessors of humans; that apes were ambidextrous; and that early hominoids started showing manual preference once they adopted erect posture, which is also when they started using tools and articulate speech.[342]

These premises were almost sufficient to explain Stier's conviction that right-handedness and left-brainedness were evolutionary *pièces de résistance*. One last assumption was missing: the inheritance of acquired characteristics. Introducing this concept required some ideological flexibility and an additional quantum of plasticity for Stier's theory. On the one hand, as mentioned above, Stier denied that education could overwrite a person's true handedness in most cases. Yet, on the other hand, he claimed that left-handers could be converted into right-handers who would pass on right-handedness to their offspring.[343] One can only assume that a minuscule inclination to left-handedness would remain in retrained individuals, which would cause the aforementioned atavistic manifestations of left-handedness several generations down the line. Be that as it may, Stier had obvious trouble reconciling his ideas of fixed innate handedness and plastic acquired handedness that could be passed on to the next generation.

[342] Stier, *Untersuchungen*, 147; 152–153.
[343] Stier, *Untersuchungen*, 94; 146.

Stier's uneasy relationship with plasticity was exacerbated when it came to the brain. Stier rejected the idea that humanity's acquired one-handedness—let alone the reversal of handedness in an individual—caused any visible changes to the brain. A few decades, centuries, or millennia were not enough time for evolution to change structures, he suggested, only functions.[344] Nonetheless, he maintained that habitual one-handedness increased the specialization of the two hemispheres for specific functions over the years.[345] To Stier, the brain seemed just as plastic as the hand, both being functionally malleable but having some innate predispositions.[346]

Stier's functional evolutionary model of handedness qualified as an anthropological machine in the sense that it defined the human/non-human boundary, and it served Stier to naturalize hierarchies between human subpopulations. According to Stier's model, left-handedness and functional right-brainedness were intermediary evolutionary characteristics, and ambidexterity as well as functional brain symmetry were lowest-level sub-human characteristics. In a classic colonial consciousness, Stier assumed that allegedly primitive "*Naturvölker*" ("natural peoples") displayed significantly more left-handedness than supposedly advanced "*Kulturvölker*" ("culturalized peoples").[347]

In line with existing social stratifications in Europe, Stier found 14.1 percent left-handers among the allegedly evolutionarily inferior prisoners of war but only 4.6 percent among the presumably more advanced German troops. Furthermore, higher military ranks displayed a lower rate of left-handedness than lower ranks, and among the latter, the prevalence of left-handedness was highest in troops from Alsace-Lorraine, a French

[344] Stier, *Untersuchungen*, 144.
[345] Stier, *Untersuchungen*, 346–47.
[346] Stier, *Untersuchungen*, 241.
[347] Stier, *Untersuchungen*, 152.

territory that the Germans had annexed in 1871.[348] Many left-handed recruits, Stier argued, were "*unbrauchbar*" ("useless") and hence left the military before they got promoted to higher ranks.[349] Even more, Stier regarded left-handers in any profession as "*sozial weniger wertvolle Menschen*" ("humans of less social worth") who would never achieve socio-cultural upward movement and were prone to criminal behavior.[350]

At this point, it may not come as a surprise that Stier also saw sex/gender and age differences in handedness. He explicitly stated that the social experience of the "*körperlichen und seelischen Unterschiede zwischen Mann und Frau*" ("physical and mental differences between man and woman"), namely female inferiority, could guide the scientific assessment of sex/gender differences in handedness.[351] Stier personally examined only twelve women, whom he found much more symmetrical than men, a statement that implied their ambidexterity and hence lower evolutionary status.[352] Nonetheless, Stier's survey indicated that there were twice as many left-handers among male than female members of German military families. Although this indicated female developmental superiority according to Stier's model, Stier explained these statistics with reference to greater male variability (that is, the idea that men's characteristics and abilities range from the great to the feeble while women are almost all average):[353] there were only more left-handed men than women because most women did not show a strong manual preference

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[348] Stier, *Untersuchungen*, 152. For tables and maps of the distribution of handedness across the German states, see Stier, *Untersuchungen*, 376–81.
[349] Stier, *Untersuchungen*, 348.
[350] Stier, *Untersuchungen*, 348.
[351] Stier, *Untersuchungen*, 149–50.
[352] Stier, *Untersuchungen*, 43–44; 52.
[353] On the origins and legacy of the variability hypothesis, see Stephanie A. Shields, "The Variability Hypothesis: The History of a Biological Model of Sex Differences in Intelligence," *Signs* 7, no. 4 (1982), https://doi.org/10.1086/493921.

at all and thus easily submitted to the cultural right-hand bias.[354] This interpretation evoked again the more strongly lateralized and hence superior man and supported the concept of the weak and malleable woman.[355]

Stier's stereotypical findings about handedness differences related to age, sex/gender, and race/ethnicity often revolved around specific statistics, cases, and examples. Stier abandoned this cautious rhetoric in favor of more sweeping statements as soon as he entered the realm of cerebral dominance. He asserted that the direction and degree of manual preference went hand in hand with specific cerebral "*Typen*" ("types").[356] He distinguished strong, medium, and weak differentiation between the hemispheres, and left- and right-brain dominance within these types. Stier speculated that weakly lateralized and hence underdeveloped brains were mostly found in women, children, as well as in men who were anything but healthy, educated, and white.[357]

Despite Stier's strong opinions about the deficiencies of left-handers, Stier advocated for their liberation. Pushing back against Fränkel, Liersch, and Lueddeckens, however, Stier strongly opposed the ambidexterity movement. Like Broca, Stier understood ambidexterity as a lack of "*Differenzierung*" ("differentiation") between the hemispheres, that is, a sub-human characteristic.[358] In Stier's opinion, the extreme inferiority of left-handers derived partially from attempts to reverse their handedness, which oftentimes forced them into ambidexterity. This use of both hands interfered with the differentiation

[354] Stier, *Untersuchungen*, 149–54.
[355] On the idea that women's minds and bodies are weak and malleable, see Cornel, "Matters"; Malane, *Sex*; Jann Matlock, *Scenes of Seduction: Prostitution, Hysteria, and Reading Difference in Nineteenth-Century France* (New York: Columbia University Press, 1994); Russett, *Sexual*.
[356] Stier, *Untersuchungen*, 314. Some scientists still support the idea that degree (but not necessarily direction) of handedness is associated with certain personality types; Grimshaw and Wilson, "A Sinister Plot?".
[357] Stier, *Untersuchungen*, 311–31.
[358] Stier, *Untersuchungen*, 331–45 (quote on p. 335).

of the brain. Stier hoped that the free use of the left hand would increase asymmetry in left-handers' brains and bodies and help them gain at least some more intellectual powers. Those left-handers who had been successfully retrained, however, should *not* retreat to using their left hands, since this would confuse their cerebral centers even more. Only converted left-handed stutterers and individuals with other speech- or writing-related impairments should be re-retrained to left-handedness to stimulate hemispheric differentiation.[359]

Quo Vadis Ambidexterity?

It is unclear from the consulted sources on what scale the above pleas for ambidexterity affected educational practice and military training. German handedness researchers reported that ambidexterity training had been introduced to several German schools in the 1900s, but this seemingly came to a halt around World War I.[360] Thornton suggested that the ambidexterity movement also encouraged educational reforms in parts of Denmark and Belgium, and that it was popular among the well-off in England, namely at Eton, for a few years in the early twentieth century. The ambidexterity movements' most enduring impact seems to have laid in the United States, where Jackson's work influenced educators and psychologists for several decades. On the western side of the Atlantic, Thornton suggested, ambidexterity proponents were less afraid of degeneracy than their European counterparts. Instead, they focused on harnessing "untapped energies," a

[359] Stier, *Untersuchungen*, 220–249; 307–308.
[360] Gaupp, "Über," 30–31; Stier, *Untersuchungen*, 337.

goal that is not too dissimilar to European researchers' quest for superior military power as presented above.[361]

Although the reformers' impact on schooling and military policies is uncertain at this point, it is clear that the discourse surrounding ambidexterity diminished in the French-, German-, and English-speaking world after its peak between 1900 and 1920. This trend also becomes visible in a Google Ngram search for "ambidexterity" and associated terms below.[362] The spike of "ambidexterity"-related terms in German and English sources in the late 1930s, which is visible in Figures 2 and 3, cannot be explained based on the above analyses and warrants further inquiry.

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[361] Thornton, "Deviance, Dominance, and the Construction of Handedness in Turn-of-the-Century Anglo-America," 97–98 (quote on p. 98).

[362] Google Ngram Viewer displays the relative frequency of keywords in Google's corpus of digitized printed sources. The results of this search are limited by Google's corpus as well as by thresholds (the keyword has to appear at least forty times or the Viewer returns a zero result) and normalization algorithms that cannot be adjusted by the user; "What Does the Ngram Viewer Do?" accessed March 15, 2019, https://books.google.com/ngrams/info. For critiques of the Viewer, see, e.g., Reeceblogostorian, "A Critique of Google NGram Viewer," accessed March 15, 2019, https://reecesamuels7.wordpress.com/2014/03/04/a-critique-of-google-ngram-viewer/; Sarah Zhang, "The Pitfalls of Using Google Ngram to Study Language," accessed March 15, 2019, https://www.wired.com/2015/10/pitfalls-of-studying-language-with-google-ngram/.

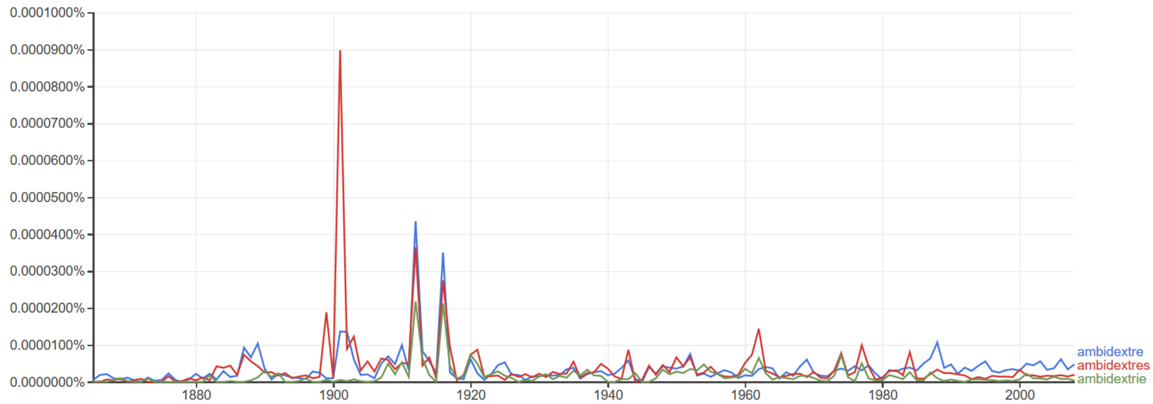

Figure 1: Google Ngram Viewer (French corpus) for "ambidextre, ambidextres, ambidextrie."[363]

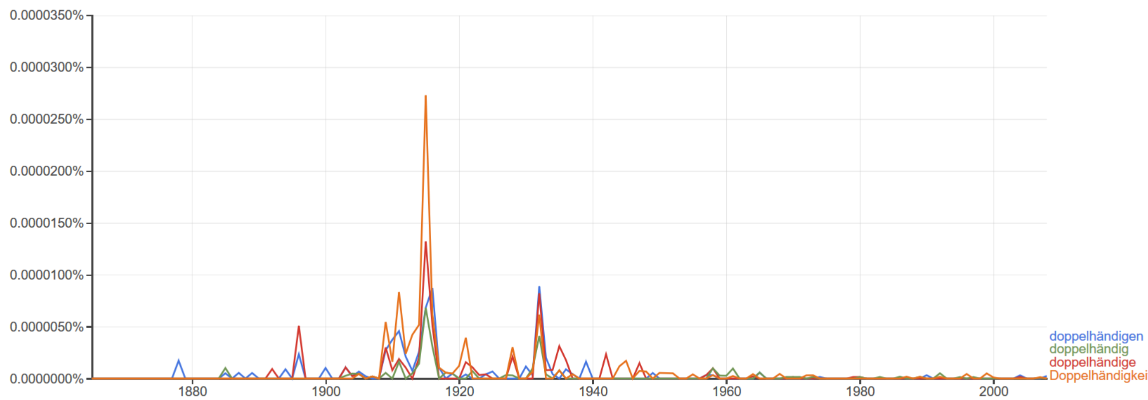

Figure 2: Google Ngram Viewer (German corpus) for "doppelhändigen, doppelhändige, doppelhändiges, doppelhändiger, doppelhändig, Doppelhändigen, Doppelhändige, Doppelhändiges, Doppelhändiger, Doppelhändig, Doppelhändigkeit" (only four of which returned results).[364]

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363 "Google Ngram Viewer French ("ambidextre, ambidextres, ambidextrie")," accessed March 15, 2019, https://books.google.com/ngrams/graph?content=ambidextre%2C+ambidextres%2C+ambidextrie&year_start=1865&year_end=2008&corpus=19&smoothing=0&share=&direct_url=t1%3B%2Cambidextre%3B%2Cc0%3B.t1%3B%2Cambidextres%3B%2Cc0%3B.t1%3B%2Cambidextrie%3B%2Cc0.

364 "Google Ngram Viewer German ("doppelhändigen, doppelhändige, doppelhändiges, doppelhändiger, doppelhändig, Doppelhändigen, Doppelhändige, Doppelhändiges, Doppelhändiger, Doppelhändig, Doppelhändigkeit")," accessed March 15, 2019,

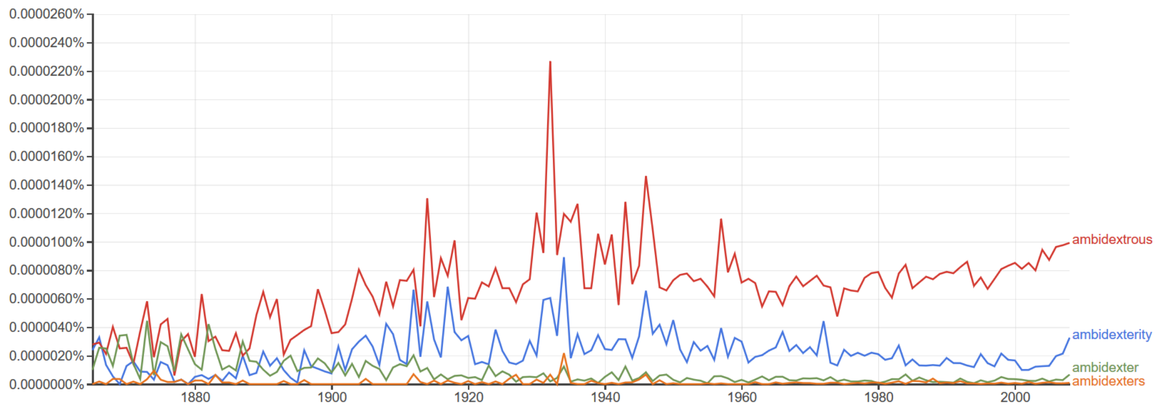

Figure 3: Google Ngram Viewer (English corpus) for "ambidexterity, ambidextrous, ambidexter, ambidexters."[365]

The Brain-Centrism Opponents

Several European researchers questioned the brain-centric concept of handedness in the early twentieth century altogether. The Brain-Centrism Opponents offered more integrated, embodied theories of hand preference than the Exceptionalist-Degenerationists and the Brain-Centric Reformers. A strong emphasis on brain plasticity and a rejection of conventional right-handedness were integral to their claims. Nonetheless, these scholars did not transcend the dichotomous concept of brainedness and thereby inadvertently sustained the idea of innate handedness.

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https://books.google.com/ngrams/graph?content=doppelh%C3%A4ndigen%2Cdoppelh%C3%A4ndige%2Cdoppelh%C3%A4ndiges%2Cdoppelh%C3%A4ndiger%2Cdoppelh%C3%A4ndig%2C+Doppelh%C3%A4ndigen%2CDoppelh%C3%A4ndige%2CDoppelh%C3%A4ndiges%2CDoppelh%C3%A4ndiger%2CDoppelh%C3%A4ndig%2CDoppelh%C3%A4ndigkeit&year_start=1865&year_end=2008&corpus=20&smoothing=0&share=&direct_url=t1%3B%2Cdoppelh%C3%A4ndigen%3B%2Cc0%3B.t1%3B%2Cdoppelh%C3%A4ndige%3B%2Cc0%3B.t1%3B%2Cdoppelh%C3%A4ndig%3B%2Cc0%3B.t1%3B%2CDoppelh%C3%A4ndigkeit%3B%2Cc0.

[365] "Google Ngram Viewer English ("ambidexterity, ambidextrous, ambidexter, ambidexters")," accessed March 15, 2019, https://books.google.com/ngrams/graph?content=ambidexterity%2C+ambidextrous%2C+ambidexter%2C+ambidexters&year_start=1865&year_end=2008&corpus=15&smoothing=0&share=&direct_url=t1%3B%2Cambidexterity%3B%2Cc0%3B.t1%3B%2Cambidextrous%3B%2Cc0%3B.t1%3B%2Cambidexter%3B%2Cc0%3B.t1%3B%2Cambidexters%3B%2Cc0.

Habitual Handedness

German physician Ernst Weber (1875?–1925?) positioned himself on the shoreline of brain-centrism and advocacy for embodied theories of handedness. He tried to turn the focus of handedness research from innateness to habit by suggesting that brainedness followed handedness, and not the other way around.[366] Interested in psychiatry, physiology, and cardiology, Weber adhered to Pye-Smith's evolutionary theory of handedness.[367] Pye-Smith's theory of the evolutionary disadvantage of an exposed heart in hand-to-hand combat did no entirely satisfy Weber, because the reasons why the heart sits on the left were still elusive.[368]

Notwithstanding researchers' ignorance about the primary cause of human asymmetry, Weber maintained that brain laterality and asymmetrical blood circulation were *consequences*, not *causes*, of a collective decision on a manual preference as Pye-Smith had described it. Pertaining to asymmetries of blood flow, he asserted that the side of the body that labors harder required more nutrients, hence the supposedly higher blood pressure in the right limbs and the left half of the brain.[369] With regard to the brain, Weber suggested that the act of writing localized speech in the contralateral hemisphere.[370] This

[366] Weber was not the first scientist who was uncertain which side to take in this chicken-and-egg debate. For instance, Bastian had speculated in 1897 that handedness might be the cause of brainedness. However, Bastian also adhered to Ogle's theory of asymmetric blood flow, assuming that the following dominance of the left hemisphere might be the cause of handedness; Henry Charlton Bastian, *The Lumleian Lectures on Some Problems in Connexion with Aphasia and Other Speech Defects* (1897), Delivered before the Royal College of Physicians of London on April 1st, 6th, and 8th, 1897; Reprinted from the Lancet, April 3rd, 10th, and 24th, and May 1st, 1897, 19–21. Bastian refused to take a clear stance on the causal relationship between the two phenomena and suggested instead that: "[cerebral] dominance … [is] brought about more or less remotely in association with right- or with left-handedness"; Bastian, *Lumleian*, 1–2.
[367] Weber, *Ursachen*, 56–66.
[368] Weber, *Ursachen*, 66–72.
[369] Weber, *Ursachen*, 31–41.
[370] Weber, *Ursachen*, 91–102.

effect was only functional, he suggested, because humans had not been right-handed for long enough to leave an anatomical mark on the brain; but several hundred or thousand years down the line, scientists might be able to measure a morphological difference between the left and right hemispheres as an effect of humanity's right-handed habits.[371]

While Weber suggested that morphological changes would take thousands of years to manifest in the brain, he assumed that the effects of functional plasticity could become visible within a few decades. He turned Broca's Rule upside down to support this theory. Left-handers' speech center lay in the right hemisphere because left-handers predominantly stimulated this half of the brain for most of their lives, not the other way around, he argued.[372] More specifically, Weber assumed that the act of writing localized speech in the contralateral hemisphere, that the act of reading reinforced this lateralization, and that illiterate individuals did not show any marked brain laterality. For when one reads or writes, one presumably activates and enhances the "chiro-kinesthetic center," which connects to auditory and motor centers in one hemisphere of one's plastic brain.[373] For this reason, Weber suggested, researchers were only able to detect brain asymmetry in the late nineteenth century, when significant numbers of Europeans had started reading and writing frequently.[374]

Weber's theory was not strongly naturally deterministic. It contained discriminatory aspects, but Weber dressed them in a socially constructivist coat. He explained, for instance, that women as a group were less strongly left-handed than men because they have historically used fewer tools and have hence avoided part of the pressure of

[371] Weber, *Ursachen*, 75–85.
[372] Weber, *Ursachen*, 85–90.
[373] German original: "cheiro-kinästhetische Zentrum"; Weber, *Ursachen*, 99.
[374] Weber, *Ursachen*, 91–102.

conforming to right-handedness. Likewise, Weber maintained that there might be more left-handers among the criminal and uneducated than in the rest of the population for *social* reasons. Those individuals were not naturally inferior, and left-handedness was not an expression of degeneracy. Rather, criminals or uneducated individuals most likely had grown up on the margins of society, where they had escaped the strong pressures to be right-handed.[375]

Weber closed by suggesting that right-handedness was an outdated version of conformism. Humans in industrializing societies were no longer bound to the use of shared hunting tools, he maintained. Instead, humans could strengthen both halves of their brains by ambidextrous activity.[376] In agreement with the Brain-Centric Reformers, he also claimed that even moderate ambidexterity training would endow humans with more cognitive endurance, although the quality of the intellect would remain the same.[377]

Spiritual Handedness

French sociologist Robert W. Hertz (1881–1915) was more radical in his anti-brain-centrism than Weber.[378] He took the understanding of handedness as a habit to its extreme and firmly integrated it in cultural life.[379] In Hertz's view, handedness was

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[375] Weber, *Ursachen*, 64–65.
[376] Weber, *Ursachen*, 103–12.
[377] Weber, *Ursachen*, 107–9.
[378] On Hertz's life and work, see Rodney Needham, "Introduction," in Needham, *Right and Left*; Robert Parkin, *The Dark Side of Humanity: The Work of Robert Hertz and Its Legacy* (Amsterdam: Harwood Academic Publishers, 1996).
[379] The idea that handedness is a cultural artifact was not entirely new. Several experimental psychologists around the turn of the twentieth century suggested that handedness is a learned behavior, but they did not succeed in explaining *how* handedness is learned. The centuries-old theory that most children are right-handed because they are carried on the left arms of their caregivers, leaving only their right arm free, was an unsatisfactory explanation because cases were known of left-handed children with right-handed caregivers and vice versa; Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 38–45; Harris, "Laterality".

entirely plastic because it depended on spiritual customs. However, Hertz stumbled when he tried to surmount the obstacle that is the brain, and he believed that the latter was not as malleable as the hand. Hertz asserted that potentially innate cerebral dominance did not contradict the cultural origins of handedness because the brain did not play a major role in the genesis of manual preference.

Hertz received his training from the most influential early French sociologists. After graduating from the École Normale Supérieure in 1904, Hertz pursued graduate studies under D. Émile Durkheim (1858–1917) and became friends with Durkheim's nephew Marcel Mauss (1872–1950). By joining the team of *L'Année Sociologique*, a journal that Durkheim had founded in 1898, Hertz became part of one of the most prolific thinkers of modern social science in continental Europe before World War I. Like many of his colleagues and teachers, Hertz did not survive the Great War.

Like Lombroso, Hertz was Jewish and a socialist.[380] He understood socialism as an application of sociological concepts developed in response to social problems.[381] Most of all, Hertz was drawn to economic, moral, and religious questions because he believed that the French society was about to sink into anarchy.[382] Apparently, the degeneration discourse shaped the worldviews even of one of the major opponents of brain-centric theories of handedness.

Despite his political inclinations, Hertz chose not to pursue a public office. The Dreyfus Affair had brought to the surface the obstacles involved in a public life for

[380] On the roots of Lombroso's and Hertz's theories on handedness in "their fears of anti-Semitism," see Kushner, *On*, ch. 2 (quote on p. 17).
[381] Parkin, *dark*, 6.
[382] Parkin, *dark*, 2–3.

members of the Jewish community.[383] Instead, he sociologically analyzed topics like sin, atonement, death, burial rites, and the veneration of saints.[384] In addition to these issues, Hertz became interested in the problem of handedness between 1904 and 1906. While conducting research at the British Museum in London, he connected with the Ambidexterity Culture Society and was struck by the persistence of a right-handed culture despite the potential educational benefits of two-handedness.[385]

The resulting 1909 paper on "The Preeminence of the Right [Hand]" epitomizes Hertz's socialistic-sociological approach.[386] More interested in questions of education and the oppression of minorities than in manual preference *per se*, Hertz provided an exemplar of "how a positivist, scientific sociology could be applied to intellectualist thinking on contemporary problems."[387] With this goal in mind, Hertz treated handedness *not* as an anatomical phenomenon, but as one expression of binary thinking, which he considered to be "a basic principle of collective human thought."[388] Drawing on Jackson and Wilson but condemning Lombroso, Hertz argued that the left hand was weaker because it had been "neglected" and "paralyze[d]," not because of any innate predisposition of humankind.[389] He explicitly compared the marginalization of left-handers to concurrent attempts to naturalize the social oppression of women.[390]

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383 Parkin, *dark*, 1.
384 For summaries of and background information on Hertz's publications, see Parkin, *dark*. On Hertz's legacy, see also Rodney Needham, ed., *Right and Left: Essays on Dual Symbolic Classification* (Chicago: University of Chicago Press, 1978).
385 Kushner, *On*, 25–26; Parkin, *dark*, ix.
386 Robert Hertz, "La prééminence de la main droite: Étude sur la polarité religieuse," *Revue philosophique de la France et de l'étranger* 68 (1909). In the following, I refer to this translation: Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*.
387 Parkin, *dark*, 3.
388 Parkin, *dark*, 173.
389 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 6.
390 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 3.

Hertz traced the "half aesthetic, half moral" roots of the cultural ideal of right-handedness to the ritualistic practices of non-industrialized cultures.[391] He did not observe handedness in the field; instead, he relied on existing ethnographies of the "Maori, or more exactly ... the very primitive Tuhoe tribe," to do so.[392] To a lesser degree, Hertz also drew on literature describing the customs of North-American indigenous peoples, Hindus, and Celts.[393] Based on his studies, Hertz learned that ostensibly primitive cultures danced around sacred persons or objects from left to right, in the same direction as they saw the sun move on the horizon. In this motion, the right shoulder would be turned inwards toward the sacred, while the left shoulder faced outwards.[394] Hence, the right side became the side of the sacred, the side of life, the strong side, the masculine side, the side of the self. The left side became the side of the profane, the side of death, the inferior side, the female side, the side of the other.[395]

Hertz explained the ways in which this spiritual dichotomy of the sacred and the profane has lived on in allegedly secular cultures. In their reliance on deities to secure their survival, archaic cultures considered their tools and weapons as sacred objects.

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391 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 7.

392 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 7. Hertz drew on New Zealander Elsdon Best's (1856–1931) ethnographic articles in the *Transactions of the New Zealand Institute* and the *Journal of the Polynesian Society*, most of which were published in the late 1890s and early 1900s.

393 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 14–15. On sidedness in other religions, see also McManus, *Right*, 16–40; Sattler, *Links*, 187–226.

394 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 11–14.

395 Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 14–18. Hertz suggested that the spiritual meanings of male/female and right/left directly map onto one another in the Maori culture; Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 13–14. On interconnected dual classifications before and after Hertz, see also Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 56–57. More recently, scholars have argued that there are many cases in which cultural binaries do not directly map onto the male/female distinction; e.g., Haraway, "Primatology"; MacCormack and Strathern, *Nature*.

Accordingly, they carried them in the right hand.[396] Although modern Europeans or North Americans did not remember the spiritual origin of this practice, the right-hand use of tools had remained a habit and sign of good manners.[397] Notwithstanding their alleged secularization, industrialized cultures had continued to enforce right-handedness by means of "obligat[ion]," "coercion," and "sanctions."[398]

The cultural institution of right-handedness might also have made humans left-brained. Hertz accepted Broca's and his followers' theories of the correlation between handedness and brain asymmetry, but he challenged Broca's assertion that: "We are right-handed because we are left-brained."[399] Like Weber, Hertz suggested that one ought to consider a reverse causal relationship, in line with the laws of plasticity. "[T]he exercise of an organ leads to the greater nourishment and consequent growth of that organ," Hertz suggested, and hence the superiority of the left hemisphere might not be innate but an artifact of our manual habits.[400]

The witty reader might have noticed that non-industrialized cultures on the southern hemisphere see the sun wander the horizon in the reverse direction compared to their northern neighbors; they would therefore dance around a sacred object the other way and would attach the opposite values to the right and left. In short, cultures south of the

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[396] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 18–19.
[397] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 17–20.
[398] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 6.
[399] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 3.
[400] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 3.

equator should be left-handed and right-brained. This is not the case, and Hertz chose not to elaborate on this point. Though he began to contradict himself.

After laying out his model of the cultural genesis of the right-handed universe, Hertz concluded that the universe was *not* “reflected” in the body after all.[401] Instead, he sought the cause for the elevation of right-handedness in “the constitution of the collective consciousness” that rested on “slight physiological advantages” of the right hand.[402] Likewise, he did not rule out a minor innate advantage of the left cerebral hemisphere.[403] In favor of these propositions, Hertz referred to the common observation that it is rarely possible to reverse someone’s handedness completely.[404] Should there be an anatomical cause for handedness after all? Hertz did not give a clear answer. “This is not the place to seek the cause and the meaning of this polarity which dominates religious life and is imposed on the body itself,” thus he belittled his own argument.[405]

A speculative explanation for why Hertz introduced a naturalistic explanation for manual preference through the backdoor lies in the failure of a theory strikingly similar to Hertz’s. As Hasseroth pointed out, “Herr von Meyer” delivered a paper on the origins of right-handedness in the spiritual habits of non-industrialized societies before the *Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* (Berlin Society of Anthropology, Ethnology, and Prehistory) on January 25, 1873. “Herr Virchow” asked during

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[401] Robert Hertz, “The Preeminence of the Right Hand: A Study in Religious Polarity,” in Needham, *Right and Left*, 20–21.
[402] Robert Hertz, “The Preeminence of the Right Hand: A Study in Religious Polarity,” in Needham, *Right and Left*, 21.
[403] Robert Hertz, “The Preeminence of the Right Hand: A Study in Religious Polarity,” in Needham, *Right and Left*, 3.
[404] Robert Hertz, “The Preeminence of the Right Hand: A Study in Religious Polarity,” in Needham, *Right and Left*, 4–5.
[405] Robert Hertz, “The Preeminence of the Right Hand: A Study in Religious Polarity,” in Needham, *Right and Left*, 21.

the discussion of the paper if indigenous peoples on the southern hemisphere were predominantly left-handed, and "Herr Bastian" denied.[406] Hasseroth suggested that this immediately shattered the theory.[407] It is unclear if Hertz had access to this paper and whether he consciously avoided a discussion of inhabitants of the southern hemisphere because, just like von Meyer, he lacked a satisfactory explanation for their right-handedness. However, it is conceivable that Hertz came across the paper during his studies. Therefore, it is possible that Hertz added the seemingly contradictory note on a probable innate advantage of the left brain and the right hand to evade the criticism that shattered von Meyer's theory.

In the same way that Hertz resisted being pinned down on an entirely constructivist argument, he refused to unequivocally advocate for ambidexterity. Two-handedness might be "possible" but not necessarily "desirable," he wrote, because there was a slight chance that our cultural custom of right-handedness might be too firmly inscribed on human bodies to be reversed without significant costs.[408] Nevertheless, as long as there was no solid evidence for the harmful effects of ambidexterity, he considered ambidexterity training as a step towards equality, secularism, a healthy brain, and a vigorous body:

> Neither aesthetics nor morality would suffer from the revolution of ... permitting the left hand to reach at least its full development. The distinction of good and evil, which for long was solidary with the antithesis of right and left, will not vanish from our conscience

[406] von Meyer, "Über den Ursprung von Rechts und Links," *Verhandlungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* 5 (1873): 34–35.
[407] Hasseroth, "Rechts," 86. The paper and following discussion were published the same year; Meyer, "Über den Ursprung von Rechts und Links". The presenter of said paper might have been German anatomist Georg H. von Meyer (1815–1892). The sceptics in the audience were certainly the founder of the *Gesellschaft,* physician and anthropologist Rudolf L.C. Virchow (1821–1902), and its Chairman, anthropologist Adolf Bastian (1826–1905).
[408] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left,* 22.

> the moment the left hand makes a more effective contribution to human labor and is able, on occasion, to take the place of the right. If the constraint of a mystical ideal has for centuries been able to make man into a unilateral being, *physiologically mutilated*, a liberated and foresighted society will strive to *develop the energies dormant in our left side and in our right cerebral hemisphere*, and to assure by an appropriate training a more harmonious development of the organism.[409]

As historian of medicine Howard Kushner has remarked, Hertz's "arguments ... were indistinguishable from those of Wilson and Jackson."[410] Hertz's main motivation might have been to liberate left-handers in an attempt to find a model for fighting the prejudice against Jews, as Kushner suggested, but without success.[411] Despite his disciplinary distance from anatomy and his attempt to tear naturalistic explanations of social hierarchies to shreds, Hertz jumped tracks and found himself on the route to brain-centrism as well as prescriptions for ambidexterity to prevent the degeneration of industrializing societies.

Broca's Legacy Maintained

Hertz's counter-model could not redirect the focus of handedness research away from innate anatomical or physiological causes. Sixteen years after Hertz had published his theory of the cultural influences on handedness, German physiologist Albrecht J.T.

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[409] Robert Hertz, "The Preeminence of the Right Hand: A Study in Religious Polarity," in Needham, *Right and Left*, 22. Italics added.
[410] Kushner, *On*, 25–26.
[411] Kushner, *On*, ch. 2.

Bethe (1872–1954) pushed back against naturalistic theories again. He argued that most available handedness statistics were flawed.[412]

As Gaupp had suggested in 1909, Bethe believed that only very few individuals had a pronounced manual preference. Most people had almost equally skilled hands and adapted to societal pressure. Thus, individuals who appeared as left-handers in most statistics were only the extremely left-handed minority, while many apparent right-handers would grow up to be left-handers in a left-handed world. Most detrimental in this context, according to Bethe, was to administer handedness tests to adults, whose plastic hands had been adjusting for years to the pressures of being right-handed. Furthermore, any statement that researchers made about left-handers (for instance, that they were prone to crime and mental illness), was in reality one about individuals of very strong manual preference, which might be a pathology *per se*, no matter if it made a person strongly left-handed or strongly right-handed.[413]

As the following chapter shows, handedness statistics remained a problem in genetically oriented handedness research throughout the twentieth century. As eugenicists and psychologists turned to the problem of manual preference, they invested much effort in the creation of appropriate classifications of manual preference. Despite their employment of pedigrees, questionnaires, statistics, and computers, the gap between the floating head and the disconnected writing hand remained. Twentieth-century scholars did not doubt Broca's association between the hand and brain laterality and handedness, and

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[412] Albrecht Bethe, "Zur Statistik der Links- und Rechtshändigkeit und der Vorherrschaft einer Hemisphäre," *Deutsche Medizinische Wochenschrift* 51 (1925).
[413] Bethe, "Zur," 681–83.

human exceptionalism persisted as an ideological substitute for concrete mechanisms that might connect the two phenomena.

Continuing the nineteenth-century tradition in yet another way, twentieth-century scholars rephrased the fear of left-handedness as degeneration in the neoliberal language of the "risk" of cognitive impairments and psychiatric illnesses. Because of the new emphasis on the heritability of handedness, sex/gender differences took on a prominent role, and the categories of male/female and right/left became more deeply enmeshed. At the same time as researchers obsessed with the genetic causes of handedness, parents and teachers continued to forcefully convert numerous left-handed children in Britain, Northern America, and continental Europe. Despite all reformist attitudes around 1900, cruel practices of retraining left-handers lingered until well into the second half of the twentieth century.

CHAPTER 3

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THE NEW LEFT: PROBABILISTIC GENES, COMPUTERS, GENDER, AND THE SEARCH FOR "TRUE" HANDEDNESS IN BRITISH PSYCHOLOGY, 1960S–1990S

> Despite differences in subject matter or historical period, theories of genetic determinism have shared a variety of methodological pitfalls that recur time and time again ... [T]hey have more often led to restricting human opportunity ... than to enhancing it; more often to reinforcing cultural prejudices than to overriding them.[414]

Introduction

After a century of fruitless inquiries into the biological underpinnings of manual preference in anatomical, physiological, and eugenic terms, British psychologists revived handedness research by employing Mendelian frameworks to cerebralize the hand in the final third of the twentieth century. Behavioral geneticists are well-known for their controversial attempts to explain individual traits and behaviors through the genome.[415] A lesser-known story is how psychologists transformed handedness research into a science

[414] Garland E. Allen, "The Double-Edged Sword of Genetic Determinism: Social and Political Agendas in Genetic Studies of Homosexuality, 1940–1994," in Rosario, *Science and Homosexualities,* 243.
[415] On the history of behavior genetics and its neo-eugenic tendencies, see Comfort, *Science*; Troy Duster, *Backdoor to Eugenics*, 2nd ed. (New York: Routledge, 2003); Panofsky, *Misbehaving*. For a concise optimistic (not to say positivistic) treatment of the same history, see John C. Loehlin, "History of Behavior Genetics," in Kim, *Handbook of Behavior Genetics*.

of big data with the help of handedness questionnaires, computerized statistics, and probabilistic genes.

Representatives of three generations of British psychologists, R.C. (Carolus) Oldfield (1909–1972), Marian Annett (b. 1931), and I.C. (Chris) McManus (b. 1951), were the main players in genetically oriented handedness research in the second half of the twentieth century. All three were personal acquaintances, but they never collaborated. The age difference may partially account for that but differing sociopolitical views may have overshadowed the similarities in methods and theories even more.

The three psychologists sustained the anthropological machine into the late twentieth century. They relied on Broca's idea that manual preference is closely tied to speech laterality, and thereby moved the demarcation between human and non-human life to the center of genetically-oriented handedness research. Statistical calculations about the inheritance of handedness and brainedness—as opposed to anatomical tests or genomic screenings—were the core mechanisms of this anthropological machine.

There were substantial differences between the three psychologists' approaches to the enigma of handedness, speech laterality, and associated disorders. Oldfield set out to find a standardized measure of the "real" handedness distribution in a population to enable effective future research on laterality.[416] To this day, his so-called Edinburgh Handedness Inventory is one of the most frequently used measures of manual preference in neuroscientific laboratories.[417] Oldfield refrained from explicit speculations about the hand–brain relationship until a firm base of handedness data had been established. Yet, he was

[416] Richard C. Oldfield, "The Assessment and Analysis of Handedness: The Edinburgh Inventory," *Neuropsychologia* 9, no. 1 (1971), https://doi.org/10.1016/0028-3932(71)90067-4.
[417] Oldfield's 1971 paper has been cited 28,830 times according to Google Scholar, and over half of these citations appeared in publications from 2011 or later (date of inquiry: March 15, 2019).

quick to interpret sex/gender differences in handedness incidence as potential evidence for a sex-linked genetic mechanism.

Annett and McManus did not shy away from speculation. They proposed hypothetical genes that left room for chance influences on brain asymmetry.[418] The probabilistic mechanisms that they built into their hereditary models suggested that handedness and cerebral dominance were *not* strictly genetically determined. The resulting models accounted for the statistical rates of brainedness and handedness, including sex differences, but they did not explain concrete biological processes.

McManus and Annett used their sex-based handedness models in conjunction with the idea of chance to craft quasi-evolutionary accounts of the adaptive function of handedness and brainedness. These theories functioned as "origin stories" in that they naturalized existing social inequities by telling a teleological tale of how the current world order has come into being, as proposed by historian and philosopher of science Donna J. Haraway.[419]

First, Annett's and McManus's models established a hierarchical order of genotypes. Annett's model even associated the "risk" for various learning disorders and

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[418] See also footnote 158. A likely explanation for McManus's and Annett's struggle to solicit genetic support or gain access to genetic databases is that Mendelian models seemed dull to geneticists of the late twentieth century, when polymorphisms and genomic research were all the rage. Both psychologists independently offered this explanation in our conversations; Marian Annett, interview by Tabea Cornel, July 11, 2016, Coventry; Ian Christopher McManus, interview by Tabea Cornel. For historical accounts of the shift from discrete gene analyses to genomic research, see Horace F. Judson, "A History of the Science and Technology behind Gene Mapping and Sequencing," in Kevles; Hood, *The Code of Codes*; Kay, *Who*. Another explanation for Annett's and McManus's retreat to computers (instead of geneticists) is the close epistemological connection between Mendelism and computers. According to Chun, both fields are characterized by a "return to a reductionist, mechanistic understanding of life, in which the human body becomes an archive" that can be harnessed for economic gain and political power; Wendy Hui Kyong Chun, *Programmed Visions: Software and Memory* (Cambridge, London: MIT Press, 2011), 10 (see also ch. 3). Paul Griffiths and Karola Stotz recently argued that the view of genes as "code" for an organism can no longer be upheld in the post-genomic and epigenomic age; Paul Griffiths and Karola Stotz, *Genetics and Philosophy: An Introduction* (Cambridge: Cambridge University Press, 2013), ch. 6.

[419] Haraway, "Primatology".

psychiatric illnesses with specific human types. Second, by integrating environmental chance into their genetic models, the theories redefined the boundaries between nature and nurture. These origin stories drew from classical sexed/gendered stereotypes, sometimes restating them in terms of handedness inheritance, and at other times offering permutations of the common associations of male/culture and female/nature. Despite her own professional marginalization as a woman psychologist, Annett was complicit in the construction of scientific dichotomies, and she contributed to discriminatory theories of manual preference.[420]

The three psychologists shared the concern to reveal "true" handedness, and their quests to delineate nurture from nature was not limited to manual preference. Annett framed handedness as a direct byproduct of genetically induced brain lateralization. This allowed her to speculate about the consequences of the gene for differences in

[420] Historian Margaret W. Rossiter analyzed the discrimination that female scientists have encountered since the nineteenth century, and she illustrated that these women were often active oppressors of themselves and/or other female scientists; Margaret W. Rossiter, *Women Scientists in America I: Struggles and Strategies to 1940* (Baltimore: Johns Hopkins University Press, 1982); Margaret W. Rossiter, *Women Scientists in America II: Before Affirmative Action, 1940–1972* (Baltimore: Johns Hopkins University Press, 1995). Philosopher Judith Butler's concept of "gender performativity," i.e., the circumstance that gendered discourse creates gender identities and that gender is repetitively enacted according to existing social norms, illuminates why Annett and other female scientists could not reinvent gender relations; Judith Butler, *Gender Trouble: Feminism and the Subversion of Identity* (New York, London: Routledge, Taylor & Francis Group, 1990). Reinforcing the salient category sex/gender promised high rewards, and defying the binary resulted in high costs for already marginalized female scientists. Foucault theorized the receptiveness of human bodies and identities to (potentially harmful) normative outside influences using the term "docile bodies"; Foucault, *Discipline*. Sociologist Pierre Bourdieu chose the term "*habitus*" to describe a related concept of unconscious adaptation of habits and identities to social norms; Pierre Bourdieu, *The Logic of Practice* (Stanford: Stanford University Press, 1990). Further relevant in this context is research on "internalized oppression," i.e., the idea that members of minority groups often take part in processes that cause or increase their own disenfranchisement; e.g., William E. Cross et al., "Identity Work: Enactment of Racial-Ethnic Identity in Everyday Life," *Identity* 17, no. 1 (2017), https://doi.org/10.1080/15283488.2016.1268535; E. J. R. David, *Internalized Oppression: The Psychology of Marginalized Groups* (New York: Springer Publishing Company, 2013); Sander L. Gilman, *Jewish Self-Hatred: Anti-Semitism and the Hidden Language of the Jews* (Baltimore, London: Johns Hopkins University Press, 1986); Audre Lorde, "Age, Race, Class, and Sex: Women Redefining Difference," in *Words of Fire: An Anthology of African-American Feminist Thought*, ed. Beverly Guy-Sheftall (New York: New Press, 1995).

mathematical abilities, reading problems, and other gendered conditions. McManus suggested a sex-specific origin of handedness and speech dominance. Oldfield studied handedness in its relationship with aphasia, professional careers, and so-called sex chromosomes. Determining handedness, then, was also a matter of the brain, mind, and character. The shared goal was a measure for "true" identity.

The history of genetic research on manual preference differs from other inquiries into the genetic bases of human behavior and character because the hypothetical genetic models were *probabilistic*. The quest for the "gay gene" or the hereditary mechanism of "general intelligence" were decidedly *deterministic*.[421] In many other ways, however, historian of science Garland E. Allen's assessment of genetic approaches to "homosexuality" in the introductory quote matches the outlined episode of handedness research just as well as the history of genetic research on intelligence or other human characteristics.[422] The history of genetic handedness research echoes many observations from previous scholarship on the history of genetic inquiries into a huge variety of physical,

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[421] Dean H. Hamer and Peter Copeland, *The Science of Desire: The Search for the Gay Gene and the Biology of Behaviour* (New York: Simon & Schuster, 1994); Spearman, "General".

[422] On genetic and post-genomic considerations of race/ethnicity, see Susan E. Bell and Anne E. Figert, eds., *Reimagining (Bio)Medicalization, Pharmaceuticals, and Genetics: Old Critiques and New Engagements* (New York: Routledge, 2015); Barbara A. Koenig, Sandra Soo-Jin Lee and Sarah S. Richardson, eds., *Revisiting Race in a Genomic Age* (New Brunswick: Rutgers University Press, 2008); Dorothy Roberts, *Fatal Invention: How Science, Politics, and Big Business Re-Create Race in the Twenty-First Century* (New York: New Press, 2011); Keith Wailoo, Alondra Nelson and Catherine Lee, *Genetics and the Unsettled Past: The Collision of DNA, Race, and History* (New Brunswick: Rutgers University Press, 2012); Michael Yudell, *Race Unmasked: Biology and Race in the Twentieth Century* (New York: Columbia University Press, 2014). On hereditarian theories of intelligence and their intersections with questions of race/ethnicity, see Gould, *Mismeasure*. Most research on the genetic basis of sexuality has focused on male "homosexuality"; e.g., Robert Alan Brookey, *Reinventing the Male Homosexual: The Rhetoric and Power of the Gay Gene* (Bloomington: Indiana University Press, 2002); Hamer and Copeland, *Science*; Vernon A. Rosario, ed., *Science and Homosexualities* (New York, London: Routledge, 1997); Hilary Rose, "Gay Brains, Gay Genes and Feminist Science Theory," in *Sexual Cultures: Communities, Values and Intimacy*, ed. Jeffrey Weeks and Janet Holland (New York: St. Martin's Press, 1996). On the disparate degrees of homophobia in scientific studies and news reports on the "gay gene," see Jenny Kitzinger, "Constructing and Deconstructing the 'Gay Gene': Media Reporting of Genetics, Sexual Diversity, and 'Deviance'," in Ellison; Goodman, *The Nature of Difference*.

psychological, and behavioral characteristics. Most importantly, the science provided categorical distinctions between humans based on their genotypes, and hence resonated with neo-eugenic agendas.[423]

This case also makes legible the changing roles of data and computation in the production of knowledge of individuals and populations in the later twentieth century. Within a few years, the epistemological status of electronic computers in handedness research changed drastically. Whereas Oldfield and Annett occasionally used computers to operationalize laborious calculations, their younger colleague McManus relied on them to unveil the "truth" that he believed to be hidden in heterogeneous data sets.[424] The three psychologists strived for an accurate quantification of handedness to combine large data sets, but only McManus employed computers to generate parameters for his model and to test the fit of various handedness theories with vast sets of data.

Comparing Annett's and McManus's computerized statistics in more detail brings to the surface an early iteration of the ways in which "[c]omputers are mediums of power."[425] In handedness research, the power dynamics of computation became visible in the differing degrees to which Annett and McManus had access to computers. Furthermore, although Annett made significant epistemological compromises (for instance, framing handedness as a binary rather than a continuous category to simplify her

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[423] On the shared conceptual basis of left-hander discrimination and eugenics, see Amir Muzur and Iva Rinčić, "Bioethics of Handedness: From Evolution to Resolution?" *Acta medico-historica Adriatica* 7, no. 1 (2009).
[424] On the heterogeneity of the data sets used, see below. On the stark contrast between computer use in the biomedical sciences before and after the 1980s, see Joseph Adam November, *Biomedical Computing: Digitizing Life in the United States* (Baltimore: Johns Hopkins University Press, 2012); Hallam Stevens, *Life out of Sequence: A Data-Driven History of Bioinformatics* (Chicago, London: University of Chicago Press, 2013).
[425] Chun, *Programmed*, xii.

computerized calculations), the use of computers endowed only McManus's but not Annett's work with additional credibility.

Early Genetic Theories and Data Sets

Throughout the first two thirds of the twentieth century, several researchers attempted to disentangle the relationship between the inheritance of cerebral dominance and handedness with simple Mendelian models.[426] Eugenicists were the first ones to transform the nineteenth-century anatomical concept of handedness into a hereditarian paradigm. US-American botanist Francis Ramaley (1870–1942) suggested in 1913 that two alleles determined handedness in humans, a dominant allele for right-handedness and a recessive allele for left-handedness.[427] Ramaley based this theory on genealogical charts, or "handedness pedigrees," that his fellow countryman Harvey E. Jordan (1878–1963) had collected.[428] Jordan, an anatomist and eugenicist, remarked that not all available handedness data fit "strict Mendelian principles," but he did not elaborate in detail on an alternative model.[429]

In the late 1920s, US-American physician Herbert D. Chamberlain collected a large data set on familial handedness from college students at Ohio State University. He

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[426] For a succinct and accessible review of genetic handedness research, see Porac, *Laterality*, 17–36. For a historical overview of population studies on handedness, see Kushner, *On*, ch. 6. On early endorsements of the argument that handedness is hereditary, see Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 35–38. For reviews of genetic theories of brain asymmetry and handedness, see Michael C. Corballis and Ivan L. Beale, *The Psychology of Left and Right* (Hillsdale: Lawrence Erlbaum Associates, 1976), 112–40; Clare Porac and Stanley Coren, *Lateral Preferences and Human Behavior* (New York: Springer-Verlag, 1981), 69–92.
[427] Francis Ramaley, "Inheritance of Left-Handedness," *American Naturalist* 47, no. 564 (1913).
[428] Harvey E. Jordan, "The Inheritance of Left-Handedness," *Journal of Heredity* 2, 1–2 (1911), https://doi.org/10.1093/jhered/2.1.19.
[429] Harvey E. Jordan, "Hereditary Lefthandedness, with a Note on Twinning (Study III.)," *Journal of Genetics* 4 (1914): 74.

reported significant sex differences in manual preference and argued that a classic Mendelian recessive trait could not account for the inheritance of left-handedness.[430] Two decades later, also at Ohio State, geneticist David C. Rife (1901–1992) revived the idea that there were a dominant and a recessive allele for handedness. Rife intended to avoid Ramaley's mistakes by postulating partial penetrance for the heterozygote (that is, the concept that the dominant allele determines the phenotype in more than half but less than all of the heterozygote population).[431]

The idea that not all carriers of the dominant allele might exhibit right-handedness was new and promising. In the 1950s, Swedish educationist and psychologist Arne Trankell (1919–1984) decreased the classic Mendelian determinism even further. He suggested that even carriers of two recessive alleles (that is, in the contemporaneous understanding, two alleles for left-handedness) could develop right-handedness.[432]

In 1964, Annett published the first version of her genetic theory, which explicitly established the link between a genetic basis of handedness and the causes of speech lateralization.[433] Like Rife, Annett proposed partial penetrance in the heterozygote. She furthermore suggested that the dominant allele would cause right-handedness and left-hemispheric speech in homozygotes, and that homozygous carriers of the recessive factor would develop left-handedness and right-brainedness. This version of Annett's model did not fit the available twin data, but the fact that it was published in *Nature* suggests that the proposal was timely.

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[430] Herbert D. Chamberlain, "The Inheritance of Left-Handedness," *Journal of Heredity* 19 (1928).
[431] David C. Rife, "An Application of Gene Frequency Analysis to the Interpretation of Data from Twins," *Human Biology* 22, no. 2 (1950).
[432] Arne Trankell, "Aspects of Genetics in Psychology," *American Journal of Human Genetics* 7, no. 3 (1955).
[433] Marian Annett, "A Model of the Inheritance of Handedness and Cerebral Dominance," *Nature* 204, no. 4953 (1964).

In 1972, US-American psychologist Jerre Levy (b. 1938) and her husband, Hungarian-American geneticist Thomas Nagylaki (b. 1944), reiterated Annett's claim that the genetic mechanisms for brainedness and handedness were connected. However, Levy and Nagylaki doubled the number of alleles that were thought to underlie the inheritance of handedness.[434] They proposed that two different loci on a chromosome were involved in the inheritance of handedness, and that two different alleles could sit at each of those loci. At one of the two loci, they suggested, the dominant allele *L* and the recessive allele *r* determined speech lateralization in the left or right hemisphere respectively. At the other locus, the dominant allele *C* caused contralateral hand dominance, and the associated recessive *i* factor was involved in the development of handedness and brainedness on the same side of the body. The backlash against Levy and Nagylaki's model was stronger than against any of the previous models.[435] This unprecedented attention is an indicator for the rising interest in physical lateralities and the stabilization of a network of laterality researchers.[436]

None of the early Mendelian models could reliably account for how handedness is passed on in families. Nonetheless, McManus and Annett derived four crucial pillars of

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434 Jerre Levy and Thomas Nagylaki, "A Model for the Genetics of Handedness," *Genetics* 72, no. 1 (1972).

435 For an overview of the debate, see Corballis and Beale, *Psychology*; Patrick T. W. Hudson, "The Genetics of Handedness: A Reply to Levy and Nagylaki," *Neuropsychologia* 13, no. 3 (1975), https://doi.org/10.1016/0028-3932(75)90010-X; Jerre Levy, "A Reply to Hudson regarding the Levy-Nagylaki Model for the Genetics of Handedness," *Neuropsychologia* 15, no. 1 (1977), https://doi.org/10.1016/0028-3932(77)90130-0.

436 To this day, there is no such profession as a "handedness researcher." The scientists that I identify as handedness researchers are, by virtue of their publications, members of a highly interdisciplinary and rather loose research network, making handedness research a methodologically and conceptually diverse field of study; see, e.g., Ian C. McManus, "*Lateral Preferences and Human Behaviour*. By C. Porac & S. Coren. New York: Springer-Verlag. 1981. Pp. 283. $24.20," *British Journal of Psychology* 74 (1983). The journal *Laterality*, first issued in 1996, has contributed to an increasing visibility of research on handedness and other asymmetries. The three founding editors were psychologists M. Philip Bryden (1934–1996), Michael C. Corballis (b. 1936), and McManus.

their late-twentieth-century theories from earlier models: First, the conviction that the genes for handedness and brainedness were associated. Second, the idea of partial penetrance in the heterozygote. Third, methods to measure manual preference and brain dominance. Fourth, the vast data sets of previous laterality researchers that traced the incidence of right- and left-handedness across generations in various communities in Europe and the United States throughout the twentieth century.

The latter two pillars caused significant methodological and epistemological challenges to laterality researchers. The data sets that handedness researchers have used are partially over one hundred years old. They include handedness pedigrees, twin data, hand preference surveys, hand skill measures, and aphasia data. Later in the twentieth century, scientists have added results from tests for cerebral laterality to their collection.[437] One of the two most prominent tests to determine speech dominance is the Wada test, which Japanese-born Canadian neurologist Juhn A. Wada (b. 1924) developed in the mid-century.[438] In this test, researchers determine the lateralization of language- and memory-related functions by injecting a local anesthetic into one hemisphere of a subject's brain. Researchers then conclude from the temporary deficits what specific functions are located in the anesthetized hemisphere. Additionally, scientists have used dichotic listening tests since the 1970s as a non-invasive method to determine speech lateralization. For this

[437] For overviews of the various methods to assess handedness and brain laterality since the late nineteenth century, see Marian Annett, *Left, Right, Hand and Brain: The Right Shift Theory* (London: Lawrence Erlbaum Associates, 1985), 183–227; 417–418; Mark Philip Bryden, *Laterality: Functional Asymmetry in the Intact Brain* (New York, London: Academic Press, 1982), 157–168; Ian C. McManus, "Neuropsychology and the Localisation of Cognitive Function," in *The Scientific Basis of Psychiatry*, ed. M. Weller (London: Bailliere Tindall, 1983), 88–89; Lesley J. Rogers and Giorgio Vallortigara, eds., *Lateralized Brain Functions: Methods in Human and Non-Human Species,* Springer Protocols 122 (New York: Humana Press, 2017).
[438] Juhn A. Wada, "A Fateful Encounter: Sixty Years Later—Reflections on the Wada Test," *Epilepsia* 49, no. 4 (2008), https://doi.org/10.1111/j.1528-1167.2008.01515_6.x.

test, experimental subjects are presented with different sounds to the left and right ear respectively. Depending on the dominant ear, scientists assume that the centers for articulate speech and speech perception are located on the contralateral side of the brain.[439]

Some peculiarities of the heterogeneous laterality data sets have opened avenues for handedness researchers to link theories about manual preference, brain anatomy, and cognitive abilities to sex/gender and reproduction. Repeatedly reported sex/gender- and twinning-related differences in rates of left-handedness have posed difficulties to generations of handedness researchers. These observed differences, which paved the way for sex/gender-specific genetic handedness models, were:[440] (1) more men than women appeared to be left-handed, (2) children were more likely to be left-handed if their mother was left-handed than if their father was left-handed (the so-called maternal effect), and (3) the rate of left-handers among twins was higher than among singletons and the manual preferences of identical twins frequently differed. If handedness were strictly genetically determined, then only fraternal twins should be discordant for handedness, but this was not the case.[441]

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[439] Michael Studdert-Kennedy and Donald Shankweiler, "Hemispheric Specialization for Speech Perception," *Journal of the Acoustical Society of America* 48, 2B (1970), https://doi.org/10.1121/1.1912174. See also Abigail R. Bradshaw et al., "Measuring Language Lateralisation with Different Language Tasks: A Systematic Review," *PeerJ* 5 (2017), https://doi.org/10.7717/peerj.3929.

[440] I have derived this list from several scientists' recurring summaries of the obstacles to formulate a successful genetic theory of handedness, including Marian Annett, *Handedness and Brain Asymmetry: The Right Shift Theory* (Hove: Psychology Press, 2002), 14–16; 124–127; Michael C. Corballis, "The Genetics and Evolution of Handedness," *Psychological Review* 104, no. 4 (1997): 716, https://doi.org/10.1037//0033-295X.104.4.714; Ian C. McManus, "The Determinants of Laterality in Man" (Dissertation, Christ's College, University of Cambridge, 1979), accessed March 15, 2019, http://www.ucl.ac.uk/medical-education/publications/phd, 233–39; Ian C. McManus, "The Genetics of Handedness in Relation to Language Disorder," in *Progress in Aphasiology*, ed. F. C. Rose, Advances in Neurology 42 (New York: Raven Press, 1984), 129–30; Porac, *Laterality*, 17–20; 25–27.

[441] On deliberations of a *paternal* effect in the inheritance of left-handedness (from father to son or grandfather to son), see Stier, *Untersuchungen*, 109; 153. On early-twentieth-century ideas surrounding handedness in twins, see Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 34–35. For an account of the importance and complexities of twin research in behavior genetics, see Lindee, *Moments*, ch. 5. On the epistemological importance of "siblings" in

The Main Players in the Late Twentieth Century

Biographies

Carolus Oldfield was the initiator of a questionnaire-based big-data approach to the origins of handedness, and Annett and McManus became its main players. Oldfield represented one member of the handedness network who contributed very few publications to the growing literature on physical lateralities. He was born in London as the son of Francis du Pré Oldfield, a lawyer and member of the Indian Civil Service, who was knighted in 1923.[442] Carolus's mother, Frances S.H. Oldfield (née Cayley), was the daughter of an influential family of bankers. Carolus was educated in the Natural and Moral Sciences at the University of Cambridge (B.A. 1931, M.A. 1935). In the 1930s, he worked at the Cambridge Psychological Laboratory. In 1933, Oldfield married Lady Kathleen C. Blanche, the fifth daughter to the second Earl of Balfour. The couple raised two daughters.

Oldfield served in the Radar Branch of the Royal Air Force Volunteer Reserve during World War II. In 1946, he commenced a lectureship in General Psychology at the University of Oxford. He was Professor of Psychology at Reading University from 1950 through 1956, followed by his positions at Oxford University as Professor of Psychology and Director of the Institute of Experimental Psychology. Oldfield worked there until 1966, when he became the director of the Medical Research Council Speech and

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the long nineteenth century, see Stefani Engelstein, *Sibling Action: The Genealogical Structure of Modernity* (New York: Columbia University Press, 2017).

[442] Oldfield's biographical information is taken from E. Ansell, *Admissions to Peterhouse* (Cambridge University Press, 2015); Colin Harris, E-Mail to Tabea Cornel, October 12, 2015; Oliver L. Zangwill, "Richard Charles Oldfield (1909–1972)," *Quarterly Journal of Experimental Psychology* 24, no. 4 (1972), https://doi.org/10.1080/14640747208400295; Oliver L. Zangwill, "R.C. Oldfield's Contribution to Neuropsychology," *Neuropsychologia* 11, no. 4 (1973), https://doi.org/10.1016/0028-3932(73)90023-7.

Communication Unit at Edinburgh University. He held this position until he passed away in 1972.

A first-generation college student, Marian Annett (née Drabble) received her undergraduate education at Bedford College (B.A. 1952), a women's college later merged with Royal Holloway College.[443] She completed her Ph.D. in the Institute of Psychiatry at the University of London in 1965. Early in her career, Marian Drabble met experimental psychologist John Annett (b. 1930) during a campus visit in Bristol. That day, Marian and John were both applying for a researcher position at the Burden Mental Research Department, and both were hired.

After they got married in 1955, the family focused on John's career advancement. Marian finished her dissertation as an external candidate and she never held a professorship. In her own words, she practiced psychology as "a hobby," mainly at home and without much institutional support.[444] She worked in researcher positions at the University of Hull and Open University in the 1960s and 1970s. Later, she was affiliated as a lecturer and reader with the psychology departments at the Lanchester Polytechnic and the University of Leicester. The latter conferred emerita status on her in 1994.

Like Annett, Chris McManus was a first-generation college graduate.[445] Apart from that, the psychologists' biographies differ significantly. McManus obtained a prestigious education in psychology from Christ's College at the University of Cambridge (Ph.D. 1979), and he received his medical training at the Universities of Birmingham and

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[443] Annett's biographical information is taken from Marian Annett, "CV and Publications {PRIVATE}," (unpublished manuscript, 2011); Marian Annett, E-mail to Tabea Cornel, October 7, 2016.
[444] Marian Annett, interview by Tabea Cornel.
[445] McManus's biographical information is taken from Ian Christopher McManus, interview by Tabea Cornel; Ian C. McManus, "Medical Education," accessed March 15, 2019, http://www.ucl.ac.uk/medical-education/medical-education-studies.

London (M.D. 1985). After several lectureships, he took up his first professorship in 1993, a joint appointment between St. Mary's Hospital Medical School and University College London (UCL). He became Professor of Psychology and Medical Education at UCL in 1997 and has held this post since.

McManus only knew Oldfield from conferences.[446] Annett considered working with Oldfield at an early stage of her career, but at this point in time neither of them had focused on handedness research. They remained in loose contact until shortly before Oldfield's death.[447] Annett and McManus had one friendly encounter in 1974.[448] From then on, their exchanges were intensely competitive. Despite the proximity of McManus's and Annett's work places and handedness models, they mainly communicated through their publications, which took an increasingly hostile tone over the years. After reading McManus's reviews of Annett's work and her rejoinders, it seems quite conceivable why McManus assumed that Annett considered him her "enemy."[449]

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[446] Ian Christopher McManus, interview by Tabea Cornel.
[447] Marian Annett, interview by Tabea Cornel.
[448] They were introduced by British psychologist Oliver L. Zangwill (1913–1987); Marian Annett, "Perceptions of the Right Shift Theory: The Author's Reply," *Cortex* 40, no. 1 (2004): 143–49. Zangwill was a mentor to both Annett and McManus; Marian Annett, interview by Tabea Cornel; Ian C. McManus, E-mail to Tabea Cornel, August 14, 2017. Zangwill's belief in handedness as a continuum and matter of normal biological variation motivated Annett to pursue handedness research; Marian Annett, interview by Tabea Cornel; Oliver Louis Zangwill, *Cerebral Dominance and Its Relation to Psychological Function*, Henderson Trust Lectures 19 (Springfield: Charles C. Thomas, 1960).
[449] Ian Christopher McManus, interview by Tabea Cornel. Approximately once per decade, the two psychologists engaged in public controversy (critiques and rejoinders). In the 1980s: Marian Annett, "Hand Preference and Skill in 115 Children of Two Left-Handed Parents," *British Journal of Psychology* 74, no. 1 (1983); Marian Annett, "Which Theory Fails? A Reply to McManus," *British Journal of Psychology* 76, no. 1 (1985), https://doi.org/10.1111/j.2044-8295.1985.tb01927.x; Ian C. McManus, "On Testing the Right Shift Theory: A Reply to Annett," *British Journal of Psychology* 76, no. 1 (1985), https://doi.org/10.1111/j.2044-8295.1985.tb01928.x; Ian C. McManus, "Right- and Left-Hand Skill: Failure of the Right Shift Model," *British Journal of Psychology*, no. 76 (1985). In the 1990s: Marian Annett, "The Fertility of the Right Shift Theory," *Current Psychology of Cognition* 14, no. 5 (1995); Marian Annett, "The Right Shift Theory of a Genetic Balanced Polymorphism for Cerebral Dominance and Cognitive Processing," *Current Psychology of Cognition* 14, no. 5 (1995); Ian C. McManus, "Achilles' Right Heel: The Vulnerabilities of the Right Shift Theory," *Current Psychology of Cognition* 14, no. 5 (1995). In the 2000s: Annett, *Handedness*; Annett, "Perceptions"; Ian C. McManus, "Grappling with the Hydra: Review

Oldfield disagreed with some of Annett's research on handedness, but he did not nearly engage as much with his two younger colleagues as they engaged with each other. Reasons for this modest exchange might be that Oldfield did not compete for resources with either Annett or McManus, and that he passed away before their research projects came to prominence in the 1970s. In contrast, the heated debate between McManus and Annett lasted for decades, and it often took a personal valence. The difference in the psychologists' social positioning—an older female researcher without a strong academic position against a younger, highly connected male professor—highlights some crucial sexed and gendered dynamics of academic life. These aspects, which are at the same time structural and personal, are important to mention explicitly as the research into the seemingly neutral domain of handedness turned out to be centrally concerned with sex differences and gendered intellectual characteristics.

To make sense of the disparity between McManus's and Annett's professional achievements and social capital, it is important to keep in mind that Annett continued an unfortunate tradition of female scientists. In many cases, social pressure or economic necessity forced these women to choose between raising a family and pursuing an academic career that culminated in a professorship. Although the first women had already been awarded doctorates in psychology in the late nineteenth century, psychology was still a male domain through the mid-twentieth century.[450]

of *Handedness and Brain Asymmetry: The Right Shift Theory* by Marian Annett, ISBN 1-84169-104-6, Hove: Psychology Press, 2002. 416 pages, Price: U.S.$ 80.00, U.K. £49.95," *Cortex* 40, no. 1 (2004).

[450] More research on twentieth-century women psychologists in Britain is wanting. Most existing scholarship focuses on the United States; e.g., Rossiter, *Women*; Rossiter, *Women*.

Oldfield's Inventory

Oldfield published around two dozen papers between 1949 and 1972, some of which engaged with deeply philosophical questions about language, memory, and perception. Nonetheless, he was deeply committed to experimental psychology. His earlier work focused on sensory perception, memory, and the psychology of language, and he studied handedness only later in his career. Oldfield's first publication on the topic was a paper on "Handedness in Musicians,"[451] in which he determined the percentage of left-handed professional musicians and conductors as well as the ratio of hand-switching in these careers. With similar interest in the manual aptitudes and potential plasticity of left- and right-handers in a highly skilled profession, Oldfield later published a short communication in the *Lancet*, asking the editors and readers to assist him in gaining information about "Ambidexterity in Surgeons."[452] This letter was published the year before his death and no publication grew from it.

Oldfield's main contribution to the study of handedness was a pragmatic measurement scale. In his widely cited paper "The Assessment and Analysis of Handedness," Oldfield proposed the Edinburgh Handedness Inventory (EHI) as a standardized measure of handedness, intended to provide a basis for further comparative research.[453] The inventory conceptually resembled Oldfield's earlier work on the measurement of intellectual and sensory qualities. British psychologist Oliver L. Zangwill (1913–1987) commented on Oldfield's fondness for *meaningful* quantification in his obituary. He suggested that Oldfield considered quantification "beyond all doubt the aim of experimental

[451] Richard C. Oldfield, "Handedness in Musicians," *British Journal of Psychology* 60, no. 1 (1969).
[452] Richard C. Oldfield, "Ambidexterity in Surgeons," *Lancet* 1, no. 7700 (1971).
[453] Oldfield, "Assessment".

psychology," while he found "[t]he use of numbers merely to enhance scientific prestige … totally abhorrent."[454]

Oldfield intended the EHI to be "a simple and brief method of assessing handedness on a quantitative scale."[455] To do so, he modified a twenty-item questionnaire that he had already used in his 1969 paper on handedness in musicians and relied on M.E. Humphrey's longer questionnaire.[456] Admitting that any selection of questions must necessarily be "arbitrary,"[457] Oldfield wanted to provide a generalizable quantification of handedness that was neutral with regard to the differences "between sexes, (Western) nations, and socio-economic and cultural factors."[458] Consequently, Oldfield excluded culturally specific tasks from his questionnaire, including the holding of silverware or using certain sports equipment.[459] Furthermore, Oldfield omitted all "superfluous" items, that is, redundant questions about related tasks for which most people use the same hand.[460] Oldfield determined this potential redundancy of questionnaire items with correlation matrices, for which he used punched cards.[461] Allegedly neutral non-redundant manual tasks including writing and sweeping made the cut.

The EHI was a comparative tool to standardize and facilitate future research on manual preference and its psychological relevance. Accordingly, Oldfield suggested a uniform notation of the results for individual handedness assessments, called a Laterality

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[454] Zangwill, "Richard," 376.
[455] Oldfield, "Assessment," 98.
[456] M. Humphrey, "Handedness and Cerebral Dominance" (B.Sc., University of Oxford, 1951).
[457] Oldfield, "Assessment," 104.
[458] Oldfield, "Assessment," 104.
[459] Oldfield, "Assessment," 101.
[460] Oldfield, "Assessment," 98. Writing and drawing are two examples for highly correlated manual tasks, but Oldfield decided to keep both in order to reflect the cultural value that society assigns to "representational or symbolic tasks"; Oldfield, "Assessment," 101.
[461] Oldfield, "Assessment," 110.

Quotient (LQ), which could range from –100 through +100, or from entirely left-handed through entirely right-handed. Oldfield computed the LQ via a series of additions and divisions of the number of left/right responses to questionnaire items. He suggested that individual LQs should be notated as a number including the decile in which this score ranked in the population under study.[462]

Oldfield chose a continuous measure of handedness in the light of uncertainty about the precise underlying mechanisms, and not to erase the lingering stigma against left-handers. "[N]ormal individuals," according to Oldfield, were right-handers.[463] He asserted that even subjects who scored as high as +70 on the EHI were not entirely "normal." In Oldfield's own words, these individuals were "deviant and reflect[ed] some unusual use of the hands" although they were not "decisively sinistral" (that is, they did not have negative LQs).[464]

Despite his comments on normal and abnormal handedness, Oldfield intended his inventory to specify the incidence of biological right- or left-handedness in *populations*, not necessarily in individuals. He intended to provide a tool "for screening purposes, for assessment where very large populations are involved and for the provision of a standard of comparison in neuropsychological work."[465] Today, however, neuroscientists use the EHI for individual typification, oftentimes in order to define a cut-off point for the exclusion of presumed non-right-handers from experiments.[466]

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[462] Oldfield, "Assessment," 107.
[463] Oldfield, "Handedness," 91.
[464] Oldfield, "Handedness," 93.
[465] Oldfield, "Assessment," 110.
[466] This exclusionary practice has only recently been challenged but is not (yet?) controversial in the field as a whole; Roel M. Willems et al., "On the Other Hand: Including Left-Handers in Cognitive Neuroscience and Neurogenetics," *Nature Reviews Neuroscience* 15, no. 3 (2014), https://doi.org/10.1038/nrn3679.

Oldfield aimed at gathering a reliable pool of data that would serve further investigations into the question of brain laterality and speech dominance.[467] Motivated by his observation that large parts of each given population exhibit left-handed tendencies, Oldfield set out to expose "true" biological handedness with the help of his inventory. He assumed that behavioral measures were useless in this connection because the extent of skill might reflect gendered habits or other cultural customs rather than innate handedness.

Oldfield saw a further obstacle to determining "true" handedness in individual's subjective assessment of their manual preference. He deemed it "unlikely" that research subjects were able to report their handedness correctly in response to a direct question, and he determined that the percentage of individuals who "claimed" to be (at least slightly) left-handed differed significantly from the factual incidence.[468] Oldfield hoped that the EHI would be unaffected by reporting biases because he had left out items that he supposed would overlap with cultural customs and/or erroneous subjective assessments.

Oldfield's concern for the biological essence of handedness also showed in his concern for the degree to which handedness is plastic. Oldfield distinguished between "physical" and "social" environmental factors that impacted an individual's "pre-existing tendency to lateralization."[469] Dining etiquette would be one example for social factors. The aforementioned paper on handedness in physicians grew out of Oldfield's interest in the physical factors. Oldfield found that professional left-handed musicians could play

[467] Oldfield, "Assessment," 98.
[468] Oldfield, "Assessment," 99–100.
[469] Oldfield, "Handedness," 97.

their instruments the right-handed way without problems, and that this habit did not cause the musicians to reverse their handedness for any other task.[470]

Oldfield believed that both social and physical factors could have a much bigger impact than it seemed from his study on left-handed musicians. In his study of college students, he encountered a virtual absence of exclusive left-handers (that is, individuals with an LQ of –100), but numerous left-handers with LQs around –70. Oldfield concluded that the significant right-hand tendencies in most left-handers "may be the result of some adaptation by left-handed people to a world predominantly organized for the right-handed."[471]

In the absence of an etiological theory of handedness, Oldfield had no means to theoretically describe or mathematically measure the gap between factual manual behavior and "true" biological handedness. Partially buried in the footnotes of the 1971 paper with which he introduced the EHI, Oldfield revealed his speculations about a connection between handedness genes and chromosomal sex. He reported to be in the process of collecting data on the incidence of left-handedness in "chromosomally abnormal individuals," that is, individuals with XXY and XYY karyotypes.[472] It is obvious that Oldfield planned to scrutinize the genetic foundations of handedness, but he passed away at the age of 62 only three years after his first publication on handedness.

Nonetheless, Oldfield provided an example for how to study sex/gender differences through handedness research, even in the absence of genetic theories. Convinced

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470 Oldfield, "Handedness," 94–95. These results relied on a crucial sampling bias, which derived from Oldfield's focus on professional musicians. There may be numerous left-handers who have trouble using "normal" musical instruments and never advance to professional levels for precisely this reason.
471 Oldfield, "Assessment," 100.
472 Oldfield, "Assessment," 105.

that the ratio of left-handed men is higher than that of left-handed women, Oldfield expected that all "reasonable" measures of handedness would produce the traditional distribution with an excess of male left-handers.[473] The EHI seemed the perfect tool for the job, because Oldfield had designed it to be free of biases (or so he thought). Accordingly, Oldfield provided only the sex-specific breakdown of LQs for some of his studies and withheld combined scores. Assuming that the genetics of handedness had something to do with sex chromosomes, he hoped that massive sex-specific data sets would bring psychologists one step closer to disentangling the "genetic as opposed to the social aspects of handedness."[474]

Annett's Theory

Annett had a more clinical perspective than Oldfield. After researching cognitive development and childhood hemiplegia towards the beginning of her career, she dedicated virtually her entire professional life to handedness research. In the mid-1960s, she used questionnaires and behavioral observations to screen hundreds of school children and college students for handedness.[475] The large number of individuals who did not show consistent hand dominance led Annett to believe that there are three handedness phenotypes: right-, left-, and mixed-handedness. Annett combined her results with data sets from the early twentieth century to determine the prevalence of each handedness phenotype, and to mathematically infer the frequency of the underlying genotypes.

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473 Oldfield, "Assessment," 105.
474 Oldfield, "Assessment," 105.
475 Marian Annett, "The Binomial Distribution of Right, Mixed and Left Handedness," *Quarterly Journal of Experimental Psychology* 19, no. 4 (1967), https://doi.org/10.1080/14640746708400109.

In her first controversial article on the binomial distribution of the three handedness phenotypes, Annett forcefully argued against the binary classification of handedness.[476] She asserted that true mixed-handedness existed, and that right-handed tendencies in mainly left-handed individuals were not—or not *only*—a consequence of social and cultural pressures. Not everybody liked the idea of a binomial distribution of handedness. In fact, Oldfield, who worked in Edinburgh at the time, visited Annett in Hull and told her to abandon her research.[477] Against Oldfield's recommendation, Annett continued her studies.

Annett did not like Oldfield's purportedly untheorized pragmatic approach to handedness more than he liked hers, and she refused to use the EHI. Annett perceived LQs as an unnecessary simplification of "messy" data.[478] In her view, Oldfield should not have limited possible responses to "left" and "right," and he should not have weighed responses to items about different hand skills equally. In Annett's own words, the lumping together of writing, sweeping, and other tasks in the EHI was "like counting together oranges, tomatoes, and cabbages—necessary perhaps on some occasions, but these are not likely to be frequent."[479]

In order to account for mixed-handers, Annett developed a new handedness questionnaire that allowed for three different responses: "left," "right," or "either."[480] Furthermore, she included questions aiming at a wide range of manual tasks. Her goal was to display the heterogeneity in hand use for skilled and unskilled manual tasks from writing

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476 Annett, "Binomial".
477 Marian Annett, E-mail to Tabea Cornel, September 23, 2016.
478 Marian Annett, interview by Tabea Cornel.
479 Annett, *Left*, 197.
480 Annett, "Binomial," 329.

to hammering a nail, and from holding a toothbrush to unscrewing the lid of a jar. What is more, Annett and her assistants investigated handedness beyond their own questionnaire. If interviewees consistently responded only “left” or only “right” to all questionnaire items, Annett and her team asked them if there were any other unimanual task that they performed with the opposite hand.[481]

Similar to Oldfield, Annett superimposed her own classification system on the questionnaire data. For instance, consistent responses of mixed task performance on the questionnaire did not earn an individual the classification of a mixed-hander. Counterintuitive as it may seem, Annett required that a mixed-handed individual answer at least once “left” *and* once “right.” Subjects who answered *only* “left” *or* “right” in combination with however many “either” responses were categorized as left- or right-handers respectively.[482] A few years later, Annett even suggested that the “either” option be entirely abandoned. Instead, she recommended to ask research subjects whether they have a strong or a weak task-specific preference for either hand.[483] This proposal illustrates two things. First, Annett had more faith in subjective handedness assessments than Oldfield. Second, mixed-handedness rested on the binary left/right, even in Annett’s supposedly continuous model of handedness.

Annett’s genetic model of manual preference was not “received all at once in some sudden illumination from on high” as Annett emphasized repeatedly.[484] She published overhauled versions of her model in four stages, starting with a publication from 1972. With this paper, Annett introduced an element of chance into the inheritance of

[481] Annett, “Binomial,” 329.
[482] Annett, “Binomial,” 329.
[483] Annett, *Left*, 197.
[484] Annett, *Left*, xi.

handedness. This concept revolutionized the etiology of handedness, and, compared to earlier simple Mendelian models, offered a new understanding of the interplay of nature and nurture in the context of handedness and speech laterality.

Based on statistical calculations and theoretical considerations, Annett propositioned a so-called "'right shift' factor," a genetic influence that supposedly biases human handedness to the right and speech lateralization to the left.[485] In a self-published pamphlet that Annett rushed to print in 1978 (with the intention to publish it before McManus defended his dissertation), Annett called her new model the Right Shift (RS) theory. The model assumed that an unspecified gene would either carry the RS factor as an allele or not. In carriers of the allele (ca. 81 percent of the population), the RS factor would cause the growth of the speech center in the left hemisphere during fetal development. Left-brain dominance for speech, Annett argued, influenced (but did *not* strictly determine) one's handedness type. She suggested that carriers of the RS factor were strongly predisposed to right-handedness as a consequence of their genetically induced left-brainedness. In non-carriers of the RS factor (ca. 19 percent of the population), the speech center could develop in the right or left brain hemisphere based on chance. Consequently, 50 percent of those individuals would be right-brained and 50 percent left-brained, and their handedness would also depend on chance.

Annett derived the above values from aphasia data that other researchers had collected over the course of the previous decades.[486] She added up the number of aphasia

[485] Marian Annett, "The Distribution of Manual Asymmetry," *British Journal of Psychology* 63, no. 3 (1972): 356.
[486] Marian Annett, "Hand Preference and the Laterality of Cerebral Speech," *Cortex* 11, no. 4 (1975): 311–20; Marian Annett, *A Single Gene Explanation of Right and Left Handedness and Brainedness: The Human Handedness Right Shift Factor Behaves Like a Single Gene* (Coventry: Lanchester Polytechnic, 1978), 7.

patients with lesions in the right hemisphere from four studies, amounting to 60 out of 647 aphasia patients with one-sided lesions. Assuming that all right-lesioned aphasia patients had their speech center in the right hemisphere, Annett inferred that the rate of right-brain dominance for speech was $60/647 \approx 0.0927$. Because only half of the non-carriers of the RS factor would be right-brained, she deduced that the proportion of non-carriers was twice as high as the latter figure, namely 0.1854, or roughly 19 percent. The remaining 81 percent of the population would carry either one or two RS alleles. Although Annett later changed her RS theory from a simple dominant/recessive model to a more complex genetic mechanism, she adhered to these same numbers. McManus later complained that the shift between theoretical models warranted a new derivation of parameters and criticized Annett for her presumed negligence.[487]

Similar to Oldfield, Annett attempted to distinguish between biological and cultural dimensions of handedness. She found reasons to believe in the existence of "pure left-handers" in the RS theory.[488] In order to single them out, "two sorts of left hander[s]"[489] had to be distinguished: those among the heterozygous carriers and those among the non-carriers of the RS factor. Annett assumed that all heterozygous left-handers were not pure, because any potential left-handers in this group had a genetic bias to right-handedness. Hence, only homozygous non-carriers of the RS factor showed a "true bias towards sinistrality."[490] However, Annett found a considerable number of non-pure left-handers even in this group. She argued that all homozygous non-carriers were

[487] McManus, "Achilles," 566–70.
[488] Annett, "Distribution," 355.
[489] Annett, "Model," 60.
[490] Marian Annett, "Handedness, Cerebral Dominance and the Growth of Intelligence," in *Specific Reading Disability: Advances in Theory and Method*, ed. Dirk J. Bakker and Paul Satz, Modern Approaches to the Diagnosis and Instruction of Multi-Handicapped Children 3 (Rotterdam: Rotterdam University Press, 1970), 66–67.

very susceptible to environmental influences; due to the absence of a genetic bias, many non-carriers adapted to cultural pressures and spoiled their genetic "purity" on the behavioral level.[491]

Foundational to the RS theory was that it defined handedness as "a by-product" of left-hemispheric speech lateralization.[492] This association remained vague and Annett explained neither the genetic nor the anatomical mechanism of this hand-brain connection, even though it was integral to establishing the credibility of her heritability rates. As laid out above, Annett deduced the parameters for the rate of RS-factor inheritance from *aphasia* data.[493] In a second step, she "applied" these estimates to handedness data to prove their validity. This means that Annett tested if data about the inheritance of handedness showed a similar pattern as the inheritance of the hypothetical RS allele for speech dominance.

The rhetoric of application was deliberate. Annett tried to avoid charges of circularity: if she had derived her parameters from handedness statistics *and* tested the fit of her formula with handedness data, nothing would have been gained. Because of the contingency of handedness categories, Annett did not use fixed handedness scores for this application. Instead, she worked with standard deviations of differences in skill between the left and right hands. Annett applied chi-squared tests to show that mixed-, right-, and left-handedness could in fact be divided up into stable fractions among the three hypothetical genotypes.[494]

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491 Marian Annett, "Implications on the Right Shift Theory of Handedness for Individual Differences in Hemisphere Specialization," in *Individual Differences in Hemispheric Specialization*, ed. A. Glass (New York: Plenum, 1987), 40.
492 Annett, *Left*, 260.
493 Annett, *Single*, 9.
494 Annett, *Single*, 9–13.

Annett's model can be described as a probabilistic version of Broca's theory of the association between hand and brain in that it black-boxed the question of how brain-edness leads to manual preference. Annett tried to escape the conservatism of her theory by explaining that handedness and cerebral laterality were statistically correlated but *not* causally linked within individual organisms.[495] Right-handedness was *most likely* concomitant with left-lateralized speech, she suggested, but any combination of left or right speech laterality with left, right, or mixed handedness could occur.

The reasons why Annett called her model the Right Shift theory provide insight into the ways in which nineteenth-century concerns about human exceptionalism were sustained by twentieth-century computational statistics in handedness research. Annett assumed that the hand-skill distribution among non-carriers of the RS factor was a bell-shaped normal curve with its peak at zero, the point of absolute ambidexterity.[496] Carriers of the RS factor were also normally distributed, but their bell-shaped curve peaked somewhere to the right of zero. This shift to the right of the normal distribution of hand skill in carriers of the RS factor is what gave the theory its name.

According to Annett's model, this shift to the right marked a crucial difference between humans and non-human animals. Annett believed that non-human primates either did not have any consistent lateral preferences or that they preferred their left or right hands (or paws or feet) at a rate of 25 percent and were ambidextrous in 50 percent of the cases. Consequently, the left-right skill distribution for non-human animals would peak

[495] Annett, *Single*.
[496] On the history of the normal distribution, see Hacking, *Taming*, 105–114; 180–188. For a pre-history of the normal curve in mid-to-late-nineteenth century medical statistics, see Cryle and Stephens, *Normality*, 100–141.

right at zero.[497] Per the RS theory, the hand-skill distribution of human *left-handers* also peaked at zero, but the human population *as a whole* displayed a Right Shift.

Annett invested significant conceptual effort to make the RS model solve the three core problems of handedness research: (1) more men than women were left-handed; (2) children were more likely to be left-handed if their mother was left-handed than if their father was left-handed (the maternal effect); and (3) the rate of left-handers among twins was higher than among singletons, and the manual preferences of identical twins frequently differed.

To explain the excess of left-handed men, only one *a-posteriori* specification was necessary. Annett claimed that the RS factor would get expressed more strongly in females than in males.[498] This means that female carriers of the RS factor should be, on average, more strongly left-dominant for speech than male carriers. This difference in the degree of Right Shift, according to Annett, also caused cognitive sex/gender differences. For instance, she suggested that it explained why girls and women had better verbal skills than their male counterparts, and why, in turn, men and boys excelled at visuo-spatial tasks.[499]

Conveniently, this tweak also solved another problem, namely the maternal effect.[500] If the Right Shift was expressed less strongly in males than in females, then more male than female carriers of the RS factor would be left-handed. Consequently, Annett suggested, left-handed fathers would be more likely to pass on an RS allele to their

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[497] Annett, “Distribution”.
[498] Annett, “Distribution”. See also Annett, *Left*, 256–59.
[499] Annett, “Distribution,” 356.
[500] Annett, *Left*, 302.

offspring than left-handed mothers, and the former would have more left-brained and right-handed offspring than the latter.[501]

The RS theory also confronted the problems posed by twin data. The chance factor in the first version of the RS theory effectively explained why the handedness of identical twins could differ, but it left open why singletons were more likely to be right-handed than twins. However, the modification that had worked for men and women seemed appropriate in this context as well, and Annett propositioned that the RS factor would get expressed less strongly in twins than in singletons.[502] She did not offer empirical evidence to back this hypothesis.

In the following years, Annett carried the statistical rhetoric one step farther, aligning her analysis with an emerging logic of "risk factors" in the biological and psychological sciences. While the concept of chance had been integral to earlier versions of the RS theory, the notion of being "at risk" was a novelty.[503] In the late 1980s, she suggested that both homozygous groups—the carriers of two RS alleles and the non-carriers—were "at risk" of lower-level brain function, which most prominently manifest in the form of dyslexia.[504] Annett explained that the heterozygous population would on average

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[501] The maternal effect still caused scientific speculation in the late 1990s; e.g., Stanley Coren, "Pathological Causes and Consequences of Left-Handedness," in *Manual Asymmetries in Motor Performance*, ed. Digby Elliott and Eric A. Roy (Taylor & Francis, 1996), 93–95. McManus suggested that the explanation for the maternal effect is cultural rather than biological: if women conceive children by cheating on their left-handed partners (the social fathers) with right-handed men (the biological fathers), the likelihood is high that the children are right-handed despite having left-handed (social) fathers; Ian Christopher McManus, interview by Tabea Cornel.

[502] Annett, *Single*, 9.

[503] On the twentieth-century transformation of the discourse surrounding crime and disease from notions of reductionism and determinism to notions of "risk" and responsibility, see Nikolas S. Rose, *The Politics of Life Itself: Biomedicine, Power, and Subjectivity in the Twenty-First Century* (Princeton: Princeton University Press, 2007), chs. 4 and 8.

[504] Annett, "Implications," 46–47. Although meta-studies have indicated that reported correlations between left-handedness and dyslexia do not hold up, this association remains popular in the twenty-first century; see, e.g., Thomas S. Scerri et al., "PCSK6 Is Associated with Handedness in Individuals with Dyslexia," *Human Molecular Genetics* 20, no. 3 (2011), https://doi.org/10.1093/hmg/ddq475.

perform on a higher intellectual level than non-carriers, providing heterozygotes with a reproductive advantage over other genotypes.[505]

In the late 1990s, Annett presented the final version of her theory.[506] It included a further addendum: the suggestion that homozygous carriers of the RS factor (if it showed a slight mutation) were also "at risk" of developing schizophrenia and autism.[507] Although claims of the genetic underpinnings of psychiatric illnesses and developmental disabilities have a long history, Annett's association did not have much grounding in empirical work. It was based on her theoretical assumptions about the connection between brain anatomy and intelligence, as well as her comparison of hypothetical frequencies of the RS factor and the incidence of dyslexia, autism, and schizophrenia.[508]

Grounded in these theoretical considerations and in her sympathy for the hardships that certain types of brainedness or handedness cause (including her left-handed son's marginalization in school due to his reading problems), Annett recommended population screenings for the RS factor.[509] In her view, the early identification of homozygous carriers and non-carriers of the RS factor would allow for targeted pedagogical or

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[505] Annett, "Implications"; Marian Annett, "Handedness and Educational Success: The Hypothesis of a Genetic Balanced Polymorphism with Heterozygote Advantage for Laterality and Ability," *British Journal of Developmental Psychology* 11, no. 4 (1993); Annett, "Right"; Marian Annett and M. Manning, "The Disadvantages of Dextrality for Intelligence," *British Journal of Psychology* 80, no. 2 (1989); Marian Annett and M. Manning, "Reading and a Balanced Polymorphism for Laterality and Ability," *Journal of Child Psychology and Psychiatry, and Allied Disciplines* 31, no. 4 (1990).
[506] Marian Annett, "Schizophrenia and Autism Considered as the Products of an Agnosic Right Shift Gene: Presented at Joint AEP & RCP Meeting," (unpublished manuscript, July 9, 1996).
[507] Marian Annett, "The Theory of an Agnosic Right Shift Gene in Schizophrenia and Autism," *Schizophrenia Research* 39, no. 3 (1999): 177.
[508] On the biological impossibility of Annett's statistical theory, see Michael C. Corballis, "A House of Cards?" *Cognitive Neuropsychiatry* 2, no. 3 (1997): 214–216. On other studies that associated left-handedness with autism, schizophrenia, and other pathologies, see Kushner, *On*, ch. 11; Porac, *Laterality*, 135–56.
[509] Marian Annett, interview by Tabea Cornel.

psychiatric interventions.[510] In doing so, Annett reinforced the RS model's tendency to create a genetic typology of personalities and cognitive types.

McManus's Theory

Despite McManus's close engagement with Annett's work in his Ph.D. thesis from 1979, *The Determinants of Laterality in Man*, McManus maintained that Annett's and his own model had been "independently developed."[511] Annett disagreed. She believed that "[McManus's] theory was to rival and supplant the RS theory."[512] Suffice it to say that the two models were very similar. Most importantly, both insisted on the importance of chance, and both assumed a genetic connection between cerebral laterality and manual preference. Most importantly, both psychologists connected handedness with the allegedly exceptionally human quality of speech, although McManus was less explicit about differences between humans and non-humans than Annett.

McManus's theory was based on two hypothetical alleles, as opposed to Annett's single RS factor.[513] McManus formalized the chance element in handedness inheritance by introducing an allele that would determine an organism's susceptibility to environmental influences. He proposed that the dextral allele *D* determined handedness and that

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[510] Marian Annett, "Laterality and Types of Dyslexia," *Neuroscience and Biobehavioral Reviews* 20, no. 4 (1996); Marian Annett, "Dyslexia and Handedness: Developmental Phonological and Surface Dyslexias Are Associated with Different Biases for Handedness," *Perceptual and Motor Skills* 112, no. 2 (2011), https://doi.org/10.2466/10.19.24.PMS.112.2.417-425; Marian Annett and Diana Kilshaw, "Lateral Preference and Skill in Dyslexics: Implications of the Right Shift Theory," *Journal of Child Psychology and Psychiatry, and Allied Disciplines* 25, no. 3 (1984).
[511] Ian C. McManus and Mark P. Bryden, "The Genetics of Handedness, Cerebral Dominance and Lateralization," in *Child Neuropsychology: Part 1*, ed. I. Rapin and Sidney J. Segalowitz, Handbook of Neuropsychology 6, Section 10 (Amsterdam: Elsevier, 1992), 126.
[512] Annett, "Perceptions," 147.
[513] McManus, "Determinants," 224–327. For McManus's account of his theory for a popular audience, see McManus, *Right*, 146–167; 202–232; 354–362.

the chance allele *C* determined the limits of environmental influences on handedness. These two alleles could combine to the homozygotes *DD* (100 percent right-handed individuals) and *CC* (50 percent left- and 50 percent right-handed individuals, because chance is the only influence on the direction of handedness). In the heterozygote (*DC*), McManus suggested, *D* would be partially penetrant, that is, more than 50 percent but less than 100 percent of the *DC* population would be right-handed. Initially, McManus offered two potential values for the proportion of right-handers among the *DC* population: 87.5 percent and 75 percent.[514] In the second version of his model, he settled on 75 percent,[515] based on computerized statistical analyses of survey data.[516]

Extending the reach of his genetic model from the hand to the brain, McManus proposed that the *C* and *D* alleles regulated not only handedness but also speech lateralization *directly*.[517] In contrast to the RS theory, handedness would thus have the same genetic cause as—and *not* be a by-product of—brain asymmetry. According to McManus's theory, *D* would advance left-hemispheric speech and right-handedness independently but with the same probability. *DD* genotypes would always be right-handed and left-brained. Heterozygotes could exhibit any combination of left- or right-handedness and brainedness, but right-handedness and left-brainedness would be most prevalent. In the *CC* genotype, handedness and speech laterality would vary randomly.[518]

McManus turned chance itself into a genetically determined factor by formalizing serendipity into an allele that could regulate handedness and speech lateralization. With

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[514] McManus, "Determinants," 330.
[515] McManus, "Genetics," 130,
[516] Ian C. McManus, "Handedness, Language Dominance and Aphasia: A Genetic Model," *Psychological Medicine Monograph Supplement* 8 (1985): 13–16.
[517] McManus, "Determinants," 328–421.
[518] McManus, "Determinants," 336.

C, the gene for responsiveness to the environment, McManus brought effects of nurture into the realm of nature, virtually enchaining environmental influences into a genetic prison.[519] In doing so, McManus biologized certain aspects of nurture more effectively than Annett did. According to the RS theory, chance could affect brain lateralization to an unspecified degree in the absence of the RS factor. Under McManus's model, the limit for *all* chance variations was precisely defined for each genotype.

Like Annett, McManus eventually suggested that the *DC* population benefitted from a heterozygote advantage.[520] This means that the *DC* population, no matter the handedness phenotype, would be fitter than *DD* or *CC* individuals. McManus was more careful than Annett in phrasing his hypothesis and called it "speculation."[521] Most importantly, he did not dwell on the inferiority of homozygotes with regard to learning and developmental disorders or psychiatric illnesses like Annett. Instead, he emphasized the superiority of the heterozygotes by proposing that *DC* individuals might have the most favorable degree of randomness in the distribution of lateralized brain centers, allowing them to survive longer and/or reproduce at a higher rate.[522]

A striking similarity between Oldfield's, Annett's, and McManus's work on handedness is the search for a demarcation between the nature and nurture of handedness. McManus acknowledged that the *degree* of handedness (weak/strong) could be culturally

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[519] This model conceptually resembles twenty-first-century epigenetic theories that tend to molecularize nurture; see, e.g., Griffiths and Stotz, *Genetics*, 227–28; Aaron Panofsky, "From Behavior Genetics to Postgenomics," in Richardson; Stevens, *Postgenomics*; Sarah S. Richardson, "Maternal Bodies in the Postgenomic Order: Gender and the Explanatory Landscape of Epigenetics," in Richardson; Stevens, *Postgenomics*.
[520] McManus, *Right*, 227–32.
[521] McManus, *Right*, 228.
[522] McManus, "Determinants," 519–23.

influenced.[523] However, he distinguished this malleable feature from the more fundamental *direction* of handedness (left/right). Handedness *direction* could be reversed by cultural pressures in rare cases alone, and only superficially. One example of such an environmentally produced "phenocopy" left-hander would be an individual who was forced to perform all unimanual tasks with their non-dominant hand.[524] With this definition, McManus considered mixed handedness off the table. He upheld that whoever appeared to be ambidextrous had in fact a very weak degree of either left- or right-handedness.[525] From this would follow that handedness is bimodally distributed, with essentially two bell-shaped normal distributions on either side of an anti-mode of (or "the valley around") zero.[526]

McManus contemplated binary classification systems for various categories. For instance, he compared the issue of handedness classification to the contemporary sex/gender system. He suggested the invention of a new terminology that could account for the differences between an underlying biological hand preference (akin to sex) and its social superstructure (akin to gender).[527]

McManus's connection between manual preference and sex/gender did not come out of nowhere. Like previous handedness researchers, McManus struggled with the problem of an excess of male left-handers in the data. He originally considered that there

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[523] For discussions of degree vs. direction of handedness, see McManus, "Determinants," 42–48; Ian C. McManus, "Ultrasonography and Handedness: Don't Confuse Direction with Degree," *British Medical Journal* 307, no. 6903 (1993); McManus and Bryden, "Genetics," 116–17; Ian C. McManus et al., "The Development of Handedness in Children," *British Journal of Developmental Psychology* 6 (1988). See also Ian Christopher McManus, interview by Tabea Cornel.
[524] McManus, "Determinants," 256–257.
[525] McManus, "Determinants," 56.
[526] McManus, "Determinants," 24–102.
[527] Ian Christopher McManus, interview by Tabea Cornel. McManus linked sex/gender and handedness in this way at the very beginning of our interview, without being prompted, and elaborated on this thought in a way that left no doubt that he had thoroughly considered this comparison before.

might be a variable expression of the *D* allele in different sexes.[528] However, in the third and final version of his theory, he linked sex/gender and handedness much more closely.[529] Together with his Canadian colleague M. Philip Bryden (1934–1996), McManus proposed a hypothetical sex-linked factor that would inhibit the expression of the *D* allele. This modifying factor, they claimed, was a recessive allele on the X chromosome and hence exerted its effect more frequently in males than in females.

This modification of McManus's original theory seems equally *ad hoc* as Annett's amendments regarding the variability of the Right Shift in men and women or twins and singletons. Likewise, it constituted a potential solution to the problem of increased inheritance of left-handedness through mothers.[530] According to the McManus-Bryden model, a significant number of left-handed fathers would be concealed *DD* homozygotes who carry the inhibiting factor. This special class of left-handers could pass on only *D* alleles, not *C* alleles. If the offspring of these *DD* fathers inherited an X chromosome without the inhibiting factor from their mother, they would be equipped with at least one *D* allele (from their father) and at least one X chromosome with the dominant non-inhibiting allele (from their mother). These children would be right-handed with a probability of significantly more than 50 percent, because directional asymmetry would *not* be suppressed.

The male case differs from maternal inheritance. The data suggested that mothers were more likely to pass on left-handedness than fathers. According to the McManus-Bryden model, this is because less left-handed women than men would have *DD*

[528] McManus, "Determinants," 258; McManus, "Handedness," 17.
[529] McManus and Bryden, "Genetics".
[530] McManus and Bryden, "Genetics," 132–33. On McManus's later social explanation for this phenomenon, see footnote 501.

genotypes. Again, the reason for this is that the inhibiting factor was supposed to be recessive, and that only a double dose of X chromosomes with the inhibiting factor would allow for left-handedness to develop in female *DD* genotypes. Consequently, most left-handed mothers would pass on at least one *C* allele to their offspring, which would increase the likelihood of left-handedness.

Controversy and Clashes

One of the strengths that McManus saw in his own theory in comparison to Annett's was his conception of handedness as a binary category. McManus gave three reasons why he considered Annett's continuous model of handedness "an unrealistic phenotypic conception."[531] First, he suggested that, in reality, handedness was "discrete."[532] Second, this reality was in line with the "commonsense" perception of handedness and thus made science more intuitive.[533] The third reason has to do with the perceived necessity to utilize older twentieth-century data sets on manual preference and brain asymmetry. McManus found Annett's mixed phenotype troublesome because it foreclosed the option to integrate and compare existing data, which all rested on a dichotomous classification of handedness.[534]

McManus rejected a further one of Annett's core concerns. No version of McManus's theory accounted for the particularities of the twin data because McManus doubted the existence of the problem. He reviewed the available data and concluded that

531 McManus, "Determinants," 243.
532 McManus, "Determinants," 243.
533 McManus and Bryden, "Genetics," 130.
534 McManus, "Determinants," 241. McManus relied on big sets of data for his computerized model building. For several parts of his dissertation, he used the traditional data of numerous available previous handedness surveys. In other places, he drew on novel data from the British National Child Development Study.

there was *no* difference in the incidence of left-handedness among twins as compared to singletons.[535] This postulate made Annett's assertion of a weaker Right Shift in twins simply superfluous. Notwithstanding the aforementioned modifications of his own theory, McManus criticized Annett for her alleged *ad hoc* modification to make the RS theory fit the twin data.[536]

McManus also criticized Annett on mathematical grounds. Throughout his career, he claimed authority when it came to statistical questions. Mostly self-trained in the matter, he taught statistics courses and published short notes correcting various misunderstandings of statistical concepts.[537] In one of his publications, he criticized Annett for her choice of a Kolmogorov statistic to determine the RS theory's level of fit with her data.[538] In the same paper, he reproached Annett for her critique that he should have derived his parameters algorithmically rather than heuristically. McManus "f[ou]nd that difference obscure and irrelevant," and he suggested that Annett unnecessarily distinguished between "statistical nit-picking" (algorithmically) and pragmatically settling on a "method [that] happens to work" (heuristically).[539] Mobilizing his up-to-date elite education,

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[535] McManus, "Determinants," 138–58; Ian C. McManus, "Handedness in Twins: A Critical Review," *Neuropsychologia* 18, no. 3 (1980). Cf. authors who continued to assume that there is an increased rate of left-handedness among twins, due to some form of pathology and/or mirror-imaging; Charles E. Boklage, "Twinning, Handedness, and the Biology of Symmetry," in Geschwind; Galaburda, *Cerebral Dominance*; William H. James and Jacob F. Orlebeke, "Determinants of Handedness in Twins," *Laterality* 7, no. 4 (2002), https://doi.org/10.1080/13576500143000320; Nancy L. Sicotte, Roger P. Woods, and John C. Mazziotta, "Handedness in Twins: A Meta-Analysis," *Laterality* 4, no. 3 (1999), https://doi.org/10.1080/713754339; Sally P. Springer and Alan Searleman, "Left-Handedness in Twins: Implications for the Mechanisms Underlying Cerebral Asymmetry of Function," in Herron, *Neuropsychology of Left-Handedness*.

[536] McManus, "Determinants," 243.

[537] See, e.g., Ian C. McManus, "On the One Hand, on the Other Hand: Statistical Fallacies in Laterality," *Behavioral and Brain Sciences* 10, no. 2 (1987); Ian C. McManus, "Early Death amongst Anaesthetists: A Statistical Howler," *Anaesthesia* 53, no. 1 (1998).

[538] McManus, "On," 31–34.

[539] McManus, "On," 32.

McManus attempted to close the argument by suggesting that his methods were in line with *current* statistical practice.

Annett neither claimed to be using the latest statistical tests nor was she willing to subordinate her work to mathematical methods. She tried to fend off McManus's critique with the following quote from a statistical textbook: "*The scientist must be the judge of his own hypotheses, not the statistician*."[540] Annett defended her calculations by insisting that she and her colleague had followed "the traditional" way of using statistics within psychology; they had determined whether their hypothesis needed to be rejected in light of the statistical evidence.[541] However, McManus would not let that count. He demanded repeatedly that Annett explain precisely what kind of data would allow for the rejection of her model and thereby prove the RS theory's falsifiability. Otherwise, McManus wrote, "there is a nagging worry that any data can somehow be explained."[542]

Furthermore, McManus questioned the empirical and analytical rigidity of Annett's work. He claimed that Annett's theory was speculative and that "the waving of arms(,) and the imprecisions of words [we]re no substitute for formal quantitative analysis and precise calculation."[543] Although both scientists depended on a hypothetical gene as their chief explanatory mechanism rather than on empirical evidence, McManus mobilized the stereotype of the unempirical and irrational female in his critiques of Annett, drawing a picture of her as an old-fashioned, emotional, second-rate scientist.[544]

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540 Annett, "Which," 28. Italics in the original. The quote is taken from A. W. F. Edwards, *Likelihood: An Account of the Statistical Concept of Likelihood and Its Application to Scientific Inference* (Cambridge: Cambridge University Press, 1972).
541 Annett, "Which," 28.
542 McManus, "Achilles," 573.
543 McManus, "Achilles," 565.
544 McManus, "Achilles," 565; Ian C. McManus, "Autism and Schizophrenia Are Not Due to a Single Genetic Locus," *Cognitive Neuropsychiatry* 2, no. 3 (1997): 226–30.

The ways in which Annett was criticized at all stages of her career by older (incl. Oldfield) and younger (incl. McManus) scientists shed light on the entwinement of handedness research with other pervasive multi-level binaries, including professor/lecturer and male/female. Considering the fragile personal and institutional support that Annett had, her defensive reactions to frequent disapproval of her theory make sense. This did not help her cause. Her colleagues' critiques became increasingly direct and Annett's own responses progressively insolent and *ad hominem*.[545]

In their last public exchange, McManus countered the final version of Annett's theory in a playfully impertinent style. Setting himself up as a heroic, tireless (and male) Hercules against Annett's (female) onslaught, he referred to the RS theory and its modifications as heads of the "Hydra" that he had been fighting for decades.[546] Annett responded that she "admire[d] the nerve and the mathematical games" of McManus, but she questioned if his work was "sensible," that is, a reflection of reality.[547] Foregoing further insults, she closed the debate with the following line: "Words suitable for academic discourse fail me."[548]

Origin Stories and Anthropological Machines

Despite the dwindling support for Annett's theory, her proposal of genetic "risks" was very timely. According to sociologist Nikolas S. Rose, the risk discourse is a characteristic of "'advanced' liberal democracies" (or neoliberal societies).[549] Rose further

[545] See, e.g., the special issues *Current Psychology of Cognition* 14, no. 5 (1995); *Cortex* 40, no. 1 (2004).
[546] McManus, "Grappling".
[547] Annett, "Perceptions," 147.
[548] Annett, "Perceptions," 149.
[549] Rose, "Governing",

argued that a molecular view of the human body and mind have evolved over the course of the twentieth century, and that it has changed the interaction between authorities and those who are governed.[550] The perfection of one's health and abilities in the interest of productivity are the markers of the new bio-medicalized politics. Rose and historian of science Joelle M. Abi-Rached did not condemn these developments. They suggested that "brains at risk" (of anti-social behavior or psychiatric disorders) may be controlled in the interest of a peaceful society.[551]

Other scholars have viewed the risk discourse with less optimism than Rose and Abi-Rached.[552] Sociologist Dorothy Nelkin, for instance, critically assessed the testing culture in genetics and neuroscience of the late twentieth century. She argued that genetic testing has created a group of "pre-symptomatic ill" people, and that these individuals are in danger of becoming a "genetic underclass."[553] Sociologist Troy Duster similarly argued that even truly benevolent recourses to "risk" and susceptibility open the "backdoor" to neo-eugenic practices.[554] Annett's suggestion to screen for the RS factor defied these cautious warnings.

Both psychologists' theories implied an evolutionary hierarchy among different genotypes or phenotypes, even though McManus did not support the idea that certain "risks" and pathologies were associated with particular handedness types. Most obviously, the concept of heterozygote advantage in both models indicated that mixed genotypes are fitter than the homozygous population. Furthermore, both models contained

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550 Rose, *Politics*, 5–7.
551 Rose and Abi-Rached, *Neuro*, 197.
552 See also footnote 55.
553 Dorothy Nelkin, "The Social Power of Genetic Information," in Kevles; Hood, *The Code of Codes*, 189–90. See also Tom Shakespeare, "The Dilemma of Predictable Disablement: A Challenge for Families and Society," in Ellison; Goodman, *The Nature of Difference*.
554 Duster, *Backdoor*.

mechanisms to modulate the strength of the laterality gene. Annett claimed that the Right Shift was stronger in singletons and women than in twins and men, and McManus hypothesized that a recessive factor inhibited the expression of the dextral allele *D* more often in males than in females. These amendments allowed the psychologists to distinguish between different kinds of humans along various intertwined categorical lines, including sex/gender, circumstances of birth, and handedness.

The science of left and right brains and hands furthermore illustrates the entanglement and hierarchization of different classification systems that Haraway has pointed to in her article "Primatology is Politics by Other Means."[555] Annett's RS theory was a conceptual intervention that separated carriers of the RS factor from non-carriers, twins from singletons, and females from males in hierarchical orders. If only carriers of the RS factor were responsible for the characteristically human shift to the right, then non-carriers would show the same distribution as non-human primates, a normal bell curve that peaks at zero. Even though this is not necessarily a proclamation of the pathological nature of left-handedness, it certainly hints at a de-humanization of non-carriers of the RS factor.[556] Similarly, if the RS factor were expressed less strongly in twins than in singletons, then twins would be, however gently, placed on a lower level of an imagined mammalian hierarchy than singletons. Likewise, if the shift were stronger in women than in men, then the latter would be closer to non-human animals on a metaphorical evolutionary tree.

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[555] Haraway, "Primatology".

[556] The implication of inferiority is inherent in human-ape comparisons, and this comparative approach does not necessarily contribute to our understanding of human characteristics; Jonathan Marks, "The Scientific and Cultural Meaning of the Odious Ape-Human Comparison," in Ellison; Goodman, *The Nature of Difference*.

Similarly, the McManus-Bryden model suggested that *D* would cause fewer males than females to be right-handed, although both populations presumably have the same ratio of *D* carriers. Because males are supposedly more susceptible to the inhibiting allele, the directive force of the *D* allele would be overwritten in males more often than in females. Hence, handedness in the male population would be less often genetically determined and more susceptible to environmental influences. The logical consequence would be that women are less malleable than men, at least regarding laterality.[557]

The idea that women are less malleable than men is as much a reversal of certain classical gender stereotypes as Annett's implication that men, by virtue of experiencing a smaller Right Shift, are closer to nature than women (though it perfectly aligns with the notion of Male as the standard, the norm, or the unmarked category against which Female is seen to be deficient). Conversely, the lesser malleability of female handedness means that women's hand characteristics are more strongly genetically determined than men's. This latter view is reminiscent of the old doctrine that males as a group are particularly variable, encompassing the "good" and "bad" extremes, while females are a more homogenous group—or average.[558]

Even the partial history of genetic handedness concepts presented here resists a clear mapping of left/right onto male/female, culture/nature, or any other binary classification construct. As Haraway observed, binary classifications do not erect static hierarchies.[559] They can be combined in many ways to create fresh iterations of traditional

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[557] On the history of the concept of the malleable woman within the brain and mind sciences, see Cornel, "Matters"; Malane, *Sex*; Matlock, *Scenes*; Russett, *Sexual*.
[558] Shields, "Variability".
[559] Haraway, "Primatology," 491.

origin stories. The categories and their hierarchical connotations are flexible in their application, but crucial as load bearers in the construction of a natural world order.

Besides crafting origin stories, McManus's and Annett's theories functioned as technologies to tell humans from non-humans. By adhering to Broca's doctrine of the connection between handedness and the speech center, the psychologists constructed anthropological machines in the Agambenian sense.[560] McManus's and Annett's theories were "man"-making machines in the sense that they demarcated human from non-human characteristics by associating the hand with articulate speech. Unlike nineteenth-century versions of human laterality, however, the psychologists' new anthropological machines relied no longer on a metaphysical concept of individual human superiority but on computerized statistics.

The history of laterality research demonstrates that it is not true, as Agamben suggested, that the anthropological machine was "idling" in the late twentieth and early twenty-first centuries.[561] After the World Wars, Agamben argued, industrialized societies found themselves in a "post-historic" state, which was characterized by the substitution of "poetry, religion, [and] philosophy" for exploitative economic enterprises and the global scientific "management" of life.[562] The history of handedness shows that the anthropological machine was alive and well in the late twentieth century, even if its fuel had taken on the form of big data and handedness statistics.

[560] On the delineation of human language from other signifying systems, see footnote 30.
[561] Agamben, *Open*, 80.
[562] Agamben, *Open*, 75–77.

The Computer as a Research Tool

Oldfield's (and his colleagues') quest to quantify entities of psychological interest, including handedness, can best be understood against the backdrop of a longer tradition of "trust in numbers."[563] Historian of science Theodore M. Porter argued that quantification has become increasingly valued by scientists, engineers, politicians, and the broader public since the early nineteenth century. Numbers, Porter explained, have become a means of communicating allegedly objective assessments. Quantification seemingly eradicates scientists' subjectivity on two levels: first, it allows the researchers to distance themselves from the object under investigation; second, it enables consumers of this knowledge (in particular larger institutions and governments) to abstract the facts from the concrete conditions of their productions. Quantified knowledge appears broadly applicable across space and time.

Annett and McManus relied heavily on statistics to extract meaning from their quantified handedness data. Whereas Oldfield's statistics had aimed at describing population-wide manual preference, Annett and McManus used statistics to determine the parameters for their causal theories of handedness and brainedness. The two younger psychologists' increasing reliance on statistics paralleled the importance of probability within their genetic models, and it reflected the necessity to analyze a growing mass of heterogeneous data. Philosopher of science Ian Hacking has traced the epistemic power of statistics back to the early nineteenth century.[564] What set Oldfield, Annett, and most

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[563] Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton: Princeton University Press, 1995).
[564] Hacking, *Taming*; Hacking, *Emergence*.

of all McManus apart from Hacking's pre-twentieth century statistics was the psychologists' use of computers.

Neither Oldfield nor Annett had *relied* on computerized data analysis to craft their theories; they *used* the machines to operationalize tedious calculations. In part, this methodological difference was a matter of institutional affiliation. Annett worked mostly in her computer-free home. The calculations for her parameters were rooted in her theory, not in electronically analyzed piles of data. Moreover, she had only occasional help from individual computer scientists or hobby programmers, including her son James.[565] Oldfield was similarly unversed in these technologies. He counted on the support of Alastair Kinloch (1943/44–2013?) to use the punched-card computer, and the acclaimed mathematician Richard M. Cormack (b. 1935) advised him on his statistics.[566]

Although Annett saw computers as calculators rather than creative apparatuses, these technologies left undeniable marks on her research. In a controversial publication from 1967, Annett claimed that there are three different handedness phenotypes (left, mixed, right), and that manual preference is a continuous, not a binary, variable.[567] To account for mixed-handers, she developed the aforementioned handedness questionnaire that allowed for three different responses to questions on preferred hand use in a wide range of tasks: "left," "right," or "either."[568] For her most widely cited paper, Annett used an association analysis to hone the distinction between these three handedness

565 Marian Annett, interview by Tabea Cornel.
566 Oldfield, "Assessment," 110.
567 Annett, "Binomial",
568 Annett, "Binomial," 329.

phenotypes.[569] The calculations of this advanced statistical method were supposed to determine the correlation between hand preference and different manual tasks.[570]

To carry out the association analysis, Annett translated her handedness theory into computer logic. The analysis was meant "to demonstrate that hand preference is distributed continuously and not discretely."[571] Nevertheless, in the process of the analysis, Annett disregarded her conviction that handedness was a non-binary category and organized her data in *two* groups. M.J. Norman of the University Sub-Department of Computation at the University of Hull collaborated with Annett on the association analysis, but "he made no decisions."[572] Annett defined the analytical categories and Norman wrote the code. At first, Annett experimented with the possible handedness distinctions of "left" vs. "not left," "right" vs. "not right," and "either" vs. "right or left." She eventually settled for the division between "left" and "not left" because it provided her with the most statistically significant associations.[573]

The inconsistent classification of hand preference permeated Annett's work throughout her career. Annett herself did not see a problem in using a binary categorization to advance her argument of the existence of a mixed-handed phenotype, let alone the continuous distribution of manual preference. When Annett's colleagues suggested that her switching between dichotomous and trifold handedness classifications undermined

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569 Marian Annett, "A Classification of Hand Preference by Association Analysis," *British Journal of Psychology* 61, no. 3 (1970), https://doi.org/10.1111/j.2044-8295.1970.tb01248.x.
570 Association analyses uncover relationships in large data sets and distinguish them from random effects. The method became popular in genetic studies of the mid-twentieth century; W. J. Ewens and R. S. Spielman, "Locating Genes by Linkage and Association," *Theoretical Population Biology* 60, no. 3 (2001): 136–37, https://doi.org/10.1006/tpbi.2001.1547.
571 Annett, "Classification," 303.
572 Marian Annett, interview by Tabea Cornel.
573 Annett, "Classification," 309. On how (not) to program non-binary categories in binary code, see Rena Bivens, "The Gender Binary Will Not Be Deprogrammed: Ten Years of Coding Gender on Facebook," *New Media & Society* 19, no. 6 (2017), https://doi.org/10.1177/1461444815621527.

the credibility of her work, and that she should decide on one of the two frameworks, she responded in scare quotes: "Oh yes I can [have it both ways], if that is what the empirical findings demand."[574]

The quarrel surrounding Annett's use of computers brings out the gender aspect to the confrontations between Annett and her colleagues most clearly. The critiques of Annett's work are best understood against the backdrop of the deeply rooted and longstanding marginalization of women in "male" professional domains. Annett had already acted up by becoming a working-class-raised woman scientist, and by leaving the province of developmental psychology, a relatively women-friendly subfield since the early twentieth century.[575] On top of that, Annett pushed into the male domain of electronic computers.[576] Instead of transferring the authority of masculine rationality to Annett's model, the use of computers further destabilized Annett's standing.

To McManus, computers were more than calculators. As statistical machines, they were unveilers of truth. McManus started using punched cards during his undergraduate studies, an opportunity that neither Annett nor Oldfield had had for reasons of age.[577]

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574 Annett, "Fertility," 636.

575 In the early twentieth century, relatively women-friendly scientific subfields evolved. Developmental psychology was one of them, because the work with children seemed to cater to women's purportedly nurturing personalities; see, e.g., Rossiter, *Women*, ch. 3.

576 Computer programming became an increasingly male domain over the course of the 1950s and 1960s. Hand in hand with the masculinization of the programmer, digital technologies and code itself became endowed with an aura of rationality and detachment, that is, masculinity; e.g., Alison Adam, *Artificial Knowing: Gender and the Thinking Machine* (London, New York: Routledge, 1998); Nathan Ensmenger, "Making Programming Masculine," in *Gender Codes: Why Women Are Leaving Computing*, ed. Thomas J. Misa (Hoboken: J. Wiley & Sons, 2010); Nathan Ensmenger, "'Beards, Sandals, and Other Signs of Rugged Individualism': Masculine Culture within the Computing Professions," *Osiris* 30, no. 1 (2015), https://doi.org/10.1086/682955. On the continued gendering of software, see . On "software's and computing's gendered, military history," see Chun, *Programmed*, chs. 1 and 2 (quote on p. 29). On the impossibility of mapping the programmer/software divide onto the male/female binary, see Chun, *Programmed*, 29–34.

577 McManus, "Determinants," 768.

McManus's ability to access the computers at the University of Cambridge added to the oftentimes very technical nature of his work and the sometimes very formal models.[578]

One assumption unites most of McManus's publications, including those outside of laterality research: the conviction that more data and proper statistical analyses can help distinguish between unjustified stereotypes and real circumstances, or between visible manifestations and underlying biological processes. For example, McManus intended to design an "optimal handedness questionnaire"[579] using multiple regression and association analyses.[580] In theory, McManus's association analysis did not differ much from Annett's, but the attempt to design a universally superlative questionnaire surpassed all of Annett's efforts, let alone Oldfield's pragmatic inventory.

While Annett could execute some of her calculations by hand (at home, over the course of several days),[581] the complexity of McManus's calculations required digital methods from the start. In the 1970s and early 1980s, many scientists hesitated to embrace computers, but not McManus.[58217] To formulate his genetic model, McManus depended heavily on "corrections" of the data (for instance, to offset response biases or measurement errors), and on successively "fitting" the model to the data.[583] In non-technical terms, this means that McManus smoothed the data set, then guessed the parameters of his model, and finally tested them against the pre-processed data. He relied on current

[578] McManus, "Determinants," 14.
[579] McManus, "Determinants," 60.
[580] McManus, "Determinants," 36–63. Multiple regressions predict the values of unknown variables based on the known values of multiple other variables.
[581] Marian Annett, interview by Tabea Cornel.
[582] On the slow adoption of computers within biology and related sciences after World War II, see November, *Biomedical*; Stevens, *Life*. Even the cracking of the genetic code in the 1960s depended in large parts on wet technologies; Kay, *Who*.
[583] McManus, "Determinants," 249–254; 273–285.

statistical conventions for calculating the model's "goodness of fit" with the data.[584] If the discrepancy between the predictions and the actual data was too large, McManus modified his model and tested again.[585]

It might be surprising that McManus charged Annett with defining her parameters based on theoretical predictions instead of empirical observations considering his own flexible approach to numbers.[586] Anticipating critiques of his procedure, McManus emphasized that his modifications were not arbitrary. He maintained that some models, including immature versions of his own theory, did not fit the corrected data. Hence, McManus argued, his measures for goodness of fit were in fact decisive. Moreover, when he tested his model on false data sets, the statistical measures indicated poor fit. McManus took this as additional support for his model, which he had designed to fit supposedly correct, not inappropriate, data sets.[587]

McManus's trust in computer-generated numbers had its limits.[588] For the first version of his model, McManus used chi-squared tests to illustrate the superiority of his model over other theories. However, proving the advantage of the McManus model was not entirely straight-forward. The statistical test did not single out McManus's formula as the superior one. A much older Mendelian model remained in the competition for the best

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[584] McManus, "Determinants," 259–62.
[585] McManus, "Determinants," 227–40. On the malleability of statistics, see, e.g., Regina Nuzzo, "How Scientists Fool Themselves—and How They Can Stop," *Nature* 526, no. 7572 (2015), https://doi.org/10.1038/526182a; Cathy O'Neil, *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy* (New York: Crown, 2016); Tom Siegfried, "Odds Are, It's Wrong: Science Fails to Face the Shortcomings of Statistics," *Science News* 177, no. 7 (2010), https://doi.org/10.1002/scin.5591770721; Stephen Thomas Ziliak and Deirdre N. McCloskey, *The Cult of Statistical Significance: How the Standard Error Costs Us Jobs, Justice, and Lives* (Ann Arbor: University of Michigan Press, 2008).
[586] McManus, "Determinants," 242–43.
[587] McManus, "Handedness," 29.
[588] McManus, "Determinants," 249–256; 348–357.

fit.[589] McManus ascribed this ambivalence to a lack of data, not to the inappropriateness of his theory. Only after the statistical methods had failed to provide sufficient evidence for the superiority of his own theory, he tried to find an advantage of his model by drawing on its concrete biological implications. McManus concluded that his formula was superior because it contained a chance element and thus left room for environmental influences.

While McManus did not entirely trust a computer to identify the best handedness model, he believed that machines could reveal "true" hand preference, which might be hidden under the surface of cultural pressures for left-handers to use the right hand. McManus used computerized corrections to account for this right-bias in the data.[590] Several years later, he adjusted the original parameters. McManus derived the new figures with the help of a maximum likelihood analysis, which was more popular than the initially used chi-squared test.[591] Furthermore, he used a goodness of fit analysis to determine 7.75 percent as "the true incidence of left-handedness," as opposed to the—supposedly smaller—incidence of "manifest left-handedness."[592]

The conviction that more data and proper computerized statistical analyses could help distinguish between common stereotypes and "real" phenomena, or between superficial manifestations and their biological foundations, permeated McManus's publications in laterality research and beyond. To McManus, quantification was not *only* a "technology of distance" or a means to defend his "objectivity" and "impersonality" against

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[589] This model was Trankell, "Aspects".
[590] McManus, "Determinants," 273–75.
[591] McManus explained that the maximum likelihood procedure relied on a broader data set than the chi-squared test; McManus, "On," 31–34. On whether the maximum likelihood method is superior to a chi-squared test, see Joseph Berkson, "Minimum Chi-Square, Not Maximum Likelihood!" *Annals of Statistics* 8, no. 3 (1980), https://doi.org/10.1214/aos/1176345003.
[592] McManus, "Handedness," 7; 16.

critics, as Porter suggested for other quantification projects in the twentieth century.[593] To McManus, they were guiding helpers and truth-generative devices.

McManus effectively utilized the latest technologies to gain trust for his work on two different levels. He did not engage in fully "mechaniz[ed]" modes of proof as illustrated in sociologist Donald A. MacKenzie's work.[594] By employing current statistical tests and operationalizing them on a computer, McManus united the authoritative potential of the traditional social-mathematical *and* the novel formalized-mechanized proving cultures. He personified the well-educated white male scientist who knew his numbers, while the computer seemed to fit the model for him in an allegedly objective way that was empirically testable and could be visualized on colorful printouts.[595]

The differing levels of acknowledgement that Annett and McManus received for their use of computers is best understood in the context of media theorist Wendy H.K. Chun's analysis of computers as "mediums of power."[596] Chun suggested that computers simultaneously empower their users and mirror existing power dynamics. For Annett, the latter characteristic outweighed the former. Annett was already marginalized as a female psychologist without a professorship, she had never been educated in the use of computers, did not have immediate access to them, and the male-coded machines did not confer the power and authority on her that she was seeking. In contrast, McManus began using computers during his undergraduate education, honed his skills in using them, and his credibility benefitted significantly from his computational analyses.

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[593] Porter, *Trust*, IX.
[594] Donald A. MacKenzie, *Mechanizing Proof: Computing, Risk, and Trust* (Cambridge: MIT Press, 2001).
[595] MacKenzie, *Mechanizing*, 299–334.
[596] Chun, *Programmed*, xii.

Conclusion

Chris McManus and Philip Bryden remarked in 1992 that "[n]either the Annett nor McManus model originally considered sex differences, and neither model in its original form dealt readily with the two important pieces of evidence suggesting sex differences in the inheritance of handedness."[597] The authors were referring to the excess of right-handers in females as well as the comparably low rate of paternal inheritance of left-handedness. Together with the (controversial) discrepancy of left-handedness between twins and singletons, these unexplained data drove handedness research in the twentieth century. Issues of sex/gender and kinship left their mark on genetic theories of handedness. At first, these puzzles challenged psychological theories of handedness. Step by step, however, incorporating these questions allowed researchers to negotiate the social order through allegedly unpolitical claims about the meaning of these handedness data. Needless to say, it was a laborious process.

From the 1980s onwards, genetic handedness theories were challenged by hormonal models (Chapter 4). The controversy between the genetically oriented psychologists and the testosterone-focused neurologists heightened the sexiness of laterality as a research topic. "Sexy" applies here in both the literal and the figurative sense. In a figurative sense, the entire field gained more popular recognition and increased funding through these controversies. In a literal sense, sex had never been more overtly linked with handedness than under the hormonal paradigm. Annett and McManus paved the way for a testosterone-related theory of manual preference by effectively molecularizing

[597] McManus and Bryden, "Genetics," 131.

questions of kinship and sex/gender that had been looming over previous anatomico-physiological and Mendelian models of handedness.

It is ironic that the computer, the very tool that made Annett's and McManus's theories possible, also shattered them. Neither Annett's nor McManus's (or any other) genetic model for handedness held up over time. One century after the creation of the first Mendelian model of handedness,[598] McManus and colleagues performed a large-scale computer-based analysis of thousands of genetic twin data sets, more than had ever been accessible before.[599] The analysis determined that there cannot be a handedness gene. According to McManus and colleagues, the possibility exists that handedness is caused by a stable polymorphism or that various handedness genes run in specific families, but no single gene can explain the data. Annett, however, has not yet conceded defeat. She is still waiting for an empirical confirmation of her model.[600] The rest of the world seems to agree that neither Annett's RS factor nor McManus's dexterity and chance alleles can remain standing after their confrontation with the twentieth century's Nemean Lion: gigantic data sets treated with large-scale data processing.[601]

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598 Jordan, "Inheritance".
599 John A. L. Armour, Angus Davison, and Ian C. McManus, "Genome-Wide Association Study of Handedness Excludes Simple Genetic Models," *Heredity* 112, no. 3 (2014), https://doi.org/10.1038/hdy.2013.93; Ian C. McManus, Angus Davison, and John A. L. Armour, "Multilocus Genetic Models of Handedness Closely Resemble Single-Locus Models in Explaining Family Data and Are Compatible with Genome-Wide Association Studies," *Annals of the New York Academy of Sciences* 1288 (2013), https://doi.org/10.1111/nyas.12102.
600 Marian Annett, interview by Tabea Cornel.
601 For an example of researchers who moved on, see Sebastian Ocklenburg et al., "The Genetics of Asymmetry: Whole Exome Sequencing in a Consanguineous Turkish Family with an Overrepresentation of Left-Handedness," *Symmetry* 9, no. 5 (2017), https://doi.org/10.3390/sym9050066.

CHAPTER 4

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FIXING THE PLASTIC BRAIN: TESTOSTERONE AS A BRIDGE BETWEEN NATURE AND NURTURE IN HORMONAL THEORIES OF LATERALITY IN THE LATE TWENTIETH CENTURY

> [M]uch of the messianism associated with glandular science stemmed from its message that the body was modifiable—significantly, if not infinitely, and in relatively painless ways. The new body, at the physiological level, was far more complex than the older, pre-glandular one, but it was also far more plastic, far more modifiable. The grounds for such modifications were, of course, shaped in large measure by cultural, moral, and social imperatives ... but the means were dazzlingly modern and scientific.[602]

> [L]eft-handers did not quietly wither away. They survived. Why? Because … they do not choose their preference; they follow a neurological imperative.[603]

Introduction

While English psychologists were still negotiating genetic theories of handedness, neurologists in Boston and Glasgow postulated that hormones were the crucial

[602] Sengoopta, *Most*, 6.
[603] Jeannine Herron, "Preface," in Herron, *Neuropsychology of Left-Handedness*, xiii–xiv.

determinants of brain asymmetry and manual preference.[604] The so-called Geschwind-Behan-Galaburda (GBG) model of cerebral lateralization specified the ways in which prenatal testosterone exposure supposedly determines a vast range of physical, mental, cognitive, and behavioral characteristics. According to the model, too much testosterone *in utero* would lead to decreased brain asymmetry, left-handedness, immune disorders, and other "abnormalities." The model was named after its creators. Norman Geschwind (1926–1984), James Jackson Putnam Professor of Neurology at Harvard Medical School, took the lead in developing the model.[605] Geschwind was a clinical neurologist at the Beth Israel Hospital in Boston (now the Beth Israel Deaconess Medical Center). He was supported by Albert M. Galaburda (b. 1948), an Assistant Professor at Beth Israel. Peter O. Behan (b. 1935), a lecturer at the University of Glasgow, collaborated with Geschwind on a population study about handedness, although he was not involved in the detailed 1985 publication.[606]

The GBG model perpetuated the concept of the deviant left-hander and the idea that the hand is a proxy for the brain. The neurologists did not consistently distinguish between brain asymmetry, its major cause (prenatal testosterone), and its manifest

[604] Norman Geschwind and Albert M. Galaburda, "Cerebral Lateralization—Biological Mechanisms, Associations, and Pathology I: A Hypothesis and a Program for Research," *Archives of Neurology* 42, no. 5 (1985), https://doi.org/10.1001/archneur.1985.04060050026008; Norman Geschwind and Albert M. Galaburda, "Cerebral Lateralization—Biological Mechanisms, Associations, and Pathology II: A Hypothesis and a Program for Research," *Archives of Neurology* 42, no. 6 (1985), https://doi.org/10.1001/archneur.1985.04060060019009; Norman Geschwind and Albert M. Galaburda, "Cerebral Lateralization—Biological Mechanisms, Associations, and Pathology III: A Hypothesis and a Program for Research," *Archives of Neurology* 42, no. 7 (1985), https://doi.org/10.1001/archneur.1985.04060070024012. For an overview of competing hormonal theories of laterality in the twentieth and twenty-first centuries, see Porac, *Laterality*, 71–85.
[605] Geschwind and Galaburda, "Cerebral," 428.
[606] Steven C. Schachter mentioned that he (Schachter) was also involved in Geschwind's handedness research, although no co-authored publications seem to have sprung from this collaboration; Steven C. Schachter, "Handedness Measurement and Correlation with Brain Structure," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 258.

behavioral consequence (handedness). As such, unusual physical asymmetries, developmental brain insults, immune disorders, and non-right-handedness served as stand-ins for one another. The neurologists speculated that any "abnormality" that was related to at least one of the four was in fact a consequence of excessive testosterone levels *in utero*.

Akin to playing dominoes, some of the GBG model's hypotheses relied on numerous links between more or less closely associated conditions to connect widely disparate phenomena. For example, the neurologists relied on observed correlations between left-handedness, aphasia, and early-onset Alzheimer's disease to suggest that left-handers had delayed speech development and were prone to learning disorders and immune disease.[607] The GBG model constructed hierarchically ordered brain types by connecting in this fashion prenatal testosterone exposure, brain development, and handedness with cognitive abilities, psychiatric conditions, and stereotypically charged characteristics. In doing so, the model naturalized social categories of race/ethnicity, sex/gender, sexual orientation, as well as mental and physical dis/ability.

The GBG model further naturalized stereotypical assumptions about sex/gender and sexual orientation by elevating testosterone, the alleged "male hormone,"[608] to a major factor in the development of the brain and immune system. In a patronizing fashion, the GBG model established connections between testosterone, "anomalous" dominance, and the female body, seemingly promising new therapeutic venues to combat gynecological disorders. Although the authors mentioned that their model was a highly speculative

[607] Geschwind and Galaburda, "Cerebral," 637.
[608] Paul de Kruif, *The Male Hormone* (New York: Harcourt, Brace and Company, 1945); N.N., Male Hormone Linked to Left Handedness, Autoimmune Disease, 1982-10, H MS c435, Box 4, Folder 25, Dyslexia, undated, Center for the History of Medicine, Francis A. Countway Library of Medicine.

"work in progress,"[609] its alignment with brain organization theory endowed it with immediate authority.

Brain organization theory rose to fame during the 1960s, and it still has numerous supporters.[610] According to this theory, prenatal testosterone exposure wires the brain for sex, gender, and sexual orientation. Generations of feminist scholars have criticized brain organization theory for its discriminatory potential and lack of empirical rigor.[611] Similar to brain organization theory, the GBG model was highly appealing to Cold War audiences who longed for stability and looked to science for the validation of traditional social structures. The GBG model's reinforcement of "Western"-centric, ableist, heteronormative values offered consolation to those terrified of communism, fascism, and the dismantling of pre-war understandings of masculinity.[612]

Although Geschwind was a clinical neurologist, his theory of handedness was even farther removed from tangible hands and brains than Marian Annett's (b. 1931) and I.C. (Chris) McManus's (b. 1951) statistical analyses of hypothetical handedness genes (Chapter 3). Geschwind and Galaburda did not conduct experiments with patients or laboratory animals,[613] and Behan and Geschwind carried out only three studies on the

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[609] Kushner, *On*, 99.
[610] See, e.g., Melissa Hines, "Gender Development and the Human Brain," *Annual Review of Neuroscience* 34 (2011), https://doi.org/10.1146/annurev-neuro-061010-113654.
[611] The most notable feminist critiques of the brain organization theory include Ruth Bleier, *Science and Gender: A Critique of Biology and Its Theories on Women* (New York: Pergamon Press, 1984); Jordan-Young, *Brain*; van den Wijngaard, Marianne, *Reinventing the Sexes: The Biomedical Construction of Femininity and Masculinity* (Bloomington: Indiana University Press, 1997).
[612] On the political importance of sex, gender, and sexuality during the Cold War, see, e.g., Catherina Gere, "Plasticity, Pathology, and Pleasure in Cold War America," in Bates; Bassiri, *Plasticity and Pathology*; David K. Johnson, *The Lavender Scare: The Cold War Persecution of Gays and Lesbians in the Federal Government* (Chicago: University of Chicago Press, 2004); Carolyn Herbst Lewis, *Prescription for Heterosexuality: Sexual Citizenship in the Cold War Era* (Chapel Hill: University of North Carolina Press, 2010); Philip E. Muehlenbeck, ed., *Gender, Sexuality, and the Cold War: A Global Perspective* (Nashville: Vanderbilt University Press, 2017); Vicedo, *Nature*; Deborah Weinstein, *The Pathological Family: Cold War America and the Rise of Family Therapy* (Ithaca: Cornell University Press, 2013).
[613] Albert M. Galaburda, interview by Tabea Cornel, July 17, 2017, Boston.

correlations between handedness, migraine, learning disorders, and immune disorders.[614] The most significant inspiration for the GBG model was Geschwind's extensive review of the scientific literature in the late 1970s and early 1980s.[615] Geschwind reviewed hundreds of publications in English, German, French, and Spanish from disciplines ranging from anatomy to zoology. Virtually crafting a Grand Unified Theory of human deviance, Geschwind theorized potential connections between handedness, brainedness, and symptoms he encountered in his patients based on over a century worth of scientific publications.

Because the GBG model was a synthesis of research from a wide range of times, places, and disciplines, it combined numerous different concepts of "the brain." Geschwind and colleagues simultaneously mobilized and glossed over the epistemic differences in the studies they drew on. They relied on multiple concepts of "the brain" to find data for their hypothetical model. Within each of these different approaches to the brain, researchers had employed diverse methods, from questionnaires to behavioral experiments and from technological monitoring to invasive procedures. Yet, Geschwind and colleagues referred to all these disparate concepts as "the brain"; they had to convey a homogeneity of epistemic concepts to justify the synthesis of this vast set of literature.

The method of decontextualized synthesis came at a price. The reliance on a brain multiple led Geschwind and colleagues to endorse seemingly contradictory concepts of

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[614] The results of both studies were published in the same paper; Norman Geschwind and Peter O. Behan, "Left-Handedness: Association with Immune Disease, Migraine, and Developmental Learning Disorder," *Proceedings of the National Academy of Sciences of the United States of America* 79, no. 16 (1982).

[615] Geschwind read all the reviewed literature and established conceptual links between the topics. Galaburda read much less and discussed Geschwind's ideas with him. The writing process was very collaborative, as the authors revealed in their article: "Although we have worked closely we have each taken special responsibility for certain sections, A.M.G. for sections dealing with normal development of the brain, asymmetry of the human brain, asymmetries in other species, and pathology of asymmetry in developmental disorders, and N.G. for the remaining sections"; Geschwind and Galaburda, "Cerebral," 428.

plasticity (nurture) and fixity (nature). On the one hand, the GBG model championed further research on therapeutic plasticity, in this case, potential hormonal reversals of unfavorable brain developments *in utero*. Furthermore, Geschwind integrated aspects of state-of-the-art research on adult neurogenesis into the model, thereby supporting the idea that neither brain structure nor function are fixed in adulthood. On the other hand, Geschwind adhered to traditional ideas of the strict localization of brain functions, which at times bordered on phrenological frameworks. The GBG model also essentialized behavioral differences as innate brain characteristics.

The neurologists employed the ambiguity of testosterone to bridge the epistemic divide between the fixed and the plastic brain. Resonating with a plastic interpretation, Geschwind and colleagues presented hormones as chemical agents of dynamic change whose levels fluctuate in every organism. In favor of concepts of fixity, the neurologists portrayed testosterone as a strictly sexed and gendered substance that is closely associated with ideas of innate sex/gender. Moreover, they explained that only some tissues in circumscribed areas of the brain contained testosterone receptors, and that the efficacy of the hormone depended on this genetically mediated prerequisite. In conceiving of testosterone in this ambiguous fashion—as an agent of genetically stimulated, chemically induced, anatomically circumscribed, long-lasting modifications of the brain and the rest of the body—testosterone functioned as a scientific mediator between the seemingly incommensurable views of a natural fixed brain and a nurtured plastic brain. The neurologists marketed their theory as a counter-proposal to genetic determinism despite the GBG model's deliberate reductionism and its strong tendencies towards biological essentialism.

The Authors

The main promoter of the theory that left-handedness is a marker of left-hemispheric underdevelopment, Norman Geschwind, "was strongly right-handed."[616] His students and colleagues described him as an avid scholar and a kind person who was "enthusiastic but gentle, knowledgeable but thoughtful, imaginative but pragmatic, and serious but playful."[617] Geschwind is also remembered as a dedicated teacher and as a person who was "generous with his time ...[,] his knowledge," and his material resources.[618] This generosity was reflected in Geschwind's bedside manners. On daily rounds through the

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[616] Albert M. Galaburda, E-mail to Tabea Cornel, July 21, 2017. Unless otherwise noted, Geschwind's biographical information is taken from Antonio R. Damasio, "Norman Geschwind (1926–1984)," *Trends in Neurosciences* 8 (1985), https://doi.org/10.1016/0166-2236(85)90139-0; Antonio R. Damasio and Albert M. Galaburda, "Norman Geschwind," *Archives of Neurology* 42, no. 5 (1985), https://doi.org/10.1001/archneur.1985.04060050102019; Orrin Devinsky, "Norman Geschwind: Influence on His Career and Comments on His Course on the Neurology of Behavior," *Epilepsy & Behavior* 15, no. 4 (2009), https://doi.org/10.1016/j.yebeh.2009.04.029; Albert M. Galaburda, "Norman Geschwind: 1926–1984," *Neuropsychologia* 23, no. 3 (1985), https://doi.org/10.1016/0028-3932(85)90016-8; Howard I. Kushner, "Norman Geschwind and the Use of History in the (Re)Birth of Behavioral Neurology," *Journal of the History of the Neurosciences* 24, no. 2 (2015), https://doi.org/10.1080/0964704X.2014.950094; M.-Marsel Mesulam, "Norman Geschwind, 1926–1984," *Annals of Neurology* 18, no. 1 (1985), https://doi.org/10.1002/ana.410180119; F. Morrell, "Norman Geschwind 1926–1984: An Appreciation," *Neurology* 35, no. 5 (1985), https://doi.org/10.1212/WNL.35.5.660; Steven C. Schachter and Orrin Devinsky, eds., *Behavioral Neurology and the Legacy of Norman Geschwind* (Philadelphia: Lippincott-Raven Publishers, 1997); Walter H. Waggoner, "Norman Geschwind, 58, Dies; Studied Architecture of Brain," *New York Times*, November 9, 1984, accessed March 15, 2019, http://www.nytimes.com/1984/11/09/obituaries/norman-geschwind-58-dies-studied-architecture-of-brain.html. Furthermore, I have drawn on documents in Geschwind's archival collection that provide more detailed insight into his career; Norman Geschwind, International Fellowship Application, December 31, 1974, H MS c435, Box 7, Folder 9, London Fellowship, 1974, Center for the History of Medicine, Francis A. Countway Library of Medicine; Norman Geschwind, Geschwind to London, January 7, 1981, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine; Norman Geschwind, Biographical Sketch, 1982, H MS c435, Box 5, Folder 7, Frontal Lobes, undated, Center for the History of Medicine, Francis A. Countway Library of Medicine; Norman Geschwind, Biographical Sketch, n.d., H MS c435, Box 2, Folder 8, Permissions, 1971–1977, Center for the History of Medicine, Francis A. Countway Library of Medicine; Schachter and Devinsky, *Behavioral*.

[617] Damasio and Galaburda, "Norman," 504; Robert J. Joynt, "A Darlin' Man," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 4; Mesulam, "Norman," 100; Michael Ronthal, "Teacher," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 36.

[618] Robert J. Joynt, "A Darlin' Man," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 4.

neurological ward, where Geschwind often encountered disoriented or intoxicated patients, he was always polite and respectful.[619]

Geschwind came from modest circumstances. He was born in New York City to emigrants from Polish Galicia in 1926. He had one brother, and their father died when Norman was four years old. His mother worked at a department store to bring the family through the Great Depression. Geschwind's Latin teacher at Boys High School encouraged him to apply to Harvard. He did so successfully, and in 1942, he commenced his undergraduate studies. After two years in college, Geschwind served in World War II, first in Germany and Czechoslovakia, and later in the Army of Occupation in Japan.

Geschwind graduated in 1947 with an A.B. in Medicine from Harvard College, and he obtained his M.D. from Harvard Medical School in 1951. After an internship at the Beth Israel Hospital in Boston, Geschwind spent three years in London at the National Hospital, Queen Square, where he worked primarily on neuromuscular disorders.

While in England, Geschwind also developed his relationship with Patricia Dougan, a British nurse whom he had met while stationed in Japan. Upon his return to Boston in 1956, the couple got married, and eventually had three children.[620] Patricia repeatedly accompanied Norman to conferences and workshops. Like numerous other twentieth-century scientists' wives, she prepared the bibliography for the 1985 publication.[621]

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[619] See, e.g., Kenneth M. Heilman, "Educator," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*.
[620] Albert M. Galaburda, interview by Tabea Cornel.
[621] Geschwind and Galaburda, "Cerebral," 652. See the related conversation that started with literary studies scholar Bruce Holsinger's use of #ThanksForTyping on Twitter; Cecilia Mazanec, "#ThanksForTyping Spotlights Unnamed Women In Literary Acknowledgments," accessed March 15, 2019, https://www.npr.org/2017/03/30/521931310/-thanksfortyping-spotlights-unnamed-women-in-literary-acknowledgements; "#ThanksForTyping: Twitter Search," Twitter, accessed March 15, 2019, https://twitter.com/search?q=%23ThanksForTyping&src=tyah.

Back in Boston, Geschwind's career proceeded rapidly. Beginning as a Chief Resident in the Neurological Unit at Boston City Hospital, he was appointed Professor and Chairman of the Department of Neurology at the Boston University School of Medicine within ten years. Three years after this appointment, in 1969, Geschwind became the Director of the Neurological Unit at Boston City Hospital, and the James Jackson Putnam Professor of Neurology at Harvard Medical School. In 1975, Geschwind moved all other Harvard-affiliates of the Neurological Unit from the Boston City Hospital to the Beth Israel Hospital. His chair at Harvard as well as his position in the Neurological Unit were unaffected by the move.[622]

Geschwind was a renowned neurologist, who was decorated with numerous academic honors,[623] and whose publications were frequently adapted for textbooks.[624] He described himself as having dedicated his professional life to researching "the neurological bases of behavior" and "the anatomical mechanisms of the higher functions and their disorders."[625] Geschwind received wide recognition for his work on disconnection syndromes, that is, cases in which the corpus callosum (the band of nervous tissue that connects the two halves of the brain) does not allow for communication between the cerebral

[622] The correspondence in preparation for the move from Boston City to Beth Israel Hospital have been preserved, and they include negotiations about space, personnel, animal facilities, etc.; Beth Israel Hospital, 1974–1975, H MS c435, Box 1, Folder 1, Center for the History of Medicine, Francis A. Countway Library of Medicine.
[623] Geschwind, Geschwind to London, 4; Paul E. Gray, Gray to Geschwind, February 8, 1978, H MS c435, Box 7, Folder 18, Health Sciences and Technology, 1978, Center for the History of Medicine, Francis A. Countway Library of Medicine; Harvard University News Office for the Medical Area, Dr. Geschwind Joins HST Division, January 4, 1979, H MS c435, Box 3, Folder 22, Reprints, Writings, Correspondence (2 of 2), undated, Center for the History of Medicine, Francis A. Countway Library of Medicine.
[624] Permissions, 1971–1977, H MS c435, Box 2, Folder 8, Center for the History of Medicine, Francis A. Countway Library of Medicine.
[625] Geschwind, International Fellowship Application, 10.

hemispheres. Conditions like alexia, agraphia, apraxia, and aphasia are associated with callosal disconnection.[626] Geschwind died in 1984, aged 58, from a heart attack.

Geschwind's dedication to the neurobiological bases of behavior was not particularly *en vogue*. In the mid-twentieth century, the thought that neurological disorders impacted human behavior, development, and cognitive function was not widely accepted. Most psychiatrists, strongly influenced by psychoanalytic frameworks, understood deviant behavior as a purely functional abnormality, and not as a consequence of a potential neuropathology.[627]

Geschwind's collaborator on the detailed 1985 publication was Albert Galaburda, currently the Emily Fisher Landau Professor of Neurology and Neuroscience at Harvard Medical School.[628] Galaburda grew up in Chile, and he described himself as "ambidextrous but more right[-] than left[-handed]."[629] After coming to the United States in 1963, he enrolled in Medical School at Boston University in 1965. Galaburda originally intended to become an endocrinologist, because he was fascinated by the physics-like structure of the field at the time. However, while in Medical School, he attended Geschwind's renowned lectures in neurology and, after an adverse experience with an endocrinology professor, decided to become a neurologist himself.

After completing his M.D. and a medical internship, Galaburda successfully applied to Geschwind's neurology training program and for a residency at Boston City

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[626] Norman Geschwind, "Disconnexion Syndromes in Animals and Man I," *Brain* 88, no. 2 (1965); Norman Geschwind, "Disconnexion Syndromes in Animals and Man II," *Brain* 88, no. 3 (1965). Geschwind conducted some of his early work on disconnection syndromes in collaboration with US-American psychologist Edith F. Kaplan (1924–2009); Norman Geschwind and Edith Kaplan, "A Human Cerebral Deconnection Syndrome: A Preliminary Report," *Neurology* 12 (1962).
[627] Kushner, "Norman".
[628] Unless otherwise noted, Galaburda's biographical information, including all quotes in this and the following paragraph, is taken from Albert M. Galaburda, interview by Tabea Cornel.
[629] Albert M. Galaburda, E-mail to Tabea Cornel.

Hospital.[630] In 1975, he moved with Geschwind to Beth Israel Hospital, and they developed a close mentor-mentee relationship. For years, Geschwind's office was two doors down from Galaburda's, and Geschwind "would always come over and talk to [him]."[631] Galaburda summarized the relationship as follows: "[Geschwind] was my Guru ... he made me the neurologist I am."[632] Galaburda described feeling "orphaned" upon Geschwind's death.[633]

The third neurologist involved in developing the GBG model was Peter Behan, a retired British neurologist.[634] The media described him as "something of a maverick," and he retired early after controversies surrounding his credibility as a researcher and commitment to patient confidentiality.[635] In 1980, Behan came to Boston with his wife, where he worked as an Assistant Professor of Neurology at Boston University. Geschwind and Behan shared an interest in pathologies associated with left-handedness,

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[630] Geschwind developed the neurology training program together with his colleagues Charles F. Barlow and H. Richard Tyler in an attempt to educate a new generation of holistically-minded neurologists. It was one of the first neurology training programs in the United States; Charles F. Barlow, Training Program Description, March 19, 1975, H MS c435, Box 1, Folder 2, Beth Israel Hospital, 1975, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1; Albert M. Galaburda, interview by Tabea Cornel; Norman Geschwind, Geschwind to Barlow, February 25, 1975, H MS c435, Box 1, Folder 2, Beth Israel Hospital, 1975, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2.
[631] Albert M. Galaburda, interview by Tabea Cornel.
[632] Albert M. Galaburda, interview by Tabea Cornel.
[633] Albert M. Galaburda, interview by Tabea Cornel.
[634] Galaburda engaged so little with Behan that he did not remember his handedness; Albert M. Galaburda, interview by Tabea Cornel.
[635] N.N., "Professor's Future in Doubt. University Inquiry Blames Academic's Sloppy Preparation for Court Fiasco," *Herald*, August 29, 1997, accessed March 15, 2019, http://www.heraldscotland.com/news/12294532.Professor_apos_s_future_in_doubt__University_inquiry_blames_academic_apos_s_sloppy_preparation_for_court_fiasco/. See also Clare Dyer, "ME Researcher Accused of Cooking the Books," *BMJ* 315, no. 7103 (1997), https://doi.org/10.1136/bmj.315.7103.269d; Clare Dyer, "Doctor Who Revealed Patient Details Cleared by GMC," *BMJ* 321, no. 7275 (2000), https://doi.org/10.1136/bmj.321.7275.1490/c; Clare Dyer, "Judge Criticises Expert Witness for Misrepresenting Research Findings," *British Medical Journal* 324, no. 7336 (2002); Ros Wynne-Jones and Charles Arthur, "Mad Cow Doctor 'Silenced' by Hospital," *Independent*, April 27, 1996, accessed March 15, 2019, http://www.independent.co.uk/news/mad-cow-doctor-silenced-by-hospital-1307060.html.

and they agreed to conduct studies on this topic.[636] Upon Behan's return to Britain, Behan continued his career at the University of Glasgow. Geschwind occasionally visited Behan to give lectures and discuss further lines of research.[637] The two neurologists also communicated via phone and occasionally via mail.[638]

In the early 1980s, Behan and Geschwind reported significant correlations between handedness, learning disorders, immune diseases, and migraines.[639] The underlying population study of about three thousand subjects from Glasgow and London was carried out mostly under Behan's watch.[640] The study design, however, was to a large extent Geschwind's.[641] Because of Behan's collaboration with Geschwind in the 1980s, scholars have called the theory of testosterone-induced laterality the "GBG" model. Galaburda implied that this is not necessarily justified, as Behan was not involved in the 1985 publication. However, Galaburda also acknowledged that Behan's and Geschwind's collaborative studies were crucial to provide some empirical foundation, and hence additional credibility, to the otherwise highly theoretical GBG model.[642]

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[636] Peter O. Behan, "Handedness and Autoimmune Disease," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 289; "We Welcome Professor Peter Behan as Our Latest Patron," accessed March 15, 2019, http://www.meassociation.org.uk/2012/02/10372/.
[637] Peter O. Behan, "Handedness and Autoimmune Disease," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 289.
[638] Norman Geschwind, Geschwind to Nottebohm, February 8, 1984, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–3.
[639] Geschwind and Behan, "Left".
[640] Peter O. Behan, Behan to Geschwind, August 25, 1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2.
[641] Norman Geschwind, Geschwind to Behan, 10-14-1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 2. See also Norman Geschwind, Geschwind to Behan, April 26, 1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–4.
[642] Albert M. Galaburda, interview by Tabea Cornel.

The Publication

Testosterone, Brain Asymmetry, Handedness, and the Immune System

The GBG model was published in three parts in consecutive issues of the *Archives of Neurology* (today: *JAMA Neurology*). In the first part, the authors provided an overview of their argument that prenatal testosterone exposure determined brain laterality and the development of the immune system. Geschwind and Galaburda foregrounded results from their clinical observations of anatomical asymmetry in adult patients, specifically focusing on speech-related areas of the frontal lobe of the cortex.[643] The authors also referred to their colleagues' research that had found similar asymmetries in the fetus and newborn child, suggesting "the importance of genetic and/or intrauterine influences" on cerebral asymmetry.[644]

The first sentence of the three-part publication reads: "We present *a set of hypotheses* about the biologic mechanisms of lateralization, i[.]e[.], the processes which lead to an asymmetrical nervous system."[645] Throughout the eighty-five-page text, the authors referred to their hypotheses as "guess[es], "speculation[s]," or even "naive speculations."[646] Despite this rhetoric of caution and humility, Geschwind and Galaburda made many far-reaching proposals and endorsed four hitherto unpopular views of the brain and its relationship to the rest of the body.

[643] Geschwind and Galaburda, "Cerebral," 428. For a detailed overview of other cerebral asymmetries in gross anatomy, neural pathways, cytoarchitecture, and response to chemicals, see Geschwind and Galaburda, "Cerebral," 434–39. For an—at times speculative—overview of the mechanisms underlying asymmetry in the brain and other parts of the body, see Geschwind and Galaburda, "Cerebral," 439–42.
[644] Geschwind and Galaburda, "Cerebral," 428.
[645] Geschwind and Galaburda, "Cerebral," 428. Italics added.
[646] Geschwind and Galaburda, "Cerebral," 432; 438; Geschwind and Galaburda, "Cerebral," 532; 536; 539; 545; 547; Geschwind and Galaburda, "Cerebral," 642; 647; 649; 652.

First, the neurologists suggested that lateralization had important structural dimensions, while the contemporaneous default view was that laterality is a question of function only.[647] Second, questioning the supremacy of genetic handedness theories and the genomic worldview more broadly, Galaburda and Geschwind posited that these structural asymmetries were only partially caused by genetic mechanisms. According to their model, developmental factors could "modify the direction and extent of ... structural asymmetries," and "the intrauterine environment [acts] as a determinant of the pattern of asymmetries."[648]

Third, the authors hypothesized that the same forces that cause asymmetrical brain development also impacted intellectual skills, "certain talents," as well as a wide range of "bodily systems."[649] Most neurologists and psychiatrists at the time did not believe that neuropathology could cause behavioral changes or developmental disorders.[650]

Finally, the authors suggested that laterality was not only a human quality, but a shared characteristic among a wide range of animals. According to Geschwind and Galaburda, researchers before the 1970s assumed "almost universally ... that functional asymmetry simply did not exist in other species."[651]

In support of their claim that fetal testosterone could override the genetic blueprint for the structural layout of the brain, Geschwind and Galaburda summarized studies that indicated structural changes in brain tissue in response to testosterone.[652] In addition, the authors cited evidence that the left half of the brain matures more slowly in the fetus

[647] Damasio, "Norman," 388–90.
[648] Geschwind and Galaburda, "Cerebral," 428.
[649] Geschwind and Galaburda, "Cerebral," 428. For an overview of more recent investigations of the association between handedness and pathology, see Porac, *Laterality*, 135–56.
[650] Kushner, "Norman".
[651] Geschwind and Galaburda, "Cerebral," 442.
[652] Geschwind and Galaburda, "Cerebral," 431–33.

than the right hemisphere.[653] To the neurologists, this asymmetric growth indicated that fetal hormones affected the two cerebral hemispheres at different stages of their development.[654] If it were the case that testosterone impedes brain development, it would inhibit the slowly maturing left hemisphere significantly more than the faster maturing right hemisphere.[655]

The impediment to the growth of the left hemisphere is only half the story. Geschwind and Galaburda supported a plastic view of the brain, and they adhered to the idea that hormone-induced damages to one half of the brain were compensated for in the opposite hemisphere, occasionally leading to a "pathology of superiority."[656] The GBG model suggests that if testosterone were to inhibit the maturation of certain testosterone-sensitive areas in the left hemisphere, then more and better-connected neurons would grow in the corresponding area of the right hemisphere.[657] Galaburda and Geschwind used this reasoning to explain the large number of highly skilled individuals with dyslexia, stuttering, autism, and other disorders that were attributed to lesions in the left hemisphere.[658]

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[653] Geschwind and Galaburda, "Cerebral," 429; 431. This assertion was controversial and contradicted nineteenth-century assumptions of the faster maturing left hemisphere on which Broca had built his theory; Corballis, *The Lopsided Ape*, 292–301. See also footnote 168.

[654] For an overview of the "normal development of the brain," see Geschwind and Galaburda, "Cerebral," 433–34.

[655] Geschwind and Galaburda assumed that hormonally induced lesions to the right-hemisphere are possible but much less likely. If they occurred, however, they would be severe; Geschwind and Galaburda, "Cerebral," 432. See also Geschwind and Galaburda, "Cerebral," 440–41.

[656] Geschwind and Galaburda, "Cerebral," 433; 445; Geschwind and Galaburda, "Cerebral," 521–23.

[657] The assumption that cell death occurs regularly *in the developing brain* is crucial to this view of compensatory growth. According to Geschwind and Galaburda, unaffected areas exhibit less cell death than affected areas, and the diminishing "competition" allows the surviving neurons in the unaffected hemisphere to establish more connections to other brain centers. Hence, the unaffected brain area grows comparably bigger than the affected area; Geschwind and Galaburda, "Cerebral," 429; 431–434. Around two decades later, the normalization of cell death *in the adult brain* was a very important step in the formulation of theories of adult neurogenesis; Tobias Rees, "On How Adult Cerebral Plasticity Research Has Decoupled Pathology from Death," in Bates; Bassiri, *Plasticity and Pathology*.

[658] Geschwind and Galaburda, "Cerebral," 428; 445–446; Geschwind and Galaburda, "Cerebral," 521–23.

The immune system figured most prominently on Geschwind and Galaburda's long list of testosterone-regulated characteristics in addition to brain asymmetry. In the 1960s, 1970s, and 1980s, Behan and others had shown that testosterone inhibits the development and function of the thymus gland, before *and* after birth. One of the major functions of the thymus is to produce T cells, which aid the immune system's distinction between self and other. If testosterone were to disrupt the thymus *in utero*, the immune system would be unable to properly discriminate between pathogens and harmless antigens. In this case, the adult individual would be predisposed to immune disorders, including ulcerative colitis, celiac disease, migraines, asthma, hay fever, and eczema. Galaburda and Geschwind's hope was that the therapeutic administration of testosterone in the adult organism could ameliorate the effects of too much prenatal testosterone, because testosterone presumably continues to suppress the thymus after birth and could thereby reduce overreactions of the immune system.[659]

This connection between the immune system and cerebral laterality was novel, but the GBG model resonated with earlier theories of handedness in many ways. One example is the preoccupation with dyslexia. Geschwind and Galaburda cited case studies of individuals with dyslexia who showed abnormal patterns of brain asymmetry that could be attributed to testosterone-induced developmental problems. The authors reported, based on their own and their colleagues' clinical experience, that several individuals with dyslexia showed similar structural "abnormalities" in the left hemisphere.[660]

[659] Geschwind and Galaburda, "Cerebral," 432; 453–455; Geschwind and Galaburda, "Cerebral," 527–30; Geschwind and Galaburda, "Cerebral," 634–40.
[660] Geschwind and Galaburda, "Cerebral," 432; 453–455.

The GBG model suggested that these and many other structural “abnormalities” could derive from unsuccessful neuronal migration, that is, an incomplete transfer of newly created neurons to the area in the brain where they are supposed to be put to work. One of the most important structures in this connection is the neural crest, a collection of embryonic cells that lays the foundation for various types of tissue. After successful migration, cells that derive from the neural crest can be found in the central and peripheral nervous system, muscles, the skin and hair, as well as in other bodily structures. If the creation and migration of cells worked better for one side of the brain than for the other one, structural differences between the hemispheres, the scientists reasoned, could be the consequence.[661] Although the effects of testosterone on the development and function of the neural crest had “not yet been studied,” Galaburda and Geschwind claimed that “indirect evidence” (for example, the worsening of neural-crest disorders during female puberty or during pregnancy) permitted the assumption that fetal testosterone causes left-hemisphere impairments by inhibiting the neural crest.[662]

Geschwind and Galaburda did not have direct evidence for the effects of prenatal testosterone on the neural crest, reading abilities, or specific immune disorders. Nonetheless, the neurologists linked numerous pathologies with the brain’s prenatal testosterone exposure via neural-crest disorders, dyslexia, immune disorders, or other conditions that they hypothesized to be connected to intrauterine testosterone levels.

In a fashion that resembled playing dominoes, Galaburda and Geschwind connected, for instance, “an elevated rate” of cardiovascular disease with elevated levels of

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[661] Geschwind and Galaburda, “Cerebral,” 428–429; 444–445; Geschwind and Galaburda, “Cerebral,” 540–48.
[662] Geschwind and Galaburda, “Cerebral,” 540.

prenatal testosterone:[663] too much testosterone *in utero* might prevent a healthy development of the immune system by inhibiting the thymus gland, which might lead to an abnormally high number of thyroid autoantibodies, which might reduce the level of thyroid hormones, which might lead to high cholesterol, which might lead to cardiovascular disease. In other words, individuals with an underdeveloped left hemisphere *might* suffer more often from cardiovascular disease than those whose brain development had not been stalled by exposure to too much prenatal testosterone.

Besides searching for comorbidities with dyslexia, immune disorders, and neural-crest disorders, Geschwind and Galaburda compiled disorders that manifest asymmetrically to connect them with prenatal testosterone. For instance, they had observed that patients with early-onset Alzheimer's disease oftentimes exhibited "early fluent aphasia and constructional and memory difficulties," pointing to damage in brain centers that are commonly attributed to the left hemisphere.[664] In the same patients, "emotional behavior," usually associated with the right hemisphere, seemed unaffected.[665] Galaburda and Geschwind inferred that certain forms of Alzheimer's disease might be caused by "lateralized immune attack[s on the brain] at a site of congenital anomaly."[666] In other words, early-onset Alzheimer's disease *might* be a consequence of testosterone-induced inhibition of the left hemisphere.

The neurologists' speculations about anomalous dominance had nothing and everything to do with manual preference. Geschwind and Galaburda attached the susceptibility to the aforementioned conditions not to left-handedness but to "anomalous [cerebral]

[663] Geschwind and Galaburda, "Cerebral," 548.
[664] Geschwind and Galaburda, "Cerebral," 642.
[665] Geschwind and Galaburda, "Cerebral," 642.
[666] Geschwind and Galaburda, "Cerebral," 637.

dominance."[667] According to the GBG model, the majority of the human population would exhibit "standard dominance," which is characterized by left-hemispheric dominance for articulate speech and handedness and right-hemispheric dominance for other tasks.[668] The remaining 30 to 35 percent of the population, who supposedly differ from this description in unspecified ways, would exhibit "anomalous dominance."[669] Geschwind, Behan, and Galaburda interchanged left-handedness for anomalous dominance for reasons of convenience[670] despite the absence of a "cutoff point" between standard and anomalous dominance[671] and the insight that "left-handedness is probably only *one* marker of anomalous dominance."[672]

The GBG model suggested that all left-handedness was "abnormal," but the neurologists rejected the view "that all sinistrality is pathologic."[673] According to the definition, all left-handers had anomalous dominance, but some individuals with anomalous dominance were not left-handers.[674] Furthermore, a higher incidence of certain disorders among left-handers *as a group* did not mean that every left-hander had a disability.[675] In fact, the neurologists suggested that left-handers might be prone to various disorders, but their anomalous constitution might protect them from other ailments. For example,

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[667] Geschwind and Galaburda, "Cerebral," 447.
[668] Geschwind and Galaburda, "Cerebral," 447–48.
[669]Geschwind and Galaburda, "Cerebral," 447.
[670] Norman Geschwind and Peter O. Behan, "Laterality, Hormones, and Immunity," in Geschwind; Galaburda, *Cerebral Dominance*, 214. The neurologists later "regretted" their decision to not distinguish more precisely between handedness and cerebral dominance; Kushner, *On*, 99.
[671] Geschwind and Galaburda, "Cerebral," 447.
[672] Norman Geschwind and Peter O. Behan, "Laterality, Hormones, and Immunity," in Geschwind; Galaburda, *Cerebral Dominance*, 214. Italics added.
[673] Geschwind and Galaburda, "Cerebral," 447. Geschwind and Galaburda were referring to Canadian psychologist Michael Bakan's theory that left-handedness is a consequence of brain lesions in early life, which mostly derive from complications during pregnancy and birth; Paul Bakan, "Handedness and Birth Order," *Nature* 229, no. 5281 (1971), https://doi.org/10.1038/229195a0; Paul Bakan, "Left Handedness and Birth Order Revisited," *Neuropsychologia* 15, no. 6 (1977), https://doi.org/10.1016/0028-3932(77)90018-5.
[674] Geschwind and Galaburda, "Cerebral," 432.
[675] Geschwind and Galaburda, "Cerebral," 451.

Galaburda and Geschwind speculated that parasitic disorders as well as certain cancers and infections were less prevalent in left-handers, and that the onset of some genetic diseases might be delayed in this population.[676] Similarly, the authors assumed that left-handers might have superior spatial, mathematical, and artistic skills.[677] Overall, however, the examples for potential advantages of left-handedness or anomalous dominance pale in comparison to the astounding range of hypothesized disadvantages.

Towards the end of the first part of their paper, Galaburda and Geschwind tied together handedness and brain asymmetry even more closely. They listed the groups of "individuals ... [who are] more likely to have anomalous language dominance" as: "(1) left-handers, (2) right-handers with first-degree left-handed relatives, (3) right-handers with developmental learning disorders, and (4) right-handers with first-degree relatives with learning disorders."[678] With this list, the authors did not only take left-handedness as a proxy for brain anatomy, but also for developmental disorders and learning disabilities.[679] In doing so, they reiterated and naturalized what they themselves called the "accumulated body of essentially folklore beliefs and prejudices concerning L[eft-]H[andedness]."[680]

Naturalization of the Social and Political Order

The clinical motivations for the GBG model were strikingly similar to the core issues of genetic handedness research (Chapter 3).[681] Most notably, questions of sex/gender

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[676] Geschwind and Galaburda, "Cerebral," 451; Geschwind and Galaburda, "Cerebral," 547.
[677] Geschwind and Galaburda, "Cerebral," 521–23. See also Norman Geschwind and Peter O. Behan, "Laterality, Hormones, and Immunity," in Geschwind; Galaburda, *Cerebral Dominance*, 213–14; Geschwind and Galaburda, "Cerebral," 429; 451; 453.
[678] Geschwind and Galaburda, "Cerebral," 448.
[679] Kushner arrived at the same conclusion; Kushner, *On*, 100.
[680] Geschwind and Galaburda, "Cerebral," 451.
[681] This is very likely the reason why Annett and McManus saw the GBG model as an affront to their own work; Kushner, *On*, 101–3.

and their connection with intellectual abilities or psychiatric illnesses were central to the genetic *and* hormonal theories of laterality. On the fourth page of Geschwind and Galaburda's publication, the authors advertised that their hypothesis would clarify and connect six well-known but hitherto unexplained phenomena:

> (1) [L]eft- handedness is usually found to be more common in men than women. (2) The developmental disorders of language, speech, cognition, and emotion, e[.]g[.], stuttering, dyslexia, and autism are strongly male predominant. (3) Women are on the average superior in verbal talents while men tend on the average to be better at spatial functions. (4) Left-handers of both sexes and those with learning disabilities often exhibit superior right-hemisphere functions. (5) Left-handedness and ambidexterity are more frequent in the developmental disorders of childhood. (6) Certain diseases are more common in non-right-handers, e[.]g[.], immune disorders.[682]

The GBG model advocated for the "and" rather than the "or" to describe the relationship between genetic and intrauterine influences, but critics often overlooked that.[683] Theoretically, the observations of sex/gender differences in the six above-mentioned cases could be explained by genetic factors. However, animal experiments from the 1970s and 1980s had attested to the crucial effect of testosterone on structural brain

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[682] Geschwind and Galaburda, "Cerebral," 431. This list shows some overlap with the three core puzzles of genetic handedness research (Chapter 3). The excess of male left-handers clearly was a concern of the GBG model, and so was the high rate of left-handed twins; Geschwind and Galaburda, "Cerebral," 534–36. However, Galaburda and Geschwind did not discuss the maternal effect, that is, the increased likelihood to inherit left-handedness from the mother rather than the father. They used a reference that discusses the maternal effect in a different context; see citation number 148 in Geschwind and Galaburda, "Cerebral," 550. On the sexed/gendered dimensions of autism, see Fine, *Delusions*, 99–106; Giordana Grossi and Cordelia Fine, "The Role of Fetal Testosterone in the Development of the 'Essential Difference' Between the Sexes: Some Essential Issues," in *Neurofeminism: Issues at the Intersection of Feminist Theory and Cognitive Science*, ed. Robyn Bluhm, Anne J. Jacobson and Heidi L. Maibom (New York: Palgrave Macmillan, 2012); Nicole C. Karafyllis, "Oneself as Another? Autism and Emotional Intelligence as Pop Science, and the Establishment of 'Essential' Differences," in Karafyllis; Ulshöfer, *Sexualized Brains*.

[683] For the detailed overview of genetic and chromosomal influences on laterality, see Geschwind and Galaburda, "Cerebral," 530–37. On the skewed reception of the theory, see Kushner, *On*, 100–103.

development and sexual behavior, independent of the genetic makeup of the animal model.[684] These effects were possible because there are steroid receptors in various parts of the neural tissue.[685] In Geschwind and Galaburda's own words, "[t]he male-related influence ... acts to alter the expression of certain genes that play an important role in neural development."[686] This means that the GBG model is compatible with genetic theories of cerebral laterality and handedness, but that hormones can override genetic dispositions.

Geschwind and Galaburda identified sex differences in talents, handedness, and developmental disorders as the first three out of six core concerns in the study of laterality.[687] Galaburda and Geschwind hypothesized that the left hemisphere was commonly less developed in males than in females because male fetuses were generally exposed to higher levels of testosterone than female fetuses. Consequently, they speculated that functions that are usually left-lateralized were less pronounced in boys or men than in girls or women, whose brains were typically exposed to much lower levels of testosterone.[688]

Many of these supposedly strictly lateralized functions were gender-coded qualities, for instance, point three on the above list: "Women are on the average superior in verbal talents [presumed to be located in the left hemisphere] while men tend on the average to be better at spatial functions [presumed to be located in the right hemisphere]."[689] Geschwind and Galaburda referred to the same mechanism to explain the marked sex

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684 Geschwind and Galaburda, "Cerebral," 429; Geschwind and Galaburda, "Cerebral," 523–27.
685 Geschwind and Galaburda, "Cerebral," 431; Geschwind and Galaburda, "Cerebral," 523–27.
686 Geschwind and Galaburda, "Cerebral," 431.
687 Geschwind and Galaburda, "Cerebral," 431.
688 Geschwind and Galaburda, "Cerebral," 431–32.
689 Geschwind and Galaburda, "Cerebral," 431.

differences in the incidences of stuttering, delayed speech, childhood autism, hyperactivity, and Tourette's syndrome.[690]

The GBG model aimed to explain sex/gender differences beyond brain structure, cognitive abilities, and the susceptibility to psychiatric illnesses. For instance, the neurologists expressed their opinions about healthy female body types. They took the "masculinizing effects" of diethylstilbestrol (DES), including acne and facial hair growth, as indicator for anomalous dominance among DES daughters.[691] Similarly, they suggested that women with mitral valve prolapse and small breasts had high testosterone levels and hence anomalous dominance.[692]

Besides facial hair, acne, and small breasts, Geschwind and Galaburda described obesity in the upper half of the body as a further female pathology. According to the neurologists, women "whose pattern of obesity resembles the common male pattern, i[.]e[.], broad shoulders and upper body fat," were much more likely to acquire diabetes than women with "lower-body obesity."[693] This correlation did not surprise Galaburda and Geschwind, since diabetes was supposed to be more common in males than in females. Consequently, women with upper-body obesity might have higher levels of testosterone,

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690 Geschwind and Galaburda, "Cerebral," 428; 451.

691 Geschwind and Galaburda, "Cerebral," 544. See also Geschwind and Galaburda, "Cerebral," 535; 545. On the detrimental effects of DES, see Nancy Langston, *Toxic Bodies: Hormone Disruptors and the Legacy of DES* (New Haven: Yale University Press, 2010). In contrast to the contemporaneous literature, Galaburda and Geschwind decided not to distinguish between "masculinization" and "defeminization" for reasons of convenience: "The literature now routinely distinguishes masculinization and defeminization. A masculinizing effect is one that leads to male-typical behavior in the female, eg, mounting other females. A defeminizing effect is one that leads to loss of female-typical traits, eg, cyclic release of gonadotropins. The two classes of effect can occur independently and depend on hormonal effects at different sites. For convenience we will use the term masculinization to mean 'masculinization and/or defeminization' except when the distinction is critical to the discussion"; Geschwind and Galaburda, "Cerebral," 525.

692 Geschwind and Galaburda, "Cerebral," 544.

693 Geschwind and Galaburda, "Cerebral," 544.

which would also explain their "high rate of menstrual irregularities," and point to anomalous dominance.[694]

The connection between testosterone, anomalous dominance, and female body types endowed the GBG model with a gynecological angle. Geschwind and Galaburda assumed "that left-handed female subjects are likely to differ endocrinologically, immunologically, or both, from right-handed women."[695] The former might suffer more from "menstrually related disorders," including migraines.[696] The authors stated that the suppression of their menstrual cycle would alleviate their symptoms.[697] These women might furthermore need special reproductive services, because they might have lower fertility and, if they conceived, carry twins.[698]

The paternalism that Geschwind and Galaburda expressed regarding anomalous dominance in females did not extend to males. Anomalous dominance in men seemed a benefit rather than an obstacle to reproduction. The GBG model suggested that left-handers' sperm might "have special properties" that increase fertility.[699] Apart from this advantage, the neurologists proposed that testosterone impacted men less than women. They supposed that additional testosterone usually corrupted femininity but not masculinity because male organisms were used to higher levels of androgens.[700]

Galaburda and Geschwind cautioned their readers against assuming that females were generally inferior to males, paralleling their rejection of the idea that all left-handers were pathological. The authors explained that "the special risk of females for many

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694 Geschwind and Galaburda, "Cerebral," 545.
695 Geschwind and Galaburda, "Cerebral," 545.
696 Geschwind and Galaburda, "Cerebral," 647.
697 Geschwind and Galaburda, "Cerebral," 647.
698 Geschwind and Galaburda, "Cerebral," 535.
699 Geschwind and Galaburda, "Cerebral," 535.
700 Geschwind and Galaburda, "Cerebral," 645.

disorders is far outweighed by their lower rates of coronary disease and lung cancer."[701] Geschwind seemed even more appreciative of women's qualities in his social life. For example, he recommended a female colleague for an award and called her an "obvious possibility,"[702] and he took seriously his wife's critiques of his academic work.[703]

Galaburda and Geschwind explicitly based the GBG model on brain organization theory, a hypothesis that has found many supporters since the late 1950s.[704] Brain organization theory suggests that steroids regulate sexual differentiation during pregnancy. Simply put, this means that the default fetus has a female body and a feminine mind, and that no fetus can fully masculinize in the absence of testosterone at certain stages of pregnancy. Depending on the chromosomal make-up of the fetus and the organs that are developing during a supposed lack or accidental oversupply of steroids, the pregnancy can result in an infant with male gonads but a "female" brain (that is, a "homosexual" man, or a non-cis-gendered individual), or an infant with female gonads but a "masculine" brain (that is, a "homosexual" woman, or a non-cis-gendered individual).[705] Other non-conforming combinations of sex, gender, and sexual orientation are also deemed possible.

Geschwind and Galaburda emphasized that "sex hormones" were only one of many environmental factors that shape the fetal brain.[706] For instance, they referred to

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[701] Geschwind and Galaburda, "Cerebral," 537.
[702] Norman Geschwind, Geschwind to Gazzaniga, August 24, 1982, H MS c435, Box 1, Folder 13, Correspondence, 1972–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2.
[703] Thomas D. Sabin, "Colleague," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 25.
[704] Geschwind and Galaburda, "Cerebral," 524. For an uncritical overview of early work on neuroendocrinology, see Chandler M. Brooks et al., eds., *Humors, Hormones, and Neurosecretions: The Origins and Development of Man's Present Knowledge of the Humoral Control of Body Function* (New York: State University of New York, 1962).
[705] Jordan-Young, *Brain*, 21–40.
[706] Geschwind and Galaburda used the term "sex hormones" excessively in their publication, but they abstained from calling testosterone the "male hormone." For critiques of the sexing/gendering and sexualization of steroids, most importantly testosterone and estrogen, see Jennifer Harding, "Sex and Control: The

studies of gestating rodents whose stress affected their fetuses.[707] Be that as it may, the GBG model suggested that fetal testosterone exposure (partially) determined an individual's brain anatomy, cognitive abilities, mental health, and behavior in alignment with the brain organization theory.

Despite its popularity, research on the hormonal wiring of sex/gender and sexual orientation in the fetus has been characterized by incommensurable quasi-experiments and inconclusive findings.[708] Social scientist Rebecca Jordan-Young provided a detailed assessment of the methodological problems of brain organization research on two levels. First, she explained that human brain researchers can only perform quasi experiments, that is, non-invasive and not randomized retroactive studies of brain development. She argued that studies of brain organization between 1959 and 2008 differed methodologically, structurally, and conceptually to a degree that did not allow for inferring any cause-effect relationships between behavior, brain structure, and hormone exposure. Moreover, Jordan-Young questioned whether animal models are appropriate for the study of very human concerns like sex/gender and sexuality.[709]

Secondly, Jordan-Young analyzed the results of the disparate studies. She illustrated that many of the findings were inconclusive or even contradictory. She concluded that brain organization theory, even if the quasi experiments were comparable to one another, is a poorly supported theory that forecloses debates surrounding the impact of gender roles, stereotypes, and education on brains and selves.[710] To solve the mystery of

Hormonal Body," *Body & Society* 2, no. 1 (2016), https://doi.org/10.1177/1357034X96002001007; Michael Pettit, "The Queer Life of a Lab Rat," *History of Psychology* 15, no. 3 (2012), https://doi.org/10.1037/a0027269.

707 Geschwind and Galaburda, "Cerebral," 527; 533.

708 Jordan-Young, *Brain*.

709 Jordan-Young, *Brain*, 41–64.

710 Jordan-Young, *Brain*, 65–236.

sex/gender and sexuality, Jordan-Young suggested, disembodied theories of brains and hormones are insufficient.[711]

Scientists have voiced concerns similar to Jordan-Young's assessment of brain organization theory for decades. Neuroanatomist Ruth Bleier, for instance, was a contemporary of Geschwind's and condemned brain organization theory more radically than Jordan-Young.[712] Bleier suggested that male scientists "creat[ed]... an elaborate mythology of women's biological inferiority as an explanation for their subordinate position in the cultures of Western civilizations."[713] Pointing to flawed methodologies, inconclusive findings, and bypassed alternative theories, Bleier argued that the scientific claim of discovering nature and objectively explaining it is nothing more than a male strategy to conceal a misogynist political endeavor.[714]

The sexed/gendered and sexualized politics inherent in the GBG model's alignment with brain organization theory were accompanied by Geschwind and Galaburda's paternalism towards gay individuals.[715] The authors justified their analysis of the

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711 Jordan-Young, *Brain*, 237–91.
712 Bleier, *Science*, 80–114.
713 Bleier, *Science*, vii.
714 As biologist Marianne van den Wijngaard argued, the criticism of feminist scientists led to significant changes in brain organization theory in the 1970s and 1980s, but not to its abandonment; Wijngaard, Marianne, *Reinventing*. To draw a daring historical parallel, feminism has also changed psychoanalysis but not led to the abandonment of many of its biased concepts; Mari Jo Buhle, *Feminism and Its Discontents: A Century of Struggle with Psychoanalysis* (Cambridge: Harvard University Press, 1998).
715 For overviews of further theories on the relationship between laterality and sexual orientation since the nineteenth century, see Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 57–63; Kushner, *On*, 129–37. For overviews of hormonal theories of sexual orientation before and after Geschwind, see Stephanie H. Kenen, "Who Counts When You're Counting Homosexuals? Hormones and Homosexuality in Mid-Twentieth-Century America," in Rosario, *Science and Homosexualities*; Florian Mildenberger, "Diskursive Deckungsgleichheit: Hermaphroditismus und Homosexualität im medizinischen Diskurs (1850–1960)," in *Medizin, Geschichte und Geschlecht: Körperhistorische Rekonstruktionen von Identitäten und Differenzen*, ed. Frank W. Stahnisch and Florian Steger, Geschichte und Philosophie der Medizin 1 (Stuttgart: Franz Steiner, 2005); Porac, *Laterality*, 78–80; Edward Stein, *The Mismeasure of Desire: The Science, Theory, and Ethics of Sexual Orientation* (New York: Oxford University Press, 1999), 129–33; Jennifer Terry, *An American Obsession: Science, Medicine, and Homosexuality in Modern Society* (Chicago, London: University of Chicago Press, 1999), 159–177; 372–373.

connection between laterality and sexual orientation by pointing to the interest of the gay population in their study: "Several homosexuals have written to us suggesting that there is a high rate of L[eft-]H[andedness] in this population but no study of this has yet been reported."[716] The authors assumed that their thoughts on the population-specific susceptibility to HIV/AIDS would be even more valuable than explaining the high incidence of left-handedness in the gay population. Geschwind and Galaburda suggested that the gay lifestyle is most likely not connected to the high prevalence of HIV/AIDS because "[t]he rarity of [HIV/AIDS] in female prostitutes renders unlikely explanations based on promiscuity."[717] Instead, Geschwind hypothesized that "[homosexuals] have a distinct immunological pattern and it is this which … accounts for the AIDS epidemic."[718] This particular immunologic constitution might be determined by fetal hormones and overlap with (or match) the group of individuals with anomalous dominance. To further examine this theory, the neurologists suggested future screenings of "homosexuals" for handedness, most importantly gay individuals who have AIDS.[719] Under the guise of laterality research and with alleged backing from the gay population, brain-based sexual types seemed in close reach of handedness researchers.[720]

[716] Geschwind and Galaburda, "Cerebral," 546.
[717] Geschwind and Galaburda, "Cerebral," 546.
[718] Norman Geschwind, Geschwind to Levy, March 3, 1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 2. See also Geschwind and Galaburda, "Cerebral," 546.
[719] Geschwind and Galaburda, "Cerebral," 546.
[720] Responding to the alleged excess of left-handers among the gay population, psychologist Marian Annett once more adapted her genetic theory. She suggested that the high rate of left-handers among "homosexual males" might be due to "differences in genotype … and/or developmental modifications of gene expression," caused by "any factor which impeded the normal expression of the [Right Shift] gene, probably as it influences cerebral maturation in late fetal or perinatal life"; Marian Annett, "Comments on Lindesay: Laterality Shift in Homosexual Men," *Neuropsychologia* 26, no. 2 (1988): 343.

The GBG model's attempt to formulate a comprehensive scientific theory of the sexed/gendered and sexual world order reflected the concerns during the "masculinity crisis" of the 1950s.[721] Geschwind completed his medical training in Boston during this decade, encountering many middle-class males who were trying to redefine their roles in the novel social environments of domestic and public life in the post-war United States, a time characterized by the rise of mass culture, consumerism, rapid demographic change, and political uncertainty. Anxieties over the collapse of familiar social structures were enmeshed with a highly politicized fear of "the other" in the face of fascist and communist threats.[722]

One of the biggest concerns during the masculinity crisis was the supposed demasculinization inherent in the ideal of companionate spouses and families.[723] Authors given voice in the rising mass media—in form of parental advice literature, newspapers, and periodicals—tried to stymie women's professional aspirations by suggesting that female self-actualization outside of the home would damage child development and society writ large.[724] Furthermore, the popular media closely linked citizenship with the fulfillment of traditional gender roles and sexual morality, resulting in the celebration of a heteronormative "essential American character" in the 1950s United States.[725] If that was not enough to get deviant individuals back on track, social scientists and psychiatrists

[721] James Burkhart Gilbert, *Men in the Middle: Searching for Masculinity in the 1950s* (Chicago, London: University of Chicago Press, 2005), 16. For a more global account of sex/gender and sexuality during the Cold War, see Muehlenbeck, *Gender*.
[722] Gilbert, *Men*.
[723] Gilbert, *Men* (particularly chs. 7, 8, and 9).
[724] Vicedo, *Nature*.
[725] Miriam G. Reumann, *American Sexual Character: Sex, Gender, and National Identity in the Kinsey Reports* (Berkeley: University of California Press, 2005), 198.

applied family therapy, trying to stabilize an entire threatened and war-torn nation by securing the functionality of the so-called nuclear family's microcosm.[726]

Homophobia was rampant during these years. The persecution of homosexuals was an extensive and deliberate political undertaking during US Senator Joseph R. McCarthy's (1908–1957) witch hunt against alleged communists and under Dwight D. Eisenhower's (1890–1969) national security program.[727] Physicians were complicit in stabilizing heterosexual lifestyles and contributed to the realization of governmental heteronormative policies by monitoring sexual health and providing (pre-)marital counseling.[728] Where heterosexuality could not be achieved with these measures, behaviorists attempted to "cure" non-heterosexuality with electroshock therapy and other invasive measures.[729]

In addition to Geschwind and Galaburda's benevolent naturalization of gender stereotypes and sexual orientation, the GBG model mirrored Cold War anxieties about the collapse of the political and racial world order.[730] For example, Galaburda and Geschwind's treatment of HIV/AIDS had marked racial undertones. The neurologists tried to explain the high incidence of HIV/AIDS in "Haitian males and Central African females" by suggesting that their immune systems corresponded to that of "Western"

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726 Weinstein, *The Pathological Family*.
727 Johnson, *Lavender*. For a longer history of the fascination of US Americans and other industrialized cultures with non-heterosexuality, see Jonathan Dollimore, *Sexual Dissidence: Augustine to Wilde, Freud to Foucault* (Oxford: Clarendon Press, 1991); Terry, *American*.
728 Lewis, *Prescription for Heterosexuality*.
729 Catherina Gere, "Plasticity, Pathology, and Pleasure in Cold War America," in Bates; Bassiri, *Plasticity and Pathology*. On attempts to "cure" gay individuals since the late nineteenth century, see Hoberman, *Testosterone*, 92–104; Sengoopta, *Most*, 75–82; 186–192.
730 Mirroring Cold War politics in his scientific work was certainly not Geschwind's conscious choice, as his colleagues asserted that politics were "[c]onspicuously absent from [Geschwind's] life's work"; Damasio and Galaburda, "Norman," 503.

individuals with anomalous dominance.[731] They clarified that "the same immunologic pattern [might form] for quite different reasons."[732] In other words, the neurologists did not suggest that all Haitian males and Central African females had abnormal brains, but that their immune system was akin to that of "Westerners" with anomalous dominance.

Geschwind and Galaburda expanded on this theory of biological differences between individuals of different sexes/genders and races/ethnicities. For instance, they cited studies of a comparably low incidence of dyslexia in the Chinese and Japanese population.[733] Furthermore, Galaburda and Geschwind discussed the "higher frequency of twinning and of neural tube defects" in northern Europe as compared to "southern Europe and the Orient."[734] Based on these data, they hypothesized that there were less left-handers in Japan (but not China) and in southern Europe (but not "the Orient") than elsewhere. They further speculated "that therefore dyslexia and other learning disabilities might be less frequent" in in Japan and southern Europe.[735] In turn, this would mean that populations other than southern Europeans and the Japanese were more prone to anomalous dominance and learning disorders.[736]

Retreating again to a virtual play of dominoes, Geschwind and Galaburda erected an even stricter typology of the brains of black and white individuals in West Africa and North America. Based on the large number of twin births in West Africa (presumably an indicator of high testosterone levels and hence anomalous dominance), the neurologists proposed that this population "would have a very high rate of L[eft-]H[andedness],

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731 Geschwind and Galaburda, "Cerebral," 546.
732 Geschwind and Galaburda, "Cerebral," 546.
733 Geschwind and Galaburda, "Cerebral," 536.
734 Geschwind and Galaburda, "Cerebral," 536.
735 Geschwind and Galaburda, "Cerebral," 536.
736 For an overview of more recent studies on the geography of laterality and its association with race/ethnicity, see Porac, *Laterality*, 119–33.

learning disabilities, and possibly neural tube defects."[737] They found support for this hypothesis in studies that suggested a larger incidence of stuttering in West-African students than in white US-American students. In the same vein, children of color in the United States, whom Geschwind and Galaburda assumed to be "of West African origin," showed higher rates of stuttering than their white classmates.[738] The neurologists concluded that: "in West Africa there is a high frequency of anomalous dominance, and therefore learning disabilities, L[eft-]H[andedness], and the other attendant talents and disabilities."[739]

In a nutshell, Galaburda and Geschwind used the GBG model as a neuroendocrinological theory of the superiority of whites over people of color. The authors were aware of potential criticism of racist aspects of their theory, and they asserted "that the distinctions … presented are not between the conventional white, black, and Oriental groups."[740] This explanatory note that the differences were matters of brain types rather than racial/ethnic affiliation was not very convincing. In a similar vein, the neurologists cautioned that, because excessive testosterone allegedly also leads to hypopigmentation, "the blond haired, blue eyed, and fair skinned northern Europeans might resemble West African blacks [with regard to brain dominance and the immune system] whereas the Japanese might bear closer resemblances to southern European whites."[741] Instead of mitigating the theory's racial hierarchies, this clarification at best reinforced stereotypes of the dumb blonde.[742]

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737 Geschwind and Galaburda, "Cerebral," 536.
738 Geschwind and Galaburda, "Cerebral," 536.
739 Geschwind and Galaburda, "Cerebral," 536–37.
740 Geschwind and Galaburda, "Cerebral," 537.
741 Geschwind and Galaburda, "Cerebral," 537.
742 On Geschwind and Galaburda's discussion of the high incidence of left-handedness among blond and blue-eyed individuals, see Geschwind and Galaburda, "Cerebral," 542.

In line with legal scholar Dorothy E. Roberts's argument in *Fatal Invention*, the GBG model mobilized science to naturalize global political divides.[743] Roberts argued that race was "invent[ed]" during the years of slavery and westwards expansion in North America "as a system of governance and 'moral apology'."[744] According to Roberts, politicians, scientists, and the broader public have been—and still are—complicit in concealing the political origins of racial categories in favor of a notion of biological differences. During slavery as well as during the Cold War, the notion of biological differences between populations served as an excuse for institutionalized economic, legal, educational, and health-related inequalities.

Similar to the paternalism that Geschwind and Galaburda exhibited with their promises of therapeutic applications of their theories on sex/gender and sexuality, the neurologists believed that their investigation of race/ethnicity would eventually "help to prevent or cure some of the brain disorders present in higher frequency" in individuals of a specific "type."[745] According to Roberts, there is no way to pronounce scientific theories about differences between races/ethnicities in a politically neutral way. In her terminology, the GBG model could be described as a "reinforce[ment of] race," which can occur in conjunction with democratic interests and progressive political attitudes.[746]

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743 Roberts, *Fatal*. On attempts to use genetic science for reconciliation for the suffering of enslaved individuals and their descendants, see Alondra Nelson, *The Social Life of DNA: Race, Reparations, and Reconciliation after the Genome* (Boston: Beacon Press, 2016).
744 Roberts, *Fatal*, 309.
745 Geschwind and Galaburda, "Cerebral," 537.
746 Roberts, *Fatal*, 27.

Methodology: Few Hands, Few Brains, and Many Publications

Geschwind and Behan conducted a three-part population study on the relationship between left-handedness, immune disease, and learning disorders in subjects from London and Glasgow.[747] The first and second parts of the study compared 900 extreme right-handers and 500 extreme left-handers in terms of learning disorders and immune disease. Behan and Geschwind reported that learning disorders were about ten times more common in left-handers than in right-handers, and that immune disorders were over two times more common in left-handers than in right-handers.[748] For the third part of this study, the neurologists compared 1,142 subjects from the general population and 632 individuals with diagnosed immune disorders. Geschwind and Behan found an increased incidence of left-handedness among patients with migraine and myasthenia gravis (the latter was of marginal significance), but not among the other patient groups.[749]

Historian of medicine Howard I. Kushner has summarized these studies and described their methodological flaw of "overrepresent[ing] left-handers."[750] This problem occurred because Behan and Geschwind treated left-handedness as a good proxy for brain asymmetry, which it was not.[751] Once the neurologists realized their error, they revised their original claim that left-handedness was associated with learning disorders and

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[747] Geschwind and Behan, "Left". In subsequent, much smaller, studies on children with learning disorders, Geschwind, Behan, and Behan's wife, pathologist Wilhelmina M.H. Behan (1939–2005), found a significant comorbidity between atopical illness and "hyperactivity" resp. dyslexia. They also reported elevated levels of various antibodies in the mothers of dyslexic children, pointing to immune disturbances in the mothers that might have possibly affected the dyslexic child during pregnancy. Geschwind passed away before the publication of these studies; Wilhelmina M. H. Behan, Peter O. Behan, and Norman Geschwind, "Anti-Ro Antibody in Mothers of Dyslexic Children," *Developmental Medicine and Child Neurology* 27, no. 4 (1985); Peter O. Behan and Norman Geschwind, "Dyslexia, Congenital Anomalies, and Immune Disorders: The Role of the Fetal Environment," *Annals of the New York Academy of Sciences* 457 (1985).

[748] Geschwind and Behan, "Left," 5097–98.

[749] Geschwind and Behan, "Left," 5098–99.

[750] Kushner, *On*, 98.

[751] Kushner, *On*, 98. For the original publication, see Norman Geschwind and Peter O. Behan, "Laterality, Hormones, and Immunity," in Geschwind; Galaburda, *Cerebral Dominance*.

immune disorders. Instead, they put emphasis on the underlying problem of anomalous dominance, which might also be found in right-handers, and conceded that left-handedness might go along with health advantages and disadvantages, an argument familiar from Geschwind and Galaburda's detailed 1985 publication.[752]

Kushner pointed out the irony that lies in the fact that Geschwind disliked population studies, and yet they contributed significantly to the public recognition of Geschwind and Galaburda's 1985 publication.[753] Profoundly skeptical of computers and big data,[754] Geschwind was much more devoted to "clinical observations … and … detailed survey[s] of the medical literature."[755]

While many could have conducted a population study on handedness, immune disorders, and learning disorders, Geschwind had a unique personality and institutional affiliation that allowed him to merge clinical observations with a large-scale literature review. Geschwind's first advantage was his worldwide network of colleagues, with whom he exchanged research ideas in letters, at conferences, or during private meetings.[756] Starting in the late 1960s, Geschwind spoke at large international conferences that also offered panels on endocrinology and immunology. At times, those sessions took place in

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752 Norman Geschwind and Peter O. Behan, "Laterality, Hormones, and Immunity," in Geschwind; Galaburda, *Cerebral Dominance*, 213–14.
753 Kushner, *On*, 95–96.
754 David B. Rosenfield, "Stuttering," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 102; Thomas D. Sabin, "Colleague," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 22; Steven C. Schachter, "Handedness Measurement and Correlation with Brain Structure," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 258.
755 Albert M. Galaburda, "Anatomy of Developmental Dyslexia: Geschwind's Last Legacy," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 92.
756 Much of Geschwind's correspondence is accessible in his archival collection; Geschwind, Norman. Papers, 1941–1984 (inclusive), 1968–1984 (bulk), H MS c435, Center for the History of Medicine, Francis A. Countway Library of Medicine.

the immediate vicinity of Geschwind's talks.[757] Hence, it is conceivable that he started drawing connections between these fields and his own work at these occasions.[758] By 1978 at the latest, Geschwind openly discussed his idea of the developmental influences in his conference talks.[759]

Furthermore, Geschwind was a fast and synthetic reader in multiple languages,[760] and his excessive engagement with the medical literature was his main source of inspiration.[761] Geschwind had access to the Francis A. Countway Library of Medicine, one of the largest medical libraries in the world. Geschwind manually searched the Library's holdings for references related to brain laterality and fetal testosterone exposure.[762] In the early 1970s, Geschwind started collecting publications at the intersection of neurology, endocrinology, genetics, and immunology.[763] During his sabbatical in 1983, he multiplied

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[757] Most of the conference programs that Geschwind collected (and sometimes annotated) can be found in Box 6, H MS c435, Center for the History of Medicine, Francis A. Countway Library of Medicine.
[758] However, Geschwind did not attend a symposium on lateralization at Rutgers Medical School in April 1975. Moreover, the editors of the volume that stems from this conference did not list him as a potential contributor, suggesting that Geschwind had not yet made his hypothesis known to his colleagues at this point; Stevan R. Harnad et al., eds., *Lateralization in the Nervous System* (New York: Academic Press, 1977), XV.
[759] Norman Geschwind, Note, n.d., H MS c435, Box 7, Folder 17, Conferences, Lectures, 1978, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1. Galaburda might have steered Geschwind in the direction of neuroendocrinology. Geschwind originally pondered chromosomal bases for laterality. Because cerebral dominance is a matter of degree, not of left or right, Galaburda countered, hormones would be better suited for an explanation. Geschwind's conversations with his brother, an endocrinologist, might have additionally shaped the conceptual direction that the GBG model took; Albert M. Galaburda, interview by Tabea Cornel.
[760] Geschwind's reading knowledge of up to eight languages is undoubted, but Geschwind's colleagues' judgement of his speaking skills varied from "perfect" to "awful"; François Boller, "International Figure," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 55; Albert M. Galaburda, interview by Tabea Cornel. Be that as it may, Geschwind delivered lectures and published articles in foreign languages, but he drafted the papers in English first and had them translated afterwards; Correspondence, 1967–1984, H MS c435, Box 1, Folder 8, Center for the History of Medicine, Francis A. Countway Library of Medicine. For a bibliography of Geschwind's work, see Galaburda, "Norman".
[761] Possible reasons for Geschwind's focus on reading include his "clums[iness]" and poor visuo-spatial orientation; Albert M. Galaburda, interview by Tabea Cornel.
[762] David B. Rosenfield, "Stuttering," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 102.
[763] Clippings and entire journals, sometimes with Geschwind's comments or mark-ups, have been preserved in Geschwind's archival papers; Geschwind, Norman. Papers, 1941–1984 (inclusive), 1968–1984 (bulk). See especially Box 6.

his collection a hundredfold. If Geschwind had not had access to the Countway Library or the luxuries of a sabbatical, he might not have been able to develop the GBG model in as much detail as he did.

Epistemic Multiplicity and Incommensurability

The GBG model synthesized over one hundred years of knowledge about laterality, endocrinology, and immunology, thereby mobilizing multiple incommensurable concepts of "the brain." This historical orientation was deliberate, and Geschwind intended to unearth allegedly neglected knowledge from the past to solve present-day scientific problems.[764] The reviewed studies rested on different tools, theories, and timeframes of observation, depending on the type of brain assessed. In synthesizing anatomical, physiological, genetic, hormonal, immunological, and zoological studies from different continents, the GBG model drew on studies of monkey brains, rodent brains, and human brains; on developing, mature, male, female, healthy, and sick brains; on sliced dead brains and injured living brains; and on brains that were indirectly assessed via questionnaires, behavioral tests, invasive experiments, or brain scans.

To further increase the number of conceptually different brains, the GBG model integrated neo-Darwinian ideas. In essence, the GBG model was a theory of the *evolutionary* advantages of *hormonal* overriding of *genetically* induced brain *anatomy and physiology*. Geschwind was positive that the intrauterine environment contributed more to human variation than a gene pool ever could, and he speculated that genetic theories of

[764] Galaburda, "Norman," 299; Kushner, "Norman," 183–89.

handedness had failed because they had ignored the hormonal source of phenotypical variation.[765]

The incommensurability of different epistemic versions of “the brain” became most visible in the GBG model’s tension between plasticity and fixity. In line with the idea of a malleable, nurtured brain, the GBG model rested on a plastic brain with environmentally induced cerebral dominance. First, Galaburda and Geschwind suggested that the anatomy of the brain depended on the timeline of fluctuating hormone levels in the womb. Stress during pregnancy, nutrition, and medication could alter the hormonal environment *in utero*, and hence impact brain lateralization in the fetus.

Second, the GBG model integrated even more radical notions of plasticity. Geschwind was in close communication with Argentinian-US-American zoologist Fernando Nottebohm (b. 1940?). Nottebohm worked on seasonal adult neurogenesis in birds, that is, the season-dependent and experience-related creation of entirely new neurons in the *mature* avian brain.[766]

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[765] Geschwind and Galaburda, “Cerebral,” 536.

[766] On the evolution of different concepts of cerebral plasticity, including adult neurogenesis, since the late nineteenth century, see Tobias Rees, “On How Adult Cerebral Plasticity Research Has Decoupled Pathology from Death,” in Bates; Bassiri, *Plasticity and Pathology*; Rees, *Plastic*, 59–90; 227–234. In his footnotes to chs. 1 and 3, Rees engaged with other interpretations of the history of cerebral plasticity that have been written by neuroscientists, journalists, philosophers, sociologists, and historians. Many of these publications are conceptually insightful and/or rich in historical detail, but some of them make anachronistic assumptions. The most important works in this context are G. Berlucchi and H. A. Buchtel, “Neuronal Plasticity: Historical Roots and Evolution of Meaning,” *Experimental Brain Research* 192, no. 3 (2009), https://doi.org/10.1007/s00221-008-1611-6; Charles G. Gross, “Neurogenesis in the Adult Brain: Death of a Dogma,” *Nature Reviews Neuroscience* 1, no. 1 (2000), https://doi.org/10.1038/35036235; Edward G. Jones, “NEUROwords 8: Plasticity and Neuroplasticity,” *Journal of the History of the Neurosciences* 9, no. 1 (2000), https://doi.org/10.1076/0964-704X(200004)9:1;1-2;FT037; Malabou, *What*; Pitts-Taylor, “Plastic”; Rose and Abi-Rached, *Neuro*; Beatrix P. Rubin, “Changing Brains: The Emergence of the Field of Adult Neurogenesis,” *BioSocieties* 4, no. 4 (2009), https://doi.org/10.1017/S1745855209990330; Michael Specter, “Rethinking the Brain: How the Songs of Canaries Upset a Fundamental Principle of Science,” *New Yorker*, July 23, 2001, accessed March 15, 2019, https://www.michaelspecter.com/2001/07/rethinking-the-brain/; Frank W. Stahnisch, “Making the Brain Plastic: Early Neuroanatomical Staining Techniques and the Pursuit of Structural Plasticity, 1910–1970,” *Journal of the History of the Neurosciences* 12, no. 4 (2003), https://doi.org/10.1076/jhin.12.4.413.27917.

Nottebohm's research was as far removed from ideas of a static, fixed brain as possible, and Geschwind and Behan actively supported this line of research. By the late 1960s, Geschwind had taken note of Nottebohm's research on brain laterality in songbirds.[767] Initially, Geschwind took Nottebohm's research as an indicator for cerebral asymmetry in presumably lower species.[768] Once Geschwind recognized the importance of Nottebohm's work for hormonal impacts on brain asymmetry and the recovery of function in neurological disorders, he requested reprints of Nottebohm's publications.[769] In the late 1970s and early 1980s, Geschwind and Nottebohm attended several conferences together and spoke at least once on a shared panel.[770] Furthermore, Geschwind and Behan appeared as speakers at Nottebohm's conference on therapeutic brain plasticity for 150 neuroscientists in 1984.[771] The goal of this conference was to create a "new neurology" based on the principle of a malleable brain.[772]

Galaburda and Geschwind simultaneously upheld views of rigid innate localizationism that were seemingly incommensurable with this commitment to the impacts of nurture on the brain. It seems only logical that Geschwind positioned himself against

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[767] George A. Miller, Miller to Geschwind, May 12, 1969, H MS c435, Box 6, Folder 25, Conferences, Lectures, 1969–1971, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2.
[768] Norman Geschwind, Asymmetries of the Human Brain, 04-25-1978, H MS c435, Box 7, Folder 13, Meeting File (1 of 3), 1977–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–4.
[769] Norman Geschwind, Geschwind to Nottebohm, 02-26-1979, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–3.
[770] Endocrine Society, Program and Abstracts, 64th Annual Meeting, June 16–18, 1982, n.d., H MS c435, Box 7, Folder 22, Meeting File, 1980–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine. See other documents in the same folder for more joint conference appearances.
[771] Institute for Child Development Research, Hope for a New Neurology, n.d., H MS c435, Box 8, Folder 6, Hope for a New Neurology, 1984, Center for the History of Medicine, Francis A. Countway Library of Medicine; Fernando Nottebohm, Nottebohm to Geschwind, July 8, 1983, H MS c435, Box 8, Folder 6, Hope for a New Neurology, 1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2.
[772] Fernando Nottebohm, "Learning, Forgetting, and Brain Repair," in Geschwind; Galaburda, *Cerebral Dominance*, 109.

equipotentiality (the notion that all parts of the brain work together as a coherent whole in producing mental functions),[773] since the lateralization of individual brain centers, let alone their dependency on testosterone, cannot be explained without some doctrine of specialized brain areas.

Geschwind was more than only an anti-equipotientialist. He adhered to one of the most conservative versions of localizationism possible. As Galaburda stated repeatedly, Geschwind "had a strong phrenologic bent."[774] This was true in two different ways. First, Geschwind trusted that circumscribed brain areas fulfilled specific functions, and, second, he assumed "that bigger is better."[775] To give a concrete example, Geschwind believed that individuals with a small planum temporale in the left hemisphere would have pronounced dyslexia, because the left planum temporale fulfils language-related functions.[776]

Geschwind aligned the seemingly conflicting concepts of plasticity and lateralization by picking and choosing different aspects of the contemporaneous concept of plasticity. For instance, he assumed that the undisturbed brain was only plastic during development. Geschwind considered individuals stuck with a fixed lateralized brain once the brain had been molded by the intrauterine environment. In this view, brain plasticity in

[773] Norman Geschwind, Anatomical Organization of Behavior: Main Points, November 29, 1982, H MS c435, Box 7, Folder 22, Meeting File, 1980–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1.
[774] Albert M. Galaburda, "Anatomy of Developmental Dyslexia: Geschwind's Last Legacy," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 89. See also Albert M. Galaburda, interview by Tabea Cornel; Albert M. Galaburda, "Anatomy of Developmental Dyslexia: Geschwind's Last Legacy," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 90.
[775] Albert M. Galaburda, "Anatomy of Developmental Dyslexia: Geschwind's Last Legacy," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 89.
[776] Albert M. Galaburda, "Anatomy of Developmental Dyslexia: Geschwind's Last Legacy," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 92. As soon as Galaburda had the brain of an individual with dyslexia at his disposal, however, he found that Geschwind's prediction had been wrong; Albert M. Galaburda, interview by Tabea Cornel.

adulthood could only occur in response to serious brain insults.[777] To arrive at this conclusion, Geschwind had to ignore the fact that Nottebohm's research was about the creation of new neurons in adulthood. He took Nottebohm's findings on the seasonal changes in songbirds' brains as evidence for the hormone-related lateralization of function in humans, but he did not adopt the view that brain plasticity continues in the healthy adult brain.[778] Aside from recovery of function, adult brains were fixed to Geschwind.

Geschwind's reluctance to jump onto the plasticity bandwagon was rooted in his neurological practice and resonated with Cold War fears of the totalitarian potential of behaviorism. According to Geschwind, regenerative plasticity after an injury was undirected neuronal growth, which might negatively impact previously healthy pathways. Consequently, Geschwind believed that plasticity was "probably bad in most cases," and Galaburda agreed with him.[779] This idea of a threatening regime of plastic cells in the adult brain mirrored the controversies surrounding behavioral concepts of plasticity up to the mid-1970s.[780] Contrary to twenty-first-century notions of freedom and regeneration, US-American behaviorists defined plasticity as a human potential to respond to operant conditioning, that is, external and potentially corrupting influences. Cold War officials associated this behavioral form of plasticity with fears of "brainwashing," "mind-control techniques," and "totalitarianism."[781]

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[777] Norman Geschwind, Another Mechanism of Recovery, August 3, 1973, H MS c435, Box 7, Folder 1, Conference on Recovery of Function, 1972–1973, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–5.
[778] Geschwind and Galaburda, "Cerebral," 442.
[779] Albert M. Galaburda, interview by Tabea Cornel. See also Albert M. Galaburda, "Anatomy of Developmental Dyslexia: Geschwind's Last Legacy," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 90.
[780] Catherina Gere, "Plasticity, Pathology, and Pleasure in Cold War America," in Bates; Bassiri, *Plasticity and Pathology*.
[781] Catherina Gere, "Plasticity, Pathology, and Pleasure in Cold War America," in Bates; Bassiri, *Plasticity and Pathology*, 36.

Geschwind and Galaburda presented the GBG model as a way out of genetic determinism despite their rejection of healthy brain plasticity in adulthood. In their own words, "an individual could have different dominance characteristics if the fertilized ovum were transplanted into another mother's uterus," and "even if one knew precisely the genetic endowment of any particular fetus, one would not be able to predict the exact lateralization pattern of the brain."[782]

Galaburda and Geschwind tried to downplay the GBG model's implication that the brain is wired *in utero* and fixed in adulthood, because continuing brain plasticity was essential to therapeutic interventions. The neurologists might have left open the backdoor for fixes of anomalous dominance in adulthood for reasons of therapeutic potential. It was almost impossible to gauge the neurological condition and cognitive abilities of a fetus, and hence interventions to correct anomalous dominance *in utero* seemed hopeless. However, hormone supplements and similar therapies in adults would be relatively easy to apply, the authors suggested.[783]

Geschwind seemed less optimistic about the human ability to intervene in nature in his handwritten notes than in his publications. He noted towards the end of a fifteen-page manuscript that "[b]iology is fate only when we are ignorant of mechanism ... [W]e can transcend it to some extent, but only if we understand it."[784] In a written monologue, he wondered if one were able to determine the exact ratio by which nature and nurture impacted individual development.[785] Galaburda suggested that Geschwind's trust in

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782 Geschwind and Galaburda, "Cerebral," 532–33.
783 Geschwind and Galaburda, "Cerebral," 536.
784 Norman Geschwind, Untitled Text about the Long-Lasting Impacts of Nineteenth-Century Science, n.d., H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 15.
785 Norman Geschwind, Note, n.d., H MS c435, Box 8, Folder 4, Meetings, 1982–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 3.

nature/fixity over nurture/plasticity won out, and that Geschwind remained “pretty much of a nativist.”[786]

These tensions between dynamic plasticity and localized fixity are mirrored in endocrinology itself, or at least Geschwind and colleagues’ understanding of it. On the one hand, the thought of hormonal effects historically bore a fundamentally plastic promise.[787] On the other hand, Geschwind’s neuroendocrinology was a very conservative localizationist doctrine.[788] According to Geschwind, one could always find the organ that, by virtue of an organism’s genetic constitution, synthesized a particular hormone.[789] Or, as Galaburda and Geschwind did, one could find circumscribed areas of tissue that did or did not have receptors for a particular hormone, again determined by genes. Furthermore, the sexed/gendered and sexualized qualities of testosterone put the alleged agent of plasticity in very close proximity with ideas of chromosomally determined sex.

Deliberate Reductionism in a Grand Unified Theory of Human Deviance

The reliance on a wide range of publications from other authors (as opposed to new empirical evidence) made possible Geschwind’s hypothesis regarding the

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786 Albert M. Galaburda, interview by Tabea Cornel.
787 Sengoopta, *Most*, 6.
788 Other versions of neuroendocrinology were (and are) much more plastic in that they allowed (and continue to allow) for environmental effects on the function of hormonal glands and hormone receptors; see, e.g., Sari M. van Anders and Neil V. Watson, “Social Neuroendocrinology,” *Human Nature* 17, no. 2 (2006), https://doi.org/10.1007/s12110-006-1018-7; David Crews, “Gamete Production, Sex Hormone Secretion, and Mating Behavior Uncoupled,” *Hormones and Behavior* 18, no. 1 (1984), https://doi.org/10.1016/0018-506X(84)90047-3; Thomas R. Insel et al., “Gonadal Steroids have Paradoxical Effects on Brain Oxytocin Receptors,” *Journal of Neuroendocrinology* 5, no. 6 (1993), https://doi.org/10.1111/j.1365-2826.1993.tb00531.x; Jonathan Lindzey and David Crews, “Effects of Progestins on Sexual Behaviour in Castrated Lizards (Cnemidophorus Inornatus),” *Journal of Endocrinology* 119, no. 2 (1988), https://doi.org/10.1677/joe.0.1190265; Viktoria Y. Topper et al., “Social and Neuromolecular Phenotypes Are Programmed by Prenatal Exposures to Endocrine-Disrupting Chemicals,” *Molecular and Cellular Endocrinology* 479 (2019), https://doi.org/10.1016/j.mce.2018.09.010.
789 See also Sengoopta, *Most*, 205–13.

developing human brain, an object of investigation that was inaccessible via experiments or laboratory studies. US-American psychologist Stanley Coren (b. 1942) remarked on Geschwind's scholarly "courage (or feistiness), which manifested itself in his willingness to express ideas that might elicit skepticism or outright disbelief at first hearing," but which actually connected "elements that reflected on the 'grand questions' of neural development."[790] It would have been difficult to answer these grand questions in any other way than by theoretical synthesis.

With the GBG model, Geschwind and Galaburda wanted to craft a Grand Unified Theory of human asymmetries as well as physical and mental impairments. They hoped that such a theory would connect "the study of evolution and embryology, … comparative zoology, … anatomy, pharmacology, physiology, endocrinology, and immunology—indeed, probably … every branch of biology and medicine."[791] Geschwind knew that this endeavor was bold, but it resonated with his conviction that "[a] good theory, even if it's wrong, is better than a boring fact."[792]

This Grand Unified Theory was not only deliberately bold, but also deliberately reductionist. As Geschwind noted, he saw the "advantage of reductionist explanations" in that they "force reevaluation of what else there is. ... Reductionist errors are testable; hence rapidly corrected; 'non-reductionist' errors are usually not and hence may hold up progress. All Science is reductionist."[793] Although Geschwind disliked philosophy, he

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790 Stanley Coren, "Left-Handed Blonds and Other Odd Correlations," in *Behavioral Neurology and the Legacy of Norman Geschwind*, ed. Steven C. Schachter and Orrin Devinsky (Philadelphia: Lippincott-Raven Publishers, 1997), 284.
791 Norman Geschwind and Peter O. Behan, "Laterality, Hormones, and Immunity," in Geschwind; Galaburda, *Cerebral Dominance*, 222.
792 Albert M. Galaburda, interview by Tabea Cornel.
793 Norman Geschwind, Note, 1979-08, H MS c435, Box 1, Folder 11, Correspondence, 1970–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine. See similar remarks in Norman

adopted a falsificationist view of science akin to that of Karl R. Popper (1902–1994) and argued that "reductionism is no *issue*."[794]

Reception

As Galaburda recalled, "people *hated* [the GBG model] ... The people in the field of lateralization *hated* it and ... everybody else loved it."[795] Although Geschwind passed away while the 1985 article was under review, this was not soon enough to evade severe criticism from physicians and laterality researchers. Geschwind and Behan's paper about the correlations between left-handedness and immune diseases sparked controversy in 1984.[796] David Wofsy, an immunologist at the University of California, San Francisco, criticized Geschwind and Behan's research on methodological grounds ("there is no basis for treating such divergent immune disorders as allergy and autoimmunity interchangea-bility [*sic*]"), and he complained that the publication omitted crucial information ("e.g., the gender of their subjects") and simultaneously provided data that did not support Geschwind and Behan's hypothesis.[797] Overall, Wofsy found the theory about an association between handedness and immunity to "rest on a weak foundation."[798]

Geschwind, Talk for Symposium, October 19, 1971, H MS c435, Box 6, Folder 26, Conferences, Lectures, 1970–1981, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–13.

794 Norman Geschwind, Note, n.d., H MS c435, Box 6, Folder 4, Notes, undated, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–9 (quote on p. 4). Italics in the original.

795 Albert M. Galaburda, interview by Tabea Cornel. Evidence in Geschwind's archival collection of numerous invited lectures of Geschwind to immunologists, developmental psychiatrists, migraine researchers, etc. corroborate this impression.

796 Norman Geschwind and Peter O. Behan, "Hormones, Handedness and Immunity," *Immunology Today* 5, no. 7 (1984), https://doi.org/10.1016/0167-5699(84)90215-9.

797 David Wofsy, "Hormones, Handedness, and Autoimmunity," *Immunology Today* 5, no. 6 (1984): 170, https://doi.org/10.1016/0167-5699(84)90009-4.

798 Wofsy, "Hormones, Handedness, and Autoimmunity," 170.

Wofsy's criticism was not only scientific, but also moral. He pointed to the extreme social impact that Behan and Geschwind's work might have on the public perception of gendered talents, or of the cognitive abilities of left-handers or individuals with autoimmune diseases. Wofsy argued that "a particularly high standard of scientific rigor and social conscience" was required to publish on a topic of such high social impact, and he found the "slender thread [in Geschwind and Behan's publication that] connects a series of controversial topics" unconvincing.[799]

Behan and Geschwind took the criticism very personally and drafted a rejoinder during a phone conversation.[800] The editor of *Immunology Today* refused to print it without alterations, because he deemed it "unjustly personal."[801] Although toned down, the printed version of the rejoinder provided sufficient insight into the neurologists' unwillingness to accept the social and moral implications of their wide-ranging theory. Geschwind and Behan repeatedly reminded their readers of the credibility of their research, which supposedly lay in the "large numbers" of subjects enrolled in their population study, and in "independent" observations that were in line with their hypothesis.[802] Furthermore, Behan and Geschwind played down their theory's discriminatory potential by stating that "there are no non-controversial topics" of scientific inquiry.[803] They emphasized that their goal was to develop a "working hypothesis," which was justified by the prospect of "help[ing] to prevent or alleviate … the impairments produced by

[799] Wofsy, "Hormones, Handedness, and Autoimmunity," 170.
[800] Peter O. Behan, "Handedness and Autoimmune Disease," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 288.
[801] John R. Inglis, Inglis to Geschwind, 05-22-1984, H MS c435, Box 2, Folder 26, Writings and Reviews (1 of 2), 1979–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1.
[802] Geschwind and Behan, "Hormones," 190.
[803] Geschwind and Behan, "Hormones," 191.

immune disease or learning disabilities, or to extend … the limits of human potential," at least to some extent.[804]

Wofsy rejoined the rejoinder. Repeating his previous critiques and resonating with the aforementioned metaphor of playing dominoes, he pointed to "some specious reasoning" and "a series of loose associations" in Geschwind and Behan's publication.[805] He furthermore restated the motivation of his critique, namely:

> that the wide dissemination of unsubstantiated hypotheses concerning such sensitive social issues as the basis for scholastic aptitude might have harmful, even if unintended, consequences. … Unwillingness to consider the implications of propagating elaborate hypotheses from preliminary data cannot be justified simply in the name of intellectual curiosity or scientific controversy.[806]

When talking about the push-back against the GBG model, Galaburda also suggested that: "mostly, the British hated [the GBG model], but ... they hate everything."[807] The reason for the disagreement of British scientists might not have been their nationality but their preeminence in late-twentieth-century handedness research. McManus, Annett, and their colleagues reproached the GBG model for being overly theoretical and not grounded in empirical research; for being methodologically problematic; for not distinguishing between left-handedness and anomalous dominance; for contributing nothing more than "a confusing and overly complex explanation" of Annett's Right Shift theory;

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[804] Geschwind and Behan, "Hormones," 191.
[805] David Wofsy, "Reply," *Immunology Today* 5, no. 7 (1984): 191, https://doi.org/10.1016/0167-5699(84)90216-0.
[806] Wofsy, "Reply," 192.
[807] Albert M. Galaburda, interview by Tabea Cornel.

and for being “unfalsifiable,” the direct opposite of Geschwind’s intention of providing an easily falsifiable reductionist hypothesis.[808]

The one critic with whom Geschwind was probably closest was US-American psychologist Jerre Levy (b. 1938). According to the archival record, Geschwind and Levy corresponded repeatedly from 1977 to 1983, and they met several times in professional and private settings.[809] Levy herself developed causal theories of handedness (Chapter 3) and speculated about a comparably high rate of left-handers among “homosexual[s].”[810] Nonetheless, she disagreed with several aspects of Geschwind’s theory, most of all with its alignment with brain organization theory.

As early as in 1978, Levy called Geschwind’s attention to conflicting data about the relationship between handedness and cerebral dominance.[811] Her critique got much more comprehensive in 1983. Levy disapproved of Geschwind’s adherence to “the classical organizing hypothesis” (the theory that the brain is sexed/gendered and sexualized by prenatal testosterone exposure), which she considered “widely accepted ... but ..., nonetheless, false.”[812] Levy suggested that left-hemispheric impairments in males might derive from the absence of estrogen, not necessarily the presence of testosterone.

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808 Kushner, *On*, 101–3 (quotes on p. 103 and p. 102). See also Corballis, *The Lopsided Ape*, 201–2.
809 For an impression of how close Levy was with Norman and Patricia Geschwind, see Jerre Levy, Levy to Geschwind, February 11, 1981, H MS c435, Box 1, Folder 13, Correspondence, 1972–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2.
810 Jerre Levy, Levy to Geschwind, 02-21-1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 6. On Levy’s plans to recruit research subjects in “‘gay’ bars,” see Levy, Levy to Geschwind, 6. On Levy’s genetic theory of handedness, see Chapter 3.
811 Jerre Levy, Levy to Geschwind, August 9, 1978, H MS c435, Box 1, Folder 7, Correspondence, 1964–1982, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–4.
812 Levy, Levy to Geschwind, 1.

Furthermore, she questioned whether rodent data, on which the GBG model heavily, rested was generalizable to humans.[813]

Geschwind responded politely but assertively. He stated that he was convinced of the value of brain organization theory. “Despite my great skepticism about it,” he wrote to Levy, “I believe that it is, in fact, essentially correct, except perhaps for some details.”[814] These might have been the last letters that the two researchers exchanged.

Galaburda suggested that Geschwind took the repeated criticism of his hypothesis very much to heart, although he usually enjoyed a good argument. The absence of correspondence from the last year of Geschwind’s life corroborates Galaburda’s impression that Geschwind was downcast and offended.[815] It might have been due to these controversies that some scholars who subsequently investigated the relationship between hormones and laterality chose not to cite Geschwind and colleagues at all.[816]

Galaburda no longer believes that the GBG model is correct, but he values it for being an “interesting” idea that stimulated much original research.[817] Be that as it may, Galaburda’s recollection that numerous people loved the GBG model was correct. On a poster announcing one of Geschwind’s lectures in Iowa in 1984, Geschwind was praised

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[813] Levy, Levy to Geschwind, 2–3.
[814] Geschwind, Geschwind to Levy, 1.
[815] Albert M. Galaburda, interview by Tabea Cornel. It is, of course, possible that Geschwind continued his correspondence and merely did not archive the letters. Up to 1983, Geschwind was very careful in filing the letters he received and copies of his responses. In any case, the virtual absence of correspondence from 1984 and 1985 points to a significant deviation from Geschwind’s earlier habits.
[816] E.g., Walter F. McKeever, “Handedness, Language Laterality and Spatial Ability,” in *Cerebral Laterality: Theory and Research*, ed. Frederick L. Kitterle (Hillsdale: Lawrence Erlbaum Associates, 1991); Iris E. C. Sommer, “Sex Differences in Handedness, Brain Asymmetry, and Language Lateralization,” in Hugdahl; Westerhausen, *The Two Halves of the Brain*, 302–3.
[817] Albert M. Galaburda, interview by Tabea Cornel. See also Albert M. Galaburda, “Anatomy of Developmental Dyslexia: Geschwind’s Last Legacy,” in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 92–93; Kushner, *On*, 104–5.

as one of the leading post-war neurologists.[818] Furthermore, numerous workshop announcements, newspaper clippings, and thank-you notes in Geschwind's archival collection reveal that medical professionals and the broader public in North America and continental Europe greeted the GBG model with much enthusiasm.[819] Moreover, Geschwind presented the GBG model at the World Congress of Neuroimmunology with great success.[820]

Popular science writers also fancied the GBG model. British filmmaker Jo Durden-Smith (1941–2007) and his wife Diane DeSimone, for instance, invited Geschwind's feedback on their book manuscript for *Sex and the Brain*, which introduced the hypothesis in two chapters.[821] Geschwind was polite but not excited about how he and his theory were presented in the book, and he corrected multiple errors in the manuscript that DeSimone had sent to him.[822]

The GBG model seems to have propped open the floodgates to left-hander discrimination in the scientific and popular press. Coren played a major part in popularizing

[818] Department of Neurology, University of Iowa, Norman Geschwind, M.D., n.d., H MS c435, Box 8, Folder 4, Meetings, 1982–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1.
[819] See, e.g., N.N., Male Hormone Linked to Left Handedness, Autoimmune Disease; Paul S. Russell, Faculty of Medicine, Minutes of the Meeting of January 28, 1983, n.d., H MS c435, Box 4, Folder 17, Denny-Brown, Derek, 1982–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine, 3–4; Anne Semmes Groo, Researcher Cites Link Between Maladies and Left-Handedness, October 4, 1983, H MS c435, Box 4, Folder 16, Clippings, undated, Center for the History of Medicine, Francis A. Countway Library of Medicine.
[820] Peter O. Behan, "Handedness and Autoimmune Disease," in Schachter; Devinsky, *Behavioral Neurology and the Legacy of Norman Geschwind*, 289.
[821] Jo Durden-Smith and Diane DeSimone, *Sex and the Brain* (New York: Arbor House, 1983).
[822] Diane DeSimone, DeSimone to Geschwind, February 6, 1983, H MS c435, Box 4, Folder 19, Denny-Brown, Derek (2 of 2), 1977–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine, 1–2; Diane DeSimone and Jo Durden-Smith, Untitled Document, n.d., H MS c435, Box 4, Folder 19, Denny-Brown, Derek (2 of 2), 1977–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine; Norman Geschwind, Geschwind to DeSimone and Durden-Smith, February 14, 1983, H MS c435, Box 4, Folder 19, Denny-Brown, Derek (2 of 2), 1977–1983, Center for the History of Medicine, Francis A. Countway Library of Medicine.

a pathology-focused version of the GBG model and promoting it in scientific circles.[823] In 1990, Coren edited a volume that defended the GBG model against critics and extended its reach.[824] Galaburda contributed to the volume,[825] although he was already doubting the GBG model at the time.[826] Most of the contributors to the volume claimed that left-handedness was pathological in many cases, and that it derived from perinatal stress (which might include testosterone exposure) and/or birth stress. An exception to this rule was US-American psychologist Lauren J. Harris, who chose to contribute a chapter on "Cultural Influences on Handedness."[827] Other contributions explored associations between left-handedness and manifold non-normative characteristics or behaviors, including immune disorders, hemiplegia, "mental retardation," psychosis, schizophrenia, autism, alcoholism, "criminality," and premature death.[828]

Shortly after editing this volume, Coren selectively reviewed previous studies on handedness in his popular monograph *The Left-Hander Syndrome* and concluded that "[t]he historical and evolutionary evidence suggests that all human beings probably carry

[823] For a summary of Coren's work, see Kushner, *On*, 100–101.
[824] Stanley Coren, ed., *Left-Handedness: Behavioral Implications and Anomalies,* Advances in Psychology 67 (Amsterdam: North-Holland, 1990).
[825] Michel Habib, Florence Touze, and Albert M. Galaburda, "Intrauterine Factors in Sinistrality: A Review," in Coren, *Left-Handedness*.
[826] Kushner, *On,* 104–5.
[827] Lauren J. Harris, "Cultural Influences on Handedness: Historical and Contemporary Theory and Evidence," in Coren, *Left-Handedness*.
[828] Susan E. Bryson, "Autism and Anomalous Handedness," in Coren, *Left-Handedness;* Lee Ellis, "Left- and Mixed-Handedness and Criminality: Explanations for a Probable Relationship," in Coren, *Left-Handedness*; Pierre Flor-Henry, "Sinistrality and Psychopathology," in Coren, *Left-Handedness*; Diane F. Halpern and Stanley Coren, "Laterality and Longevity: Is Left-Handedness Associated with a Younger Age at Death?" in Coren, *Left-Handedness*; Merrill Hiscock and Cheryl K. Hiscock, "Laterality in Hemiplegic Children: Implications for the Concept of Pathological Left-Handedness," in Coren, *Left-Handedness*; Wayne P. London, "Left-Handedness and Alcoholism," in Coren, *Left-Handedness*; Margaret-Ellen Pipe, "Mental Retardation and Left-Handedness: Evidence and Theories," in Coren, *Left-Handedness*; Paul Satz et al., "The Neuroanatomy of Atypical Handedness in Schizophrenia," in Coren, *Left-Handedness*.

the genetic coding to be right-handed."[829] In Coren's view, right-handedness was as elementary a characteristic as "the tendency to have five fingers on each hand,"[830] and he proposed that the majority of left-handers owed their manual preference to "pathological processes."[831] Coren coined the term "alinormal" (instead of "abnormal") for left-handers,[832] and he cautioned that left-handers were "not definitely pathological, but … likely to have some pathological condition."[833]

Throwing this caution to the winds, Coren analyzed in detail the supposed ways in which left-handedness is caused by brain damage. Such brain damage could be inflicted by the fetal environment before birth (an explicit nod to the GBG model)[834]; premature birth; and/or during birth, when "birth stress" and the associated lack of oxygen or other factors might cause left-hemispheric damage to the brain.[835] Going beyond the GBG model and the contributors to Coren's edited volume,[836] Coren named a range of additional characteristics that he thought were associated with left-handedness, including "attempted suicide," "bed-wetting," "chromosomal damage," "drug abuse," "emotionality,"

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[829] Stanley Coren, *The Left-Hander Syndrome: The Causes and Consequences of Left-Handedness* (New York: The Free Press, 1992), 410. Coren and his colleague had published the same argument a decade earlier in a more scholarly monograph; Porac and Coren, *Lateral*.
[830] Coren, *Left,* 83. See also Coren, "Pathological Causes and Consequences of Left-Handedness," 84–88.
[831] Coren, "Pathological Causes and Consequences of Left-Handedness," 93.
[832] Coren explained this term as follows: "The *ali* in 'alinormal' is the same as the *ali* in 'alibi', and it means 'elsewhere' or 'otherwise' … Thus we could say that although left-handedness itself may arise from pathological influences, we begin with the presumption that any given left-hander is otherwise normal"; Coren, *Left*, 169.
[833] Coren, *Left*, 163.
[834] Coren, *Left*, 188–94.
[835] Coren, *Left*, 139–52. According to the research that Coren drew on, the "normal" position of the fetus during birth made it more likely for the left hemisphere to be deprived of oxygen than the right one; Coren, *Left*, 139. For a table providing an overview of the correlation between different birth stressors and parental handedness, see Coren, "Pathological Causes and Consequences of Left-Handedness," 95.
[836] Coren, *Left*.

"neuroticism," "predisposition towards aggression," "school failure," "sleep difficulty," and "slow physical development."[837]

Several studies since the publication of the GBG model, including meta-analyses, have repeated the claim that testosterone and handedness are related.[838] However, some of them suggested that *low* levels of testosterone are associated with left-handedness, and not *high* levels, as Geschwind and colleagues had suggested.[839] US-American psychologist and laterality researcher Clare Porac did not give much credence to these studies. She argued that it is "*fiction*" that prenatal testosterone causes sex differences in manual preference or determines the rates of left-handers in groups of a particular sexual orientation.[840] Versions of this fiction are still taken for a fact by various neuroscientists.[841]

Research on mirror neurons and epigenetics as well as the introduction of novel neuroimaging methods in the 1980s added yet again to the number of epistemic things that are contained in the brain multiple. How these new theories and technologies

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[837] Coren, *Left*, 153–54. For a relatively recent textbook reiteration the idea that the "type[s]" of the "pathological left-hander" and the "normal left-hander" need to be distinguished, see Ira B. Perelle and Lee Ehrman, "Handedness: A Behavioral Laterality Manifestation," in Kim, *Handbook of Behavior Genetics*, 338.
[838] E.g., G. C. Westergaard et al., "Hormonal Correlates of Hand Preference in Free-Ranging Primates," *Neuropsychopharmacology* 23, no. 5 (2000), https://doi.org/10.1016/S0893-133X(00)00141-X.
[839] Porac, *Laterality*, 73–75.
[840] Porac, *Laterality*, 81. Italics in the original.
[841] E.g., Kovel, Carolien G. F. de, Amaia Carrión-Castillo, and Clyde Francks, "A Large-Scale Population Study of Early Life Factors Influencing Left-Handedness," *Nature Scientific Reports* 9, no. 1, https://doi.org/10.1038/s41598-018-37423-8; Michael V. Lombardo et al., "Fetal Testosterone Influences Sexually Dimorphic Gray Matter in the Human Brain," *Journal of Neuroscience* 32, no. 2 (2012), https://doi.org/10.1523/JNEUROSCI.4389-11.2012; N. Negrev, Piareta Nikolova, and R. Nikolova, "Serum Levels of Female Sex Hormones in Left-Handed and Right-Handed Menopausal Women," *Laterality* 5, no. 1 (2000), https://doi.org/10.1080/713754352; Westergaard et al., "Hormonal Correlates of Hand Preference in Free-Ranging Primates". See also the theory of male and female brains, including a testosterone-related theory of autism, in Simon Baron-Cohen, "The extreme male brain theory of autism," *Trends in Cognitive Sciences* 6, no. 6 (2002), https://doi.org/10.1016/S1364-6613(02)01904-6; Simon Baron-Cohen, *The Essential Difference* (New York: Basic Books, 2003). For critiques of Baron-Cohen's theory, see Fine, *Delusions*, 99–106; Grossi and Fine, "Role"; Nicole C. Karafyllis, "Oneself as Another? Autism and Emotional Intelligence as Pop Science, and the Establishment of 'Essential' Differences," in Karafyllis; Ulshöfer, *Sexualized Brains*.

intervened in research on manual preference and how they continued the marginalization of non-right-handers are the topics of the next and final chapter.

CHAPTER 5

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THE MULTIPLE MULTIPLIED

> To the casual observer, these lists [of correlations between left-handedness and pathologies] probably seem to be overinclusive. In much the same way that the popular press seems to claim that there is no human activity that does not ultimately lead to heart failure, it would almost seem that neuropsychologists are claiming that there is no negative aspect of human health or behavior that is not associated with left-handedness. Does that make sense?[842]

Introduction

To end this history of a story that is still unfolding, the present chapter provides insight into the most recent theories of the causes of manual preference and brain asymmetry. From the late nineteenth through the late twentieth century, the list of potential causes for handedness included anatomical, physiological, genetic, and hormonal mechanisms. More recently, scientists have proposed that the roots of handedness might lie in the brain's mirror-neuron system or in epigenetic mechanisms underlying the asymmetric expression of genes in the brain and spinal cord. Neither of the two theories aroused as much public interest as previous models had done, possibly because the science behind the proposed mechanisms has become increasingly difficult to understand. Nonetheless,

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[842] Coren, "Left," 273.

the two most recent theories multiplied once more the number of epistemic “brain” things, and they did not do away with the stereotype of the pathological left-hander.

The pervasiveness of the trope of the sinister left-hander also becomes visible in an analysis of over 1,300 scientific journal articles on the relationship between the brain and the hand. Large-scale digital text analyses of these sources revealed that neuroscientists continue to associate left-handedness and right-brainedness with anatomical abnormalities, learning disorders, and psychiatric illnesses. Because of this stigmatization, left-handers remain excluded from most neuroscientific and neurogenetic studies, despite isolated calls to include this significant minority into the participant pool of neuroscientific research.[843]

Since the late twentieth century, the exclusion of left-handers from neuroscientific experiments and unsuccessful attempts to determine the causes of handedness have been paralleled by successful attempts to monetize the troubles of left-handers *and* right-handers’ anxieties that they (right-handers) are “too normal” and have to break out of their conservative patterns to achieve superior productivity. A look at parent-advice literature, self-help books, and psychological consulting businesses shows that handedness has become a significant stage on which biopower is enacted, and a field of responsibility for neoliberal citizens to perfect themselves and their labor.

The continued singling-out of left-handers in combination with the absence of empirical studies on the concrete features of their presumed deviance is problematic. If left-handers are not given a voice—or a scan—in neuroscientific laboratories, neuroscientific studies cannot be representative of the entire population (an epistemic problem).

843 Willems et al., “On”.

The exclusion of non-right-handers from many neuroscientific experiments also subverts moral commitments to an inclusive society (an ethical problem). If scientists believe that left-handedness is a deviance, they have to conduct empirical studies with left-handers and formulate a coherent theory of their pathologies. If scientists do not believe that left-handedness is a deviance, they have to stop excluding left-handers from their studies and end the "risk" discourse surrounding non-right-handedness. In any case, to allow for generalizing findings in neuroscientific studies to the general population, scientists have to include the same proportion of left-handers into their experiments as there is in the general population (presumably about 10 percent).

I close with an answer to the question that I get asked second-most frequently: "Which of the theories of handedness do *you* think are true?"[844]

More Etiological Theories

Mirror Neurons

The theory that handedness is associated with the mirror-neuron system of the brain is a reformulation of the old claim that handedness, brain asymmetry, and articulate speech are closely associated. The mirror-neuron theory of handedness incorporated a proto-idea from the late eighteenth century: the argument that gestural communication might have been a precursor to articulate speech. French philosopher Étienne Bonnot de Condillac (1714–1780) and Italian philosopher Giambattista Vico (1668–1744) proposed this so-called "gesture-first" theory, and various anthropologists and natural scientists

[844] The most-frequently asked question is: "Are you left-handed?" I responded to it in the Preface.

endorsed it in the nineteenth century, including physiologist Wilhelm M. Wundt (1832–1920).[845]

In the 1960s, bolstering the assumption that sign language was an evolutionary predecessor to articulate speech, US-American psychologist Beatrix T. Gardner (1933–1995) and her husband R. Allen Gardner (b. 1936?) taught sign language to chimpanzees. US-American anthropologist Gordon W. Hewes (1917–1997) widely promoted and reinvigorated the gesture-first theory in the following years, and the theory has numerous supporters to this day.[846] Adherents of the gesture-first theory uphold that "language can be understood as a gestural system, with vocal gestures [that is, movements of the lips, velum and larynx, as well as the blade, body, and root of the tongue] gradually replacing manual and perhaps facial ones."[847]

The popularity of the gesture-first theory in the twenty-first century can in large part be attributed to mirror-neuron research,[848] a cutting-edge neuroscientific subfield that

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845 Adam Kendon, "Reflections on the 'Gesture-First' Hypothesis of Language Origins," *Psychonomic Bulletin & Review* 24, no. 1 (2016): 163, https://doi.org/10.3758/s13423-016-1117-3. See also Michael C. Corballis, "The Gestural Origins of Language," *Wiley Interdisciplinary Reviews Cognitive Science* 1, no. 1 (2010): 2, https://doi.org/10.1002/wcs.2; Michael C. Corballis, *The Recursive Mind: The Origins of Human Language, Thought, and Civilization* (Princeton: Princeton University Press, 2011), 57–59; Michael C. Corballis, *The Truth about Language: What It Is and Where It Came From* (Chicago, London: University of Chicago Press, 2017), 123–28.

846 Corballis, "The Gestural Origins of Language," 2–3; Corballis, *The Recursive Mind*, 59; Kendon, "Reflections on the 'Gesture-First' Hypothesis of Language Origins," 163–64. Kendon opposed the gesture-first theory and suggested instead that language has evolved from the movements of mouth and tongue. He argued that the sign language of chimpanzees and other non-human animals probably on reaches lower-level "symbolic" levels, and only in captivity and when taught by humans; Kendon, "Reflections on the 'Gesture-First' Hypothesis of Language Origins," 164. Other authors have denied the existence of a non-human ability for symbolic communication; see, e.g., Terrence William Deacon, *The Symbolic Species: The Co-Evolution of Language and the Brain* (New York: W.W. Norton & Company, 1998). Cf. the argument that social cognition has been much more important for the evolution of language than symbolic thinking; Benoît Dubreuil and Christopher S. Henshilwood, "Material Culture and Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*.

847 Corballis, "The Gestural Origins of Language," 3.

848 Corballis suggested that mirror-neuron research has "boosted" the gesture-first theory, but I think that this is an understatement considering the unprecedented credibility with which mirror-neuron theory endowed Corballis's highly speculative theory; Corballis, "The Gestural Origins of Language," 4. After Corballis had added mirror neurons to his theory on the origins of language, he was invited to a two-week

has silenced many opponents of the admittedly "speculative" gesture-first theory.[849] In the 1990s, Italian neurophysiologists Giacomo Rizzolatti (b. 1937), Leonardo Fogassi (b. 1958), Vittorio Gallese (b. 1959), Luciano Fadiga (b. 1961), and Giuseppe Di Pellegrino made the coincidental observation that motor action and its visual perception share the same neural pathways. Specifically, they recorded neural activity in area F5, located in the ventral premotor cortex, in macaque monkeys. The researchers found a similar brain activation pattern when a monkey grasped food and when the monkey observed an experimenter perform the same movement.[850]

Scientists assumed that mirror neurons in monkeys provide evidence for the evolution of human speech because neuroscience still rests on conservative localizationist doctrines. The area F5 in primates corresponds to part of Broca's area in humans, that is, the neural center for articulate speech. To be more precise, neuroscientists sub-divide Broca's area in humans into Brodman's area 44 and 45, and Brodman's area 44 is "considered the true analog of area F5" in non-human primates.[851] Brodman's area 44 is also

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workshop in 2010 for over 150 researchers and students who work on the "problem" of language. Corballis contributed one out of twenty-one chapters to the resulting edited volume; Michael C. Corballis, "Gestural Theory of the Origins of Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*. The editors justified Corballis's chapter on the gesture-first theory, an "idea that has not found much support among linguists or anthropologists," by noting that mirror-neuron research lends "[i]ndirect support" to the theory; Claire Lefebvre, Bernard Comrie and Henri Cohen, eds., *New Perspectives on the Origins of Language*, Studies in Language Companion Series 144 (Amsterdam, Philadelphia: John Benjamins Publishing Company, 2013), XII.

[849] Corballis, *truth*, 1.

[850] For a history of mirror-neuron research, see Katja M. Guenther, "Imperfect Reflections: Norms, Pathology, and Difference in Mirror Neuron Research," in Bates; Bassiri, *Plasticity and Pathology*. For reviews of the most important primary literature, see Ferdinand Binkofski and Giovanni Buccino, "Motor Functions of the Broca's Region," *Brain and Language* 89, no. 2 (2004), https://doi.org/10.1016/S0093-934X(03)00358-4; Giacomo Rizzolatti, Leonardo Fogassi, and Vittorio Gallese, "Neurophysiological Mechanisms Underlying the Understanding and Imitation of Action," *Nature Reviews Neuroscience* 2, no. 9 (2001), https://doi.org/10.1038/35090060; Giacomo Rizzolatti and Laila Craighero, "The Mirror-Neuron System," *Annual Review of Neuroscience* 27 (2004), https://doi.org/10.1146/annurev.neuro.27.070203.144230. On mirror-neuron-related theories of aesthetic perception, see Vidal and Ortega, *Being*, 123–29.

[851] Corballis, "The Gestural Origins of Language," 4.

supposed to underlie hand-movements and other motor actions that are unrelated to articulate speech. Supporters of the gesture-first theory take this dual responsibility as additional evidence for their claim that human speech has evolved from a gestural proto-language in apes.[852]

The gesture-first theory does not automatically follow from mirror-neuron research. Mirror-neuron theory only suggests "that perceiving a speech sound should activate the same motor representation in the brain as producing that speech sound."[853] Several neuroimaging studies and experiments with transcranial magnetic stimulation have supported this hypothesis.[854] Since the first description of the mirror-neuron system in the 1990s as "a system for action understanding," neuroscientists have reframed mirror neurons as the neurological basis for empathy, theory of mind, and communication.[855]

New Zealand psychologist Michael C. Corballis (b. 1936) has most prominently linked mirror-neuron theory to the idea that gesture was a proto-language.[856] In 1970, even before Geschwind started working on his grand theory of laterality (Chapter 4),

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[852] Corballis, "The Gestural Origins of Language," 4.
[853] Roel M. Willems and Peter Hagoort, "Neural Evidence for the Interplay between Language, Gesture, and Action: A Review," *Brain and Language* 101, no. 3 (2007): 280, https://doi.org/10.1016/j.bandl.2007.03.004.
[854] Willems and Hagoort, "Neural Evidence for the Interplay between Language, Gesture, and Action," 280–81.
[855] Corballis, "The Gestural Origins of Language," 4.
[856] There are some promoters of the idea who have been more silent than Corballis. For example, Arbib himself has suggested that gestural and spoken proto-languages derived from the mirror-neuron system; Michael A. Arbib, "From Monkey-Like Action Recognition to Human Language: An Evolutionary Framework for Neurolinguistics," *Behavioral and Brain Sciences* 28, no. 2 (2005), https://doi.org/10.1017/S0140525X05000038; Michael A. Arbib, "Mirror Systems: Evolving Imitation and the Bridge from Praxis to Language," in Tallerman; Gibson, *The Oxford Handbook of Language Evolution*; Michael A. Arbib, "Evolving a Bridge from Praxis to Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*. For researchers who welcomed the addition of mirror neurons to the gesture-first theory but did *not* provide empirical evidence to support it, see Denis Bouchard, "Arbitrary Signs and the Emergence of Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*; Blondin A. Massé et al., "Symbol Grounding and the Origin of Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*; Nathalie Tzourio-Mazoyer and Cyril Courtin, "Brain Lateralization and the Emergence of Language," in Lefebvre; Comrie; Cohen, *New Perspectives on the Origins of Language*.

Corballis started publishing on questions of laterality and language.[857] After several iterations of his take on the gesture-first hypothesis, Corballis suggested in 2017 that articulate speech was a form of "*miniaturization*" of gestural language, which freed the hands of our bipedal ancestors for tasks other than communication.[858] Specifically, this movement of speech from the hands into the mouth would have enabled early hominins to communicate during their hunts and fights, which might have put them at a significant advantage over other animals.

For two decades, Corballis proposed theories of the potential origins of handedness in his monographs. In 1983, he speculated that the specific direction of human laterality was rooted in "molecular asymmetries in biological tissue," which were exacerbated to large-scale functional and physical asymmetries during ontogenesis and species evolution.[859] Eight years later, the gesture-first theory led Corballis to hypothesize about handedness in more brain-centric terms.[860] He dropped the question of why left-handers are the minority, and he focused instead on the evolutionary processes by which left-brainedness, once established, led to right-handedness.

Corballis drew on US-American anthropologist Dean Falk's (b. 1944) concept of the "*field effect*" to explain how left-hemispheric dominance for speech might have spread to the hands.[861] In opposition to the gesture-first theory, Falk suggested that a neural center for language had been located in the left brain hemisphere since the early days

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[857] For a current bibliography of Corballis, see "Michael Corballis - Google Scholar Citations," accessed March 15, 2019, https://scholar.google.de/citations?hl=de&user=kSPEbcI-AAAAJ&view_op=list_works&sortby=pubdate.
[858] Corballis, *truth*, 147–71 (quote on p. 158). Italics in the original.
[859] Corballis, *Human*, 201. See also Michael C. Corballis, *From Hand to Mouth: The Origins of Language* (Princeton: Princeton University Press, 2002), 161–65.
[860] Corballis, *The Lopsided Ape*.
[861] Corballis, *The Lopsided Ape*, 186. Italics in the original.

of mammalian evolution, and that there was a continuous evolution from primate vocalizations to human language.[862] Subsequently, and visible only after the onset of bipedalism, a "*Field Effect on the brain*" caused a virtual overspill of left-hemispheric dominance for speech and speech-related movements to adjacent motor regions of the brain, making humans right-handed.[863] In Falk's own words:

> [N]eurological asymmetries homologous to those discovered in extant monkeys … ascended medially to include hand areas directly above association areas bordering on representations of tongue, lips, face, etc., as a neurological correlate of selection for a wider variety of communication behaviors (which were already localized in *left* hemispheres).[864]

Notwithstanding Falk's explicit rejection of the gesture-first hypothesis,[865] Corballis used her concept of the field effect to explain the neurological processes by which handedness might have developed from gestural proto-language.[866] He suggested that language and manual motor action were intrinsically intertwined from the early days of hominid evolution, because both of them relied at least in part on a shared neural center for communication. Corballis proposed that the close proximity of the neural centers for speech and manual motor action was *not* the sole reason why most of us are right-handed, an argument that opposed Falk's claim that dominance has coincidentally spilled over from speech to the hands. The contemporary neural center for articulate speech, Corballis argued, used to be the center for gestural language, and it has always been left-lateralized

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[862] Dean Falk, "Language, Handedness, and Primate Brains: Did the Australopithecines Sign?" *American Anthropologist* 82, no. 1 (1980): 75–76, https://doi.org/10.1525/aa.1980.82.1.02a00040.
[863] Falk, "Language, Handedness, and Primate Brains: Did the Australopithecines Sign?" 75. Italics in the original.
[864] Falk, "Language, Handedness, and Primate Brains: Did the Australopithecines Sign?" 75–76. Italics in the original.
[865] Falk, "Language, Handedness, and Primate Brains: Did the Australopithecines Sign?" 72.
[866] Corballis, *The Lopsided Ape*, 209–210; 213–214.

(maybe because of the aforementioned molecular asymmetries). As a consequence, humans (or a majority of them) have always favored their right hand in gestural communication.[867]

Corballis suggested that the field effect, potentially mediated by the genetic mechanism proposed by Marian Annett (Chapter 3), had caused left-brain dominance for gestural movements to spread to neighboring neural centers that underlay other intentional movements.[868] Most notably, he argued that the left-bias might have spread to the neural centers that control movements of the face and hands, which are adjacent to the neural center for gestural and/or vocalized communication. According to Corballis, this process turned the left hemisphere into a hub for praxic skills (that is, the ideation, planning, sequencing, and execution of purposive actions).[869]

The conceptual significance of mirror neurons to Corballis's version of the gesture-first theory and associated models of handedness is dubious. Corballis reiterated his initial argument that articulate speech derived from a gestural proto-language and that handedness was a consequence of a lateralized neural center for communication in his 2002 monograph *From Hand to Mouth*.[870] He interwove mirror neurons with the same account of gestural proto language that he had provided previously, now pointing to the overlap of neural foundations for motor actions and language in area F5 and Broca's area

[867] Corballis, *The Lopsided Ape*, 208–9. For an account of how the descent of the larynx in hominin evolution might have caused the switch from gestural language to vocalization, see Corballis, *The Lopsided Ape*, 155–65. On evolutionary changes in the anatomy of the head, throat, thorax, and abdomen that made possible articulate speech, see Corballis, *From*, 138–51.
[868] Corballis, *The Lopsided Ape*, 209. On Corballis's long adherence to Annett's genetic theory of laterality and the shared commitment to handedness as a continuous variable, see Corballis, *From*, 172–78.
[869] Corballis, *The Lopsided Ape*, 209–10.
[870] Corballis, *From*.

respectively. This strengthened but did not conceptually change Corballis's claim of the shared neural foundations for gesture and articulate speech.[871]

The addition of mirror neurons to the equation did not change Corballis's framework or the implication that lateralized generative abilities are what makes us human. In fact, the apparent differences between area F5 in monkeys and Broca's area further bolstered Corballis's claim that monkey communication (based on area F5) is much less complex than human communication (based on Broca's area). The former is found bilaterally in monkeys, whereas Broca's area only exists in the left cerebral hemisphere of most humans. Corballis assumed that simple cognitive tasks could be distributed across the brain, while complex cognitive tasks were commonly localized in small areas of the brain to facilitate the rapid interaction of different neural sub-centers.[872] This interpretation of the distribution of mirror neuron centers in monkeys, combined with the belief that mirror neurons are foundational to their communication, resonates with the idea that human language engages uniquely specialized lateralized brain centers and that articulate speech is the pinnacle of the evolution of primate communication.[873]

It seems that almost three decades' worth of research into mirror neurons has not clarified anything regarding the roots of handedness. In Corballis's two most recent monographs, the psychologist focused on the importance of theory of mind and "mental time travel" for language,[874] and on the structure of language and how it corresponds to other

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[871] Corballis, *From*, 46–48. See also Corballis, *From*, 214–15.
[872] Corballis, *From*, 46–47.
[873] Corballis conflated correlation with causation because he only claimed that complex tasks are localized, and not that all localized tasks are complex. Nonetheless, he suggested that the circumscribed lateralized speech center in Broca's area proves the complexity of human language. For an overview of the neuroscientific pattern of conflating correlation and causation in late-twentieth-century and early-twenty-first-century neuroscience, see Vidal and Ortega, *Being*, especially pp. 155–61.
[874] Corballis, *The Recursive Mind*.

aspects of human cognition.[875] Neither handedness nor laterality were substantially discussed in the books, let alone listed in their indices.

To some researchers and their audience, the compelling promise of the mirror-neuron system seemed to override important questions at the core of the gesture-first theory. For example: Why would articulate language evolve in apes, who have much better voluntary control over their limbs rather than their mouths and tongues? Why, in evolutionary terms, did early hominids switch from a gestural proto-language to articulate speech?[876]

One thing is certain: Corballis's model perpetuated many old ideas despite drawing on the topical doctrine of mirror neurons. First, the gesture-first theory, combined with the concept of a field effect, was a high point of the cerebralization of the hand. Corballis himself noted: "This explanation for handedness explains why handedness seems to have so little to do with the structure of the hands themselves."[877] This theory of handedness that has nothing to do with the hand also seemed to explain why previous evolutionary theories of handedness were fruitless, namely because right-handedness does not endow an individual with any evolutionary advantage. According to Corballis, "right-handedness may be *simply* a by-product of the left-hemispheric specialization for praxis."[878] In other words, manual preference is all in the brain, and as long as we can explain brain asymmetry, there is no need to furnish a separate explanation for handedness.

Corballis also did not break with the idea that left-handedness might be pathological. The theory of how bipedalism led to a left-hemispheric concentration for praxis does

[875] Corballis, *truth*.
[876] Kendon, "Reflections on the 'Gesture-First' Hypothesis of Language Origins," 165–67.
[877] Corballis, *The Lopsided Ape*, 209.
[878] Corballis, *The Lopsided Ape*, 209. Italics added.

not leave much room for left-handers. Admittedly, Corballis warned his readers not to write off all left-handers and right-brainers as inferior. Nonetheless, he insisted that there was "little direct information" to prove that left-handers were *not* inferior.[879]

Finally, bipedalism, left-lateralized praxis, and vocalized language kept the anthropological machine running in Corballis's work. Initially, Corballis assumed that the combined left-laterality of "vocal and manual praxis" (that is, left-brain dominance for speech-related movements and skilled movements of the hands) was *the* exceptional human quality. While other animals have shown left-hemispheric dominance for vocalization, humans seemed to be the only species that was also (relatively) consistently right-handed. This heterogeneity in manual preference suggested a concentration of all forms of praxis in the left hemisphere. Corballis speculated that humans, in whom all praxic skills are supposedly located in close proximity in the left hemisphere, had been able to carry out much more "complex praxic skills" than other organisms, in whom praxic centers are distributed across the cortex.[880]

Corballis saw the cause of this left-hemispheric center for praxis in bipedalism, although he could not specify the mechanism by which the freeing of the hands and the generation of tools shifted praxis into the left hemisphere.[881] He suggested that this exceptional human biology had allowed for the human property of "*generativity*," a core concept in Corballis's theory of human cognition.[882] Generativity emerged from Corballis's work as a precondition for behavioral and neural plasticity, which might have been

[879] Corballis, *The Lopsided Ape*, 281.
[880] Corballis, *The Lopsided Ape*, 214.
[881] Corballis, *The Lopsided Ape*, 305–7; Corballis, *From*, 66–81; 82–101.
[882] Corballis, *The Lopsided Ape*, 219. Italics in the original. See also Corballis, *The Lopsided Ape*, 308–9; Corballis, *From*, 204–11. On the biologically determined roots of this ability, see Corballis, *The Lopsided Ape*, 280–287; 302. On Corballis's understanding of language and its evolutionary origins, see Corballis, *truth*.

the necessary factors that underlay humans' "rapid and ready … means of adapting to the pace of environmental change,"[883] including the development of tools and articulate speech.[884] Corballis concluded that, by allowing for the development of generativity, bipedalism had been the stepping stone for the present "fundamental discontinuity between ourselves and other species."[885]

Corballis recently reviewed evidence for laterality in non-human animals, even in non-mammalian animals, and abandoned the idea "that laterality somehow defines the human condition."[886] However, he held on to the view that generativity, which allegedly underlies the human abilities to speak and "to manipulate the physical and biological environment, including each other," is both central and exclusive to humanity.[887]

Epigenetics

Epigenetic theories are the latest fad in handedness research (or, rather, they might become one). German psychologist Sebastian Ocklenburg and his collaborators have published several papers in the past three years that claim to have found a potential cause for handedness in DNA methylation (that is, the process by which methyl groups get attached to DNA molecules).[888] In 2016, Ocklenburg et al. found that methyltransferases *SETDB2* and *SETDB1* (enzymes that are involved in the methylation of DNA)

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[883] Corballis, *The Lopsided Ape*, 280–304. (quote on p. 280).
[884] On Corballis's view that "it is language that makes us human" and that other animals do not possess language, see Corballis, *From*, 20–40 (quote on p. 20).
[885] Corballis, *The Lopsided Ape*, 311.
[886] Michael C. Corballis, "Handedness and Cerebral Asymmetry: An Evolutionary Perspective," in Hugdahl; Westerhausen, *The Two Halves of the Brain*, 80.
[887] Michael C. Corballis, "Handedness and Cerebral Asymmetry: An Evolutionary Perspective," in Hugdahl; Westerhausen, *The Two Halves of the Brain*, 80.
[888] Methylation does not affect the gene sequence, but it can influence the expression of certain genes, which is per definition a problem of epigenetics—the environmentally dependent expression of one and the same gene.

correlated with the degree *and* direction of handedness in humans, indicating that DNA methylation is crucial for the ontogenesis of manual preference.[889] If handedness were determined by DNA methylation, this would explain why the search for a handedness gene has been fruitless. It would mean that left-handers and right-handers carry the same genes for physical asymmetries, only with varying methyl-groups on them.

Since 2016, Ocklenburg and colleagues have dug more deeply into epigenetic mechanisms that might be the key to unlocking the mystery of handedness. They have identified genes that are expressed asymmetrically in the human brain and spinal cord, that is, genes that cause different developmental processes/outcomes in the left half of the brain and body than in the right.[890] The researchers suggested that the methylation and resulting asymmetric expression of genes in the fetal spinal cord might precede handedness and brain asymmetries, because fetuses often exhibit hand/arm preferences even before the motor cortex and the spinal cord are fully connected.[891]

This epigenetic theory of handedness and brainedness in-the-making resonates with older theories in various ways. First, Ocklenburg et al.'s papers do not address the specific mechanisms by which physical asymmetries (no matter if in the brain or spinal cord) lead to manual preference. In fact, Ocklenburg and colleagues have suggested that

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[889] Sebastian Ocklenburg et al., "Left-Right Axis Differentiation and Functional Lateralization: A Haplotype in the Methyltransferase Encoding Gene SETDB2 Might Mediate Handedness in Healthy Adults," *Molecular Neurobiology* 53, no. 9 (2016), https://doi.org/10.1007/s12035-015-9534-2. On the distinction between degree (or "consistency") and direction of handedness, see footnote 523.

[890] Judith Schmitz et al., "DNA Methylation in Candidate Genes for Handedness Predicts Handedness Direction," *Laterality* 23, no. 4 (2018), https://doi.org/10.1080/1357650X.2017.1377726; Judith Schmitz et al., "Beyond the Genome: Towards an Epigenetic Understanding of Handedness Ontogenesis," *Progress in Neurobiology* 159 (2017), https://doi.org/10.1016/j.pneurobio.2017.10.005.

[891] Sebastian Ocklenburg et al., "Epigenetic Regulation of Lateralized Fetal Spinal Gene Expression Underlies Hemispheric Asymmetries," *eLife* 6 (2017), https://doi.org/10.7554/eLife.22784.

brainedness and handedness derive from different neurophysiological conditions and have separate genetic origins.[892]

The researchers' proposal that manual preference and brain asymmetry might have different (epi)genetic causes does *not* mean that handedness is about to escape the reign of the mind-, brain-, and neurosciences. Ocklenburg and his colleagues are (bio)psychologists and cognitive neuroscientists, and hence predominantly interested in matters of the brain and mind. Accordingly, their (epi)genetic investigations target genes whose expression determines the development of the brain and its functions, not the anatomy or physiology of the hand. Under this framework, handedness remains a function of the brain, even if researchers might start doubting whether it is a direct consequence of speech laterality.

Moreover, like previous models, the epigenetic theory of handedness lies in close proximity to investigations of socio-politically relevant topics. For instance, Ocklenburg has (co-)authored articles on connections between non-right-handedness and the androgen receptor gene on the X chromosome[893]; the relationship of handedness and lateralized brain activation in hugging and kissing[894]; and the connection between schizophrenia,

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[892] Sebastian Ocklenburg et al., "The Ontogenesis of Language Lateralization and Its Relation to Handedness," *Neuroscience and Biobehavioral Reviews* 43 (2014), https://doi.org/10.1016/j.neubiorev.2014.04.008; Judith Schmitz et al., "The Functional Genetics of Handedness and Language Lateralization: Insights from Gene Ontology, Pathway and Disease Association Analyses," *Frontiers in Psychology* 8 (2017), https://doi.org/10.3389/fpsyg.2017.01144.
[893] Larissa Arning et al., "Handedness and the X Chromosome: The Role of Androgen Receptor CAG-Repeat Length," *Nature Scientific Reports* 5 (2015), accessed March 15, 2019, https://doi.org/10.1038/srep08325, https://www.nature.com/articles/srep08325.
[894] Sebastian Ocklenburg and Onur Güntürkün, "Head-Turning Asymmetries during Kissing and Their Association with Lateral Preference," *Laterality* 14, no. 1 (2009), https://doi.org/10.1080/13576500802243689; Sebastian Ocklenburg et al., "Hugs and Kisses: The Role of Motor Preferences and Emotional Lateralization for Hemispheric Asymmetries in Human Social Touch," *Neuroscience and Biobehavioral Reviews* 95 (2018), https://doi.org/10.1016/j.neubiorev.2018.10.007.

speech lateralization, and handedness.[895] (Needless to say, the researchers operate from the assumption that individuals with schizophrenia have a higher incidence of left-handedness than the "normal" population.) Ocklenburg has also been involved in studies pertaining to the menstrual cycle (for example, changes in language lateralization[896] and visuo-tactile interaction[897]), and classical gendered stereotypes (for example, left-right confusion[898] and parking skills[899]). Last but not least, the question of whether non-human animals show consistent handedness or brainedness has been part of Ocklenburg and colleagues' research program.[900]

[895] Sebastian Ocklenburg et al., "Cholecystokinin a Receptor (CCKAR) Gene Variation Is Associated with Language Lateralization," *PLOS One* 8, no. 1 (2013), https://doi.org/10.1371/journal.pone.0053643; Sebastian Ocklenburg et al., "Laterality and Mental Disorders in the Postgenomic Age: A Closer Look at Schizophrenia and Language Lateralization," *Neuroscience and Biobehavioral Reviews* 59 (2015), https://doi.org/10.1016/j.neubiorev.2015.08.019; Sebastian Ocklenburg et al., "Auditory Hallucinations and Reduced Language Lateralization in Schizophrenia: A Meta-Analysis of Dichotic Listening Studies," *Journal of the International Neuropsychological Society* 19, no. 4 (2013), https://doi.org/10.1017/S1355617712001476.
[896] Handan Can et al., "Language Asymmetry and Hormonal Fluctuations During The Menstrual Cycle," *Journal of Neurological Sciences* 29, no. 4 (2012).
[897] Sebastian Ocklenburg et al., "Multisensory Integration across the Menstrual Cycle," *Frontiers in Psychology* 4 (2013), https://doi.org/10.3389/fpsyg.2013.00666.
[898] Marco Hirnstein et al., "Sex Differences in Left-Right Confusion Depend on Hemispheric Asymmetry," *Cortex* 45, no. 7 (2009), https://doi.org/10.1016/j.cortex.2008.11.009; Sebastian Ocklenburg et al., "Mental Rotation Does Not Account for Sex Differences in Left-Right Confusion," *Brain and Cognition* 76, no. 1 (2011), https://doi.org/10.1016/j.bandc.2011.01.010.
[899] Claudia C. Wolf et al., "Sex Differences in Parking Are Affected by Biological and Social Factors," *Psychological Research* 74, no. 4 (2010), https://doi.org/10.1007/s00426-009-0267-6.
[900] Martina Manns et al., "Paw Preferences in the Asian Small-Clawed Otter: Using an Inexpensive, Video-Based Protocol to Study Laterality of Rare Species in the Zoo," *Laterality* 23, no. 6 (2018), https://doi.org/10.1080/1357650X.2018.1457047; Sebastian Ocklenburg, "Manual Laterality in Marsupials," *Laterality*, 2018, https://doi.org/10.1080/1357650X.2018.1524897; Sebastian Ocklenburg et al., "Paw Preferences in Cats and Dogs: Meta-Analysis," *Laterality*, 2019, https://doi.org/10.1080/1357650X.2019.1578228; Sebastian Ocklenburg, Felix Ströckens, and Onur Güntürkün, "Lateralisation of Conspecific Vocalisation in Non-Human Vertebrates," *Laterality* 18, no. 1 (2013), https://doi.org/10.1080/1357650X.2011.626561; Felix Ströckens, Onur Güntürkün, and Sebastian Ocklenburg, "Limb Preferences in Non-Human Vertebrates," *Laterality* 18, no. 5 (2013), https://doi.org/10.1080/1357650X.2012.723008.

Sinister Persistence

Digital Analysis of Publications from 1986 through 2017

Large-scale digital analyses of scientific publications make further visible the close proximity of studies on handedness, brainedness, and pathology since 1986, that is, after the publication of Norman Geschwind (1926–1984) and colleagues' hormonal model of laterality (Chapter 4).[901] In a first analysis, I searched for shared themes across 1,331 publications on handedness and the brain between 1986 and 2017 (Corpus 1 = C1). A so-called topic-model analysis suggested that neuroscientific publications have continued to connect left-handedness with behavioral and mental abnormalities that surpass an

[901] This corpus derives from a literature search with the search engine PubMed in the database MEDLINE. All publications in the corpus fulfill the criteria of MeSH Major Topic "brain" and "handedness" or a related term in the title or abstract. Here are the concrete search criteria: (((((((((((((((((((((“left-handed”[Title/Abstract]) OR “left-handedness”[Title/Abstract]) OR “left-hander”[Title/Abstract]) OR “left-handers”[Title/Abstract]) OR sinister[Title/Abstract]) OR sinistrality[Title/Abstract]) OR “mixed-handed”[Title/Abstract]) OR “mixed-handedness”[Title/Abstract]) OR “mixed-hander”[Title/Abstract]) OR “mixed-handers”[Title/Abstract]) OR ambidextrous[Title/Abstract]) OR ambidexterity[Title/Abstract]) OR “right-handed”[Title/Abstract]) OR “right-handedness”[Title/Abstract]) OR “right-hander”[Title/Abstract]) OR “right-handers”[Title/Abstract]) OR dextrous[Title/Abstract]) OR dexterity[Title/Abstract])) AND brain[MeSH Major Topic])) AND (“1986”[Date - Publication] : “2017”[Date - Publication]). The corpus C1 contains 35 percent of the total results for this search (3,822 references). Sixty-five percent of the original search results had to be eliminated because their full texts were inaccessible, or because the full texts could not be reliably transcribed with Adobe Acrobat. The digital text mining was conducted in the programming language R (incl. the packages “tm” and “topicmodels”).

allegedly abnormal brain laterality.[902] This is true for clinical *and* cognitive neuroscience.[903]

When grouping key terms across C1 into two topics (Analysis $C1_a$), Topic 1_a emerged as a cluster of cognitive and clinical studies on brain function and their localization in the brain (Appendix A). The studies reflected in Topic 1_a have used neuroimaging methods in experimental setups with healthy participants, but also with patient populations, who were classified according to handedness. Terms relating to clinical events including lesions and strokes, as well as their impact on brain development and the recovery of function, most distinctly characterize Topic 1_a. Topic 2_a paints a different picture. Also drawn from studies on both sides of the cognitive/clinical divide in neuroscience, the studies reflected in Topic 2_a focused more clearly on events in the "abnormal" brain. Investigations of psychiatric illnesses including epilepsy, depression, autism, and schizophrenia are characteristic for these publications. Experimental studies with exclusively healthy populations are less visible in Topic 2_a; instead, it appears that researchers

[902] Topic modelling relies on computerized statistical analyses of words that are likely to occur in similar contexts across a corpus of texts (i.e., beyond individual publications). To provide an example, if the corpus consisted of cookbooks and textbooks on marine biology, one would expect several topics (i.e., lists of words that are likely to occur in the same context) relating to food and food preparation, several topics on marine life, and a few topics in which both overlap: fish and seafood recipes as well as the biology of fish and seafood. The number of returned topics can be chosen for each analysis. Depending on the prevalence of themes within the corpus and the chosen number of topics, it is it is more or less likely that any theme that a human reader would find in the corpus will appear as a topic in the digital analysis (e.g., if one chose to return three topics for the aforementioned corpus of cookbooks and marine biology textbooks, there would not necessarily be a topic containing terms associated with seafood recipes and the respective marine animals). As one increases the number of topics, the topics usually reflect more of the themes covered in the corpus, because the computer is allowed to find more contextual word clusters across the corpus and return them as individual topics.

[903] Clinical neuroscientists focus on "abnormal" brains and often compare in their studies patients with so-called healthy controls that are matched to the respective patients for sex/gender, handedness, and sometimes also for age, education, IQ, race/ethnicity, and/or socio-economic status. Cognitive neuroscientists mostly research "normal" brains and tend to exclude left-handers more often than clinical neuroscientists because they are not bound to a specific patient group.

matched psychiatric patients and healthy controls according to sex and handedness, and then compared the two groups according to brain function and anatomy.

The fact that both topics combine handedness and severe pathologies suggests that cognitive and clinical scientists continue to consider handedness an important factor associated with brain health. This is very apparent from the occurrence of terms for psychiatric illnesses in Topic 2_a. Still, it is possible that there is a substantial number of studies in C1 that considered strokes and other brain lesions as a way of determining localized brain activity, not left-handers' pathologies, and that these studies are reflected in Topic 1_a. However, the emphasis on recovery of function in Topic 1_a suggests that there is in fact a strong association of matters of handedness and pathology in the studies that are reflected in Topic 1_a.

A similar but more detailed pattern of research themes evolved when the number of topics was extended to twenty-five (Analysis $C1_b$, Appendix B). Methodical terms are less prevalent in the twenty-five topics of Analysis $C1_b$, and specific pathological conditions are spread out across various topics. For example, Topic 4_b comprises terms relating to clinical conditions in aging brains, such as Parkinson's disease, dementia, apraxia, atrophy, and sclerosis. Topics 7_b, 10_b, and 21_b represent studies that attended to the effects of stroke-related lesions in human and non-human monkey brains. Topic 14_b comprises the widest range of mental disorders and psychiatric illnesses, including ADHD, schizophrenia, and depression. Several topics attend to a smaller number of pathologies (for example, Topic 9_b to autism-spectrum disorders and related sex differences, Topic 12_b to tumors and treatments of depression, and Topic 19_b to epilepsy and migraines).

Analysis $C1_b$ also revealed that there are in fact significant themes within research on handedness in the brain that do not focus on deviance. Topics 8_b and 22_b, for example, comprise key words that directly relate to manual preference but no terms that relate to specific pathologies or pain, aside from the term "patients."[904] Overall in Analysis $C1_b$, twelve topics (Topics 3_b, 8_b, 11_b, 13_b, 15_b, 16_b, 17_b, 18_b, 20_b, 22_b, 23_b, and 24_b, that is, 48 percent of the topics in Analysis $C1_b$) do not mention pathologies.

This does *not* mean that 48 percent of the evaluated 1,331 publications are void of considerations of pathology or deviance. Instead, it suggests that 48 percent of all themes discussed across the publications in C1 surround healthy brain development, the localization of function, and the connection between the brain and the hand. Conversely, the fact that thirteen out of twenty-five topics (52 percent) in Analysis $C1_b$ contain terms related to pathology suggests that the discourse surrounding deviance still takes up much space in publications on handedness and the brain in the twenty-first century.

One more note of caution is warranted. These topic-model analyses do not flag where the extracted words appear in the publications they are drawn from (for example, in the literature review, discussion section, or bibliography). Theoretically, each of the papers in C1 could argue that left-handedness is *not* pathological, and that it has *nothing* to do with schizophrenia, epilepsy, or autism. The topic models would still pick up on the presumably abundant occurrences of the terms "pathological," "schizophrenia," "epilepsy," and "autism" in the literature review and bibliography, and the topics would contain these terms.

[904] All publications in C1 mentioned handedness or a closely related term in their title or abstract (see footnote 901). However, only Topics 8_b and 9_b specifically contain the term "handedness" or a closely related term; seven further topics (Topics 4_b, 6_b, 10_b, 20_b, 22_b, 24_b, and 25_b) contain other terms relating to the hand or manual function.

This problem can be partially ameliorated by a keywords-in-context analysis, which can extract a key term (for example, "handedness") and a chosen number of words before and after this key term from any publication in a corpus. Besides clearing up whether a certain publication endorsed or rejected the notion of pathological handedness, these words-in-context analyses can also clarify what kind of handedness (left, right, or mixed) is (or is not) supposedly associated with the pathologies that have emerged so prominently from analyses $C1_a$ and $C1_b$.

Analysis $C1_c$, a keywords-in-context search in C1, showed that many of the publications endorsed an association of manual preference with deviance (Appendix C). Specifically, left-handedness was repeatedly mentioned in conjunction with anatomical or behavioral "abnormalities" (for example, ventricle size, size of corpus callosum, language lateralization, lateralization of other functions, mirror writing, "homosexuality"), learning disorders (for example, dyslexia, dysgraphia, "mental retardation"), and psychiatric illnesses (for example, epilepsy, schizophrenia). The condition of "pathological left-handedness" appeared sixty-one times in a keywords-in-context search for the term "handedness" in C1, and "pathological right-handedness" only once.

Here are selected outputs of the keywords-in-context analysis:

-"… clinical and research reports association of lefthandedness with ventricle size and neuropsychological performance in schizophrenia joanna …"[905]

[905] J. Katsanis and W. G. Iacono, "Association of Left-Handedness with Ventricle Size and Neuropsychological Performance in Schizophrenia," *American Journal of Psychiatry* 146, no. 8 (1989), https://doi.org/10.1176/ajp.146.8.1056.

-"… w wittling ra schweiger e wittling w effects of handedness and gender on macro and microstructure of the corpus callosum and …"[906]

-"… [the midbody of the callosum, which carries fibers to and from the motor] cortex is larger in individuals who have less lateralization in handedness also the callosal cross-sectional area is proportionally larger for left [handers] …"[907]

-"… also a hallmark of human evolution behavioral studies have associated handedness with differences in language lateralization specically [*sic*] righthanders have shown left [hemisphere dominance in language] …"[908]

-"… been discussed earlier in dyslexia stuttering in addition to left handedness and mirror writing may occur and among a variety of …"[909]

-"… that three participants in the t[raumatic]b[rain]i[njury] group were lefthanded since lefthandedness may affect hemispheric dominance for cognitivemotor functions and there were …"[910]

-"… each of the studies which reported a greater incidence of lefthandedness among homosexual people in the lalumiere et al review eg …"[911]

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[906] Khader M. Hasan et al., "Quantification of the Spatiotemporal Microstructural Organization of the Human Brain Association, Projection and Commissural Pathways across the Lifespan Using Diffusion Tensor Tractography," *Brain Structure & Function* 214, no. 4 (2010), https://doi.org/10.1007/s00429-009-0238-0.
[907] Marlene Behrmann and David C. Plaut, "A Vision of Graded Hemispheric Specialization," *Annals of the New York Academy of Sciences* 1359 (2015), https://doi.org/10.1111/nyas.12833.
[908] Meiling Li et al., "Handedness- and Brain Size-Related Efficiency Differences in Small-World Brain Networks: A Resting-State Functional Magnetic Resonance Imaging Study," *Brain Connectivity* 5, no. 4 (2015), https://doi.org/10.1089/brain.2014.0291.
[909] G. D. Schott, "Mirror Writing: Neurological Reflections on an Unusual Phenomenon," *Journal of Neurology, Neurosurgery, and Psychiatry* 78, no. 1 (2007), https://doi.org/10.1136/jnnp.2006.094870.
[910] Adam D. Falchook et al., "Cognitive-Motor Dysfunction after Severe Traumatic Brain Injury: A Cerebral Interhemispheric Disconnection Syndrome," *Journal of Clinical and Experimental Neuropsychology* 37, no. 10 (2015), https://doi.org/10.1080/13803395.2015.1077930.
[911] Sandra F. Witelson et al., "Corpus Callosum Anatomy in Right-Handed Homosexual and Heterosexual Men," *Archives of Sexual Behavior* 37, no. 6 (2008), https://doi.org/10.1007/s10508-007-9276-y.

-"… rare case of a patient jnr with history of mixed handedness developmental dyslexia dysgraphia and attentional deficits associated with a klippel[-]tr[ènaunay syndrome] …"[912]

-"… lewin kohen mathew an increased incidence of lefthandedness also seems to be present in mental retardation harris …"[913]

-"… relationships could not be excluded a relationship between left handedness and atypical speech representation among epileptic patients undergoing neurosurgical evaluation …"[914]

-"… intrauterine disturbances are also associated with lefthandedness e lefthandedness is reportedly to times more common among schizophrenics …"[915]

-"… general population nevertheless schizophrenia has long been associated with increased lefthandedness or ambidexterity as have schizotypy and tendencies to magical [thinking] …"[916]

-"… even being congenital the absence of any family history of lefthandedness is suggestive of this being a case of pathological lefthandedness …"[917]

To sum up Analyses $C1_a$, $C1_b$, and $C1_c$, left-handers still carry the stigma of poor language-related skills, learning disabilities, and psychiatric illnesses, to name only a few. The epistemic problem in this context is that current protocols do not properly

[912] Marcelo L. Berthier et al., "Atypical Conduction Aphasia and the Right Hemisphere: Cross-Hemispheric Plasticity of Phonology in a Developmentally Dyslexic and Dysgraphic Patient with Early Left Frontal Damage," *Neurocase* 17, no. 2 (2011), https://doi.org/10.1080/13554794.2010.498380.
[913] Josef P. Janssen, "Evaluation of Empirical Methods and Methodological Foundations of Human Left-Handedness," *Perceptual and Motor Skills* 98, no. 2 (2004), https://doi.org/10.2466/pms.98.2.487-506.
[914] R. P. Woods, C. B. Dodrill, and G. A. Ojemann, "Brain Injury, Handedness, and Speech Lateralization in a Series of Amobarbital Studies," *Annals of Neurology* 23, no. 5 (1988), https://doi.org/10.1002/ana.410230514.
[915] Stefan Gutwinski et al., "Understanding Left-Handedness," *Deutsches Ärzteblatt International* 108, no. 50 (2011), https://doi.org/10.3238/arztebl.2011.0849.
[916] Michael C. Corballis, "Left Brain, Right Brain: Facts and Fantasies," *PLOS Biology* 12, no. 1 (2014), https://doi.org/10.1371/journal.pbio.1001767.
[917] P. Dedman and S. Numa, "A Case of Parietal Lobe Atrophy," *British Journal of Psychiatry* 148 (1986).

distinguish between handedness and brain anatomy or function. Although researchers assess manual preference with a specific test (oftentimes the Edinburgh Handedness Inventory),[918] they frequently take left-handedness as a proxy for abnormalities unrelated to manual behavior. In these cases, handedness, psychiatric conditions, and cognitive abilities are implicitly conflated.

Digital Analysis of Publications before and after Willems et al. 2014

Due to the conflation of left-handedness with abnormal brain anatomy and potential cognitive deficiencies or psychiatric illnesses, left-handers continue to be excluded from many neuroscientific experiments, especially in cognitive neuroscience, where the focus is on the “normal” brain. One word sequence of the keywords-in-context search $C1_c$ reveals the rationale behind this exclusion: “[T]he fact that previous studies partly included females or lefthanded subjects may explain some discrepancies in the results.”[919] Apparently, left-handers and women cannot be assumed to have “normal” brains.

The exclusion of left-handers from research on brain areas that are supposed to be strongly lateralized seems to be an unwritten rule.[920] To numerous neuroscientists, handedness introduces unwanted variance into their experiments, and they want to control for it. Because neuroscientific experiments (most notably neuroimaging analyses) are very costly, it has become part of the standard protocol for many neurocognitive investigations

[918] Oldfield, “Assessment”. See also Chapter 3.
[919] Thomas Zetzsche et al., “White Matter Alterations in Schizophrenic Patients with Pronounced Negative Symptomatology and with Positive Family History for Schizophrenia,” *European Archives of Psychiatry and Clinical Neuroscience* 258, no. 5 (2008), https://doi.org/10.1007/s00406-007-0793-4.
[920] In studies on vision, for example, where lateralization is deemed less important, neuroscientists include left-handers; sionnachglic, “Why Are Left-Handed People Often Excluded from Psychological and Neurological Research Studies?” accessed March 15, 2019, https://www.reddit.com/r/askscience/comments/86ewqe/why_are_lefthanded_people_often_excluded_from/.

to focus on the majority of right-handers and exclude left-handers from the study. This seems to be mainly a precaution and an attempt to guarantee the generalizability of findings despite small sample sizes, just in case left-handers' brains are in fact different.

In 2014, Willems et al. challenged this practice with a publication in *Nature Reviews Neuroscience* and insisted that neurogeneticists and cognitive neuroscientists include more left-handed subjects in their studies.[921] They argued that excluding about 10 percent of the population foreclosed new insights into neural development.

To determine whether Willems et al.'s call for the inclusion of left-handers had an effect on the research practice, I performed subanalyses within C1 for 235 texts before Willems et al. published their paper (years 2011 through 2013, Corpus 2 = C2), and 177 texts after it had appeared (years 2015 through 2017, Corpus 3 = C3). Topic models based on C2 and C3 (with two and twenty-five topics) led to similar results as Analyses $C1_a$ and $C1_b$. This suggests that there was no crucial shift in the themes of research on handedness and the brain in the 2010s as compared to all publications in the field since 1986.

More significantly, an unsuccessful key-term search for "Willems" in C3 (zero results) suggested that none of the 177 publications in C3 cited Willems and colleagues' paper.[922] It seems that Willems et al.'s publication had a negligible impact on the themes in research on handedness and the brain despite appearing in a so-called high-impact

[921] Willems et al., "On".
[922] Google Scholar lists eighty-nine publications from 2015 through 2017 that cite Willems et al.'s paper, some of which *do* relate to handedness and the brain, but none of these citing publications are part of C3 (date of inquiry: March 15, 2019). Two possible explanations for this circumstance are that Citavi, the software I use for batch-downloading PDFs, could not access said citing papers, and that Adobe Acrobat, the software I use for converting PDFs into machine-readable text files, could not convert the citing papers.

journal. An increase of left-handed subjects in neurogenetic and neurocognitive studies is probably not to be expected anytime soon.

Neoliberal Handedness

While handedness researchers since the 1970s have debated the cognitive and psychiatric risks inherent to left-handedness, popular literature has suggested that manual behavior helps unlock two complementary minds. US-American psychologist Stanley Coren (b. 1942), who has himself put forth a very controversial theory of left-handedness as a deadly pathology, called the two-mind movement "Psycho-Neuro-Astrology."[923] Based on "distortions and oversimplifications of the neuropsychological data,"[924] such popular texts have argued that a "left-handed" (or "right-brained") mode of thinking unleashes creative potential, happiness, sexual prowess, business savviness, and problem-solving skills.[925]

The line between distorted and "real" science in the literature on manual preference is a fine one. Several psychologists are among the authors of popular books on left-handedness. This literature falls broadly into two overlapping categories of advice

923 Coren, *Left*, 113–33. For Coren's discussion of further evidence that the two hemispheres are specialized for some tasks but do not create separate minds, see . Coren, *Left*, 93–112.
924 Coren, *Left*, 132.
925 See, e.g., Thomas R. Blakeslee, *The Right Brain: A New Understanding of the Unconscious Mind and Its Creative Powers* (Garden City: Anchor Press / Doubleday, 1980); Betty Edwards, *Drawing on the Right Side of the Brain*, 4th ed. (New York: Tarcher; Penguin, 2012); Frank Peschanel, *Sind Linkshänder besser? Durch gezieltes Training beider Gehirnhälften Kreativität und Rationalität fördern,* Goldmann-Ratgeber 12390 (Munich: Goldmann, 1993); Daniel H. Pink, *A Whole New Mind: Why Right-Brainers Will Rule the Future* (New York: Riverhead, 2006); Sally P. Springer and Georg Deutsch, *Left Brain, Right Brain* (Oxford: W. H. Freeman, 1981); Herbert Wiedemann, *Klavierspiel und das rechte Gehirn: Neue Erkenntnisse der Gehirnforschung als Grundlage einer Klavierdidaktik für erwachsene Anfänger,* Perspektiven zur Musikpädagogik und Musikwissenschaft 9 (Regensburg: Bosse, 1985). On the history of ascribing creativity to lefties, see Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 57–60.

literature for parents and teachers of left-handed children,[926] and handbooks for left-handed children and adults.[927] The latter category frequently contains instructions for how to re-convert one's handedness after forced conversion during childhood.

Several psychologists have made it their profession to counsel left-handers on how to best function in a right-handed world and advise policy makers on how to best accommodate this special population. For example, Marie-Alice Du Pasquier-Grall, a French psychologist, psychoanalyst, relaxation psychotherapist and graphotherapist, explained in her monograph the relationship between brain asymmetry, manual preference, and learning disorders.[928] She provided advice for the parents of left-handers regarding how to aid their children in learning how to write.

German psychologist and psychotherapist Johanna B. Sattler (b. 1953) has published widely on the problems of left-handers in a right-handed world, with particular

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[926] E.g., Wolfgang Aschmoneit, *Zur Pädagogik der Lateralität Linkshändigkeit,* Brennende Probleme der Pädagogik A (Limburg an der Lahn: Frankonius-Verlag, 1972); Pierre-Michel Bertrand, *Je suis gaucher: La latéralité expliquée aux jeunes … et à leurs parents!* (Brive-La-Gaillarde (Corrèze): Riv'gauche distribution, 2010); Marion Eder, *Pädagogische Aspekte der Linkshändigkeit* (Hamburg: Diplom.de, 2001); Dieter Gramm, *Probleme der Linkshändigkeit: Ein Ratgeber für Lehrer, Eltern und Erzieher* (Donauwörth: Auer, 1977); James T. de Kay, *Left-Handed Kids* (New York: M. Evans, 1989); Rolf W. Meyer, *Linkshändig? Rat & Information, Tipps & Adressen*, 9th ed. (Hannover: Humboldt, 2008); Lauren Milsom et al., *Your Left-Handed Child: Making Things Easy for Left-Handers in a Right-Handed World* (New York: Hachette Book Group, 2008); Diane B. Paul, *Das Linkshänderbuch,* Lebenshilfe Psychologie 84037 (Munich: Droemer Knaur, 1994).

[927] E.g., Nora Babel, *Linkshänder sind bessere Menschen: Linksherum, das ist nicht schwer – ein heiteres Handbuch* (Frankfurt am Main: Eichborn, 1992); Bertrand, *Je suis gaucher*; Petra L. Handke, *Handbuch für Linkshänder und ihre Freunde: Mach's mit links* (Frankfurt am Main: Eichborn, 1989); James T. de Kay, *The Left-Hander's Handbook* (New York: MJF Books, 1997); Rae Lindsay, *Left Is Right: The Survival Guide for Living Lefty in a Right-Handed World* (Englewood Cliffs: Gilmour House, 1996); Meyer, *Linkshändig?*; Paul, *Das Linkshänderbuch*; Michel Piquemal and Jacques Azam, *Je suis gaucher… et alors?* (Paris: De La Martinière Jeunesse, 2013); Zoche, *Ich sehe die Welt auch von der anderen Seite!*; Alfred Zuckrigl, *Linkshändige Kinder in Familie und Schule*, 5th ed., Kinder sind Kinder 1 (Munich: E. Reinhardt, 1995).

[928] Marie-Alice Du Pasquier-Grall, *Les gauchers du bon cote: A la maison, a l'ecole, dans la vie* (Paris: Hachette, 1987). See also Marie-Alice Du Pasquier-Grall, *Les gauchers,* Idées reçues: Santé & médecine 16 (Paris: Cavalier bleu, 2001); Marie-Alice Du Pasquier, "L'enfant qui écrit mal: Ou la difficulté d'accès au symbolique interrogée à travers l'écriture," *La psychiatrie de l'enfant* 45, no. 2 (2002); Marie-Alice Du Pasquier, "Les troubles de l'écriture," in *Nouveau traité de psychiatrie de l'enfant et de l'adolescent*, ed. Serge Lebovici, René Diatkine and Michel Soulé (Paris: Presses Universitaires de France, 2004), 2.

emphasis on the challenges for left-handers in school.[929] She has also become an activist and supporter of the first German office for counseling and information for left-handers (founded in Munich in 1985),[930] a self-help organization for left-handers (also founded in 1985),[931] and the German "Brain Breaking Help" where therapists, physicians, and educators can share their experiences in working with left-handers.[932]

German psychologist and psychotherapist Marina Neumann was retrained to use her right hand for skilled tasks when she entered elementary school.[933] After becoming a psychologist, she re-converted herself back to left-handedness and experienced this as a process of "physical and psychological liberation."[934] Neumann mainly works with children and adults who have been converted to right-handedness to help them find the same liberation in returning to their "innate left-handedness."[935]

US-American clinical neuropsychologist Jane M. Healey focuses on "brain behavior relationships" in children and young adults, including handedness, learning and attention disorders, autism spectrum disorders, and the results of traumatic brain injuries.[936] In the 1980s, she worked with US-American neurologist Norman Geschwind

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[929] Thomas Noll, Johanna B. Sattler, and Hans Ibel, "Imitation Behavior and Subsequent Complications," *Deutsches Arzteblatt international* 109, 27-28 (2012), https://doi.org/10.3238/arztebl.2012.0490a; Johanna B. Sattler, "Linkshänder und umgeschulte Linkshänder in der Ergotherapie," *Praxis Ergotherapie* 12, no. 2 (1999), accessed March 15, 2019, http://www.lefthander-consulting.org/deutsch/Praxisergo.htm; Sattler, *Links*; Johanna Barbara Sattler, *Die Psyche des linkshändigen Kindes: Von der Seele, die mit Tieren spricht*, 6th ed. (Donauwörth: Auer, 2012); Johanna Barbara Sattler, *Der umgeschulte Linkshänder oder der Knoten im Gehirn*, 12th ed. (Donauwörth: Auer, 2013); Johanna Barbara Sattler, *Das linkshändige Kind in der Grundschule*, 17th ed. (Augsburg: Auer, 2018).

[930] Sattler, *Links*, 20–21.

[931] Sattler, *Links*, 22.

[932] German name: "Brain-Breaking-Hilfe"; Sattler, *Links*, 22–23. For detailed descriptions of Sattler's activism, patient letters, images of her counseling sessions, fundraisers, teacher trainings, etc. see Sattler, *Links*, 256–436.

[933] Marina Neumann, "Über mich," accessed March 15, 2019, https://www.linkerhand.de/ueber-mich/.

[934] German original: "körperliche[r] und psychische[r] Befreiung"; Neumann, "Über mich".

[935] German original: "angeborene Linkshändigkeit"; Neumann, "Über mich".

[936] Jane M. Healey, "About Us," accessed March 15, 2019, https://drjanehealey.vpweb.com/About-Us.html. See also Jane M. Healey, *Loving Lefties: How to Raise Your Left-Handed Child in a Right-Handed World* (New York: Pocket Books, 2001); Jane M. Healey, Jacqueline Liederman, and Norman Geschwind,

(1926–1984).[937] Currently, Healey's advocacy for children and adolescents in the legal system, in schools, and in families relies heavily on what Healey calls "Neuropsychological and Psychoeducational Evaluations."[938] These evaluations usually last between twenty-four and twenty-seven hours, spread out over three sessions, and aim at unveiling the relationship between behavior, brain structure, brain function, and cognitive abilities. Healey's goals are the "demystification" of the reasons for a child's struggle in the educational system (that is, a diagnosis in psychological, psychiatric, or neurological terms), appropriate treatment, and "predictions" about the patient's future behavioral and/or cognitive performance.[939]

The work of these four women and their colleagues combines benevolent concerns for the well-being of left-handers with the neoliberal value of individual responsibility for one's health and productivity. In line with what sociologist Nikolas Rose called a new form of "politics of life," these brain-, mind-, and neuroscientists are monetizing the fact that handedness has become a matter of "optimization."[940] Rose argued that the characteristically neoliberal "obligation of autonomy and responsibility" is empowering

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"Handedness Is Not a Unidimensional Trait," *Cortex* 22, no. 1 (1986); Jacqueline Liederman and Jane M. Healey, "Independent Dimensions of Hand Preference: Reliability of the Factor Structure and the Handedness Inventory," *Archives of Clinical Neuropsychology* 1, no. 4 (1986), https://doi.org/10.1016/0887-6177(86)90141-1; Heino F. L. Meyer-Bahlburg et al., "Cognitive Abilities and Hemispheric Lateralization in Females Following Idiopathic Precocious Puberty," *Developmental Psychology* 21, no. 5 (1985), https://doi.org/10.1037/0012-1649.21.5.878; Rita G. Rudel, Jane Healey, and Martha B. Denckla, "Development of Motor Co-Ordination by Normal Left-Handed Children," *Developmental Medicine & Child Neurology* 26, no. 1 (1984), https://doi.org/10.1111/j.1469-8749.1984.tb04414.x.

[937] See, e.g., Norman Geschwind, Geschwind to Healey, December 9, 1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine; Jane M. Healey, Healey to Geschwind, 08-16-1983, H MS c435, Box 1, Folder 8, Correspondence, 1967–1984, Center for the History of Medicine, Francis A. Countway Library of Medicine; Healey, Liederman and Geschwind, "Handedness".

[938] Healey, "About Us".

[939] Healey, "About Us".

[940] Rose, *Politics*, 5–7; ch. 1. See also footnote 125.

and frees subjects from fatalism.[941] This escape from fatalism by means of studying advice literature and subjecting oneself to (neuro)psychological tests and treatments is certainly true in the case of traumatized left-handers, converted or not. However, implied in these opportunities is the threat that not utilizing these services will lead to an unacceptable disadvantage in a competitive world that has little tolerance for physical dis/abilities and neurodiversity.

Ethical and Epistemological Considerations

I already mentioned the epistemic problem inherent in current neuroscientific protocols that do not properly distinguish between handedness and brain anatomy or function. Although researchers assess manual preference with distinct tests, left-handedness is frequently taken as a proxy for abnormalities unrelated to manual preference. In these cases, handedness, psychiatric condition, and cognitive abilities are implicitly conflated.

In addition, ethical challenges are inherent in the exclusion of left-handers from neuroscientific studies, which goes hand-in-hand with the assumption that left-handers have "abnormal" brains. Diverse neuroscientific subfields share the assumption that the brains and minds of left-handers are different from those of right-handers, but the researchers in these fields come to opposing conclusions about whether to include left-handed subjects. Clinical neuroscientists tend to include more left-handers than researchers in other neuroscientific subfields, a trend that stabilizes the historically grown assumption that left-handedness is a matter of pathology. Cognitive neuroscientists often

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[941] Rose, *Politics*, 128.

avoid studying left-handed subjects altogether, and thereby perpetuate the idea of the deviant left-hander.

According to sociologist Erving Goffman's definition, the over-150-year-old tradition of associating left-handedness with anatomical and behavioral abnormalities as well as psychological disorders and psychiatric illnesses has established left-handedness as a "stigma" on three levels:[942] a stigmatized character trait (through its association with, for example, homosexuality, learning disability, or psychiatric illness), a physical stigma (through its association with, for example, abnormal brain laterality), and a stigma of group identity (for example, through the postulation of sex differences).

Philosopher Miranda Fricker's concept of "epistemic injustice" has most succinctly theorized the entanglement of knowledge about minority groups and social power.[943] Fricker argued that the exclusion of minority groups from social discourse marginalizes these groups even more and deprives them of possessing and/or sharing knowledge about themselves. Applied to the neurosciences, this means that the exclusion of left-handers from neuroscientific experiments only increases the already existing stigma of non-right-handedness. Furthermore, historically speaking, almost all handedness researchers have been right-handed. That is, scientists who belong to the non-stigmatized majority have conducted research with subjects from the non-stigmatized majority and formulated their findings in ways that have re-stigmatized the already stigmatized minority.

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[942] Erving Goffman, *Stigma: Notes on the Management of Spoiled Identity* (New York: Simon & Schuster, 1986).

[943] Miranda Fricker, *Epistemic Injustice: Power and the Ethics of Knowing* (New York: Oxford University Press, 2010). For an elaboration on the concept of epistemic injustice with relevance to disability theory, see Barnes, *The Minority Body*.

Introducing the notion of intersectionality to neuroethics and the neuroscientific laboratory could ameliorate these problems. Philosophers and social scientists have defined intersectionality as a structural characteristic of societies that describes the close intertwinement of categories including sex/gender, sexual orientation, dis/ability, class, and race/ethnicity.[944] If an individual inhabits various minority categories at the same time (for example, a woman of color in a wheelchair), then the stigmas that this person would bear solely because of her dis/ability, or her sex/gender, or her race/ethnicity are mutually intensified. Similarly, non-right-handers under neuroscientific scrutiny suffer interdisciplinary discrimination. They are either included (in many clinical studies) or excluded (from many neurogenetic and neurocognitive studies) because scientists treat them not as left-handers *per se* but as intersectional subjects who bear the stigma of morphological, psychological, and psychiatric abnormalities.

Current research protocols that exclude left-handers from studies of the "normal" brain and include them in studies of the "pathological" brain are ethically unwarranted and epistemically flawed. It is time to consider left-handers as "normal" subjects or explicitly state the ways in which left-handers differ from right-handers, based on empirical findings. Educationist Margaret M. Clark remarked sixty years ago in her study on the correlation between physical lateralities:

> [I]t is worth pointing out that no essential difference was apparent between left-handers and right-handers, except for their use of a different hand. This is no empty statement; on the contrary, it is a finding which requires to be emphasised in view of current attitudes to the phenomenon of left-handedness.[945]

[944] See footnote 41.
[945] Clark, *Left*.

If empirical studies uncover differences between handedness groups that exceed manual preference, especially that left-handed brains differ from right-handed brains, there is still no reason to flatly exclude left-handers from numerous neuroscientific studies. Instead, researchers should carefully consider (and explicitly state in the methods sections of their publications) why the inclusion or exclusion of certain kinds of manual preference would undermine the goals of their study.

Including left-handers into all neuroscientific studies would help ameliorate ethical and epistemic concerns simultaneously, and it would speak to neuroscientists' own growing concerns to make their research more ecologically valid (or "more realistic"). Contemporary research increasingly includes subjects or animal models of different sexes and at different life stages; likewise, studies can benefit from including various manual preferences.

The multiple understandings of handedness since Broca have turned manual preference into this intersectional quality that allows for the stigmatization of left-handers on various levels. Handedness has been understood as a behavior in manual experiments, a preference or identity in questionnaires, a family characteristic in pedigrees, a brain structure in structural brain scans, and a brain function in functional imaging experiments. This list is not exhaustive. Despite these different conceptions, handedness researchers have combined the data and theories from various approaches and used them as if they were speaking to the same quality. These different ways of assessing handedness have produced different epistemic "handedness" things. There is only one word for what is in fact a handedness multiple, and the singularity of the word has rendered invisible the epistemic gaps and incommensurabilities in previous and current models of manual preference.

What is more, researchers have proposed anatomical, physiological, genetic, hormonal, mirror-neuron-related, and epigenetic concepts of handedness—*and* of the brain, *and* of the relationship between the two. Each new theory of handedness has incorporated previous theories and data sets to some extent. For example, the hormonal theory of handedness was a theory about *hormones* that override *genes* that determine brain *anatomy* and manual preference.

Left-handers are caught in the intersectional quagmire of brain anatomy, manual preference, intellectual disabilities, and psychiatric illnesses. The brain itself is caught in the epistemic quagmire of the brain multiple that can allegedly be assessed via questionnaires, family data, behavioral experiments, brain imaging, or—eventually—dissection. Corballis himself acknowledged the multiplicity inherent in his study on *Human Laterality*: "I have … tried to examine laterality from as many perspectives as possible. I have therefore drawn on evidence from normal, intact human beings as well as from neurological patients, and where it has seemed appropriate I have also covered material on asymmetries in other species."[946]

Because of the far reach of the brain multiple into the moral and social realms, the potential for intersectional discrimination of individuals based on their bodies, minds, and behaviors has become a characteristic feature of modern neuroscience writ large. Going forward, one option is to subject ourselves to neoliberal scientific and corporate understandings of interlocking brain multiples and their prescriptions for "being neurologically

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[946] Corballis, *Human*, 9–10.

human."[947] Another option is to attend to the often incommensurate epistemic "brain" things that many stigmatizing scientific theories rest on. If we identify the inadvertently shaky epistemic ground of many neuroscientific theories about difference and identity, we will find it easier to recognize the intersectional hierarchies on which our current world order rests.

The "Truth" about Handedness?

Contemporary neuroscientists adhere to the idea that language is left-lateralized in almost all right-handers, and in about two-thirds of left-handers (!); they have expanded the functions of Broca's Area and no longer presume that it underlies speech only; and they have identified additional brain areas that might be involved in articulate speech.[948] Scientists no longer assume that right-handedness is a specifically human feature. It has become textbook knowledge that a range of non-human primates (at least in captivity)

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[947] Rees, "Being"; Rees, *Plastic*, 198–218.

[948] Patrick Friedrich et al., "Fundamental or Forgotten? Is Pierre Paul Broca Still Relevant in Modern Neuroscience?" *Laterality* 24, no. 2 (2019), https://doi.org/10.1080/1357650X.2018.1489827; Gutwinski et al., "Understanding Left-Handedness"; Harris, "Right". Cf. Rutten, *The Broca-Wernicke Doctrine*.

also exhibit population-wide right-"hand"edness.[949] Other species have been found to show consistent laterality on the individual level, although not on the population level.[950]

To this day, I have not come across any (to me) satisfactory explanation for why some species or individuals exhibit consistent manual preference and others do not. I have been equally unsuccessful at locating a coherent theory that illuminates why the human species has such a high ratio of right-handers. However, there are several related theories that sound reasonable, and I want to share them at this point.

First, it looks like there are different handednesses.[951] An individual's writing hand and throwing hand, for example, do not necessarily overlap because both tasks engage different muscle groups and require distinct skills.

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[949] Gillian S. Forrester et al., "Human Handedness: An Inherited Evolutionary Trait," *Behavioural Brain Research* 237 (2013), https://doi.org/10.1016/j.bbr.2012.09.037; William D. Hopkins, ed., *The Evolution of Hemispheric Specialization in Primates*, Special Topics in Primatology 5 (London: Academic Press, 2007); William D. Hopkins and Jacques Vauclair, "Evolution of Behavioural and Brain Asymmetries in Primates," in Tallerman; Gibson, *The Oxford Handbook of Language Evolution*; Jeannette P. Ward and William D. Hopkins, eds., *Primate Laterality: Current Behavioral Evidence of Primate Asymmetries* (New York: Springer New York, 1993). For reviews of studies on non-human handedness, see Hécaen, *gauchers*, 66–72; Porac, *Laterality*, 208–10. For a historical perspective on studies of hon-human handedness, see Lauren J. Harris, "Left-Handedness: Early Theories, Facts, and Fancies," in Herron, *Neuropsychology of Left-Handedness*, 65-68; Lauren J. Harris, "Handedness in Apes and Monkeys: Some Views from the Past," in *Primate Laterality: Current Behavioral Evidence of Primate Asymmetries*, ed. Jeannette P. Ward and William D. Hopkins (New York: Springer New York, 1993); Lauren J. Harris, "On the Evolution of Handedness: A Speculative Analysis of Darwin's Views and a Review of Early Studies of Handedness in 'the Nearest Allies of Man'," *Brain and Language* 73, no. 2 (2000), https://doi.org/10.1006/brln.2000.2302.

[950] E.g., Angelo Bisazza et al., "Pawedness and Motor Asymmetries in Toads," *Laterality* 2, no. 1 (1997), https://doi.org/10.1080/713754252; Andrey N. Giljov et al., "Parallel Emergence of True Handedness in the Evolution of Marsupials and Placentals," *Current Biology* 25, no. 14 (2015), https://doi.org/10.1016/j.cub.2015.05.043; Lauren J. Harris, "Footedness in Peacocks: Is the Dominant Foot the One Raised First in Climbing, and What, in Any Case, Does the Emperor's Tale Really Mean?" *Laterality* 3, no. 4 (1998), https://doi.org/10.1080/713754313; Manns et al., "Paw Preferences in the Asian Small-Clawed Otter"; Ocklenburg, "Manual Laterality in Marsupials"; Ocklenburg et al., "Paw Preferences in Cats and Dogs"; Christoph Randler, Michael Braun, and Stephanie Lintker, "Foot Preferences in Wild-Living Ring-Necked Parakeets (Psittacula Krameri, Psittacidae)," *Laterality* 16, no. 2 (2011), https://doi.org/10.1080/13576500903513188; T. E. Reimchen and M. A. Spoljaric, "Right Paw Foraging Bias in Wild Black Bear (Ursus Americanus Kermodei)," *Laterality* 16, no. 4 (2011), https://doi.org/10.1080/1357650X.2010.485202; Ströckens, Güntürkün and Ocklenburg, "Limb Preferences in Non-Human Vertebrates".

[951] See, e.g., Anthony Lambert and Charlene Hallett, "Hand Preference for Sending Mobile-Phone Text Messages: Associations with Sex, Writing Hand, and Throwing Hand," *Laterality* 14, no. 4 (2009), https://doi.org/10.1080/13576500802396545; Ian C. McManus et al., "Eye-Dominance, Writing Hand, and Throwing Hand," *Laterality* 4, no. 2 (1999), https://doi.org/10.1080/713754334. See also the literature on

Second, there seems to be a difference between the direction (left/right) and the degree/consistency (weak/strong) of handedness.[952] Some researchers have suggested that distinguishing between strong lateralization and weak lateralization, instead of and/or in addition to considerations of the direction of laterality, would be a productive avenue for future studies on handedness.[953]

Third, it is useful to distinguish between manual preference and manual skill/performance/proficiency.[954] It is unclear if manual preference is a choice or an innate characteristic, but it seems clear that manual skill is acquired and a consequence of practice and habit. If this were not the case, the conversion of left-handers into practicing right-

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other lateralities, including hand clasping, arm folding, eyedness, earedness, and footedness; e.g., D. C. Bourassa, Ian C. McManus, and Mark P. Bryden, "Handedness and Eye-Dominance: A Meta-Analysis of Their Relationship," *Laterality* 1, no. 1 (1996), https://doi.org/10.1080/713754206; Miriam Ittyerah, "Hand and Foot Preference in Two Cultures," *Laterality*, 2019, https://doi.org/10.1080/1357650X.2019.1575389; Imhokhai Ogah et al., "Hand Clasping, Arm Folding, and Handedness: Relationships and Strengths of Preference," *Laterality* 17, no. 2 (2012), https://doi.org/10.1080/1357650X.2010.551126; Chiara Sacco et al., "Joint Assessment of Handedness and Footedness through Latent Class Factor Analysis," *Laterality* 23, no. 6 (2018), https://doi.org/10.1080/1357650X.2018.1435675; K. Saudino and Ian C. McManus, "Handedness, Footedness, Eyedness and Earedness in the Colorado Adoption Project," *British Journal of Developmental Psychology* 16, no. 2 (1998), https://doi.org/10.1111/j.2044-835X.1998.tb00916.x; Kunitake Suzuki and Juko Ando, "Genetic and Environmental Structure of Individual Differences in Hand, Foot, and Ear Preferences: A Twin Study," *Laterality* 19, no. 1 (2014), https://doi.org/10.1080/1357650X.2013.790396; Ulrich S. Tran et al., "Lateral Preferences for Hand Clasping and Arm Folding Are Associated with Handedness in Two Large-Sample Latent Variable Analyses," *Laterality* 19, no. 5 (2014), https://doi.org/10.1080/1357650X.2014.891607; Diane M. Warren et al., "Heritability and Linkage Analysis of Hand, Foot, and Eye Preference in Mexican Americans," *Laterality* 11, no. 6 (2006), https://doi.org/10.1080/13576500600761056.

[952] See, e.g., Kristen A. Kaploun and Christopher A. Abeare, "Degree versus direction: a comparison of four handedness classification schemes through the investigation of lateralised semantic priming," *Laterality* 15, no. 5 (2010), https://doi.org/10.1080/13576500902958871; Eric C. Prichard, Ruth E. Propper, and Stephen D. Christman, "Degree of Handedness, but Not Direction, Is a Systematic Predictor of Cognitive Performance," *Frontiers in Psychology* 4 (2013), https://doi.org/10.3389/fpsyg.2013.00009. See also footnote 523.

[953] E.g., Bethe, "Zur," 681–83; Baris Ozener, "Extreme Behavioral Lateralization and the Remodeling of the Distal Humerus," *American Journal of Human Biology* 24, no. 4 (2012), https://doi.org/10.1002/ajhb.22240; Adam R. Reddon and Peter L. Hurd, "Acting Unilaterally: Why Do Animals with Strongly Lateralized Brains Behave Differently Than Those with Weakly Lateralized Brains?" *Bioscience Hypotheses* 2, no. 6 (2009), https://doi.org/10.1016/j.bihy.2009.06.007.

[954] See, e.g., Sara M. Scharoun and Pamela J. Bryden, "Hand Preference, Performance Abilities, and Hand Selection in Children," *Frontiers in Psychology* 5 (2014), https://doi.org/10.3389/fpsyg.2014.00082; J. I. Todor and T. Doane, "Handedness Classification: Preference versus Proficiency," *Perceptual and Motor Skills* 45, no. 3 (1977), https://doi.org/10.2466/pms.1977.45.3f.1041.

handers would not be possible. Separating skill from preference also helps explain why once-converted left-handers find it hard to unlearn violently imposed right-handed practice and to carry out skilled tasks with their preferred (but untrained) left hand after re-conversion.

Fourth, manual preference might lie on a continuum, and the ratio of practicing left-handers might, at least to some extent, "serve(s) as a barometer of wider cultural toleration and permissiveness," as historian of medicine Howard Kushner has suggested.[955] Although we do not know why we live in a right-handed world, this reality significantly affects our manual behavior. For over a century, scholars have repeatedly argued that most humans are at least partially ambidextrous, and some have even proposed that there are only 10 percent "real" right-handers, like there are 10 percent left-handers.[956] For individuals in the (somewhat) ambidextrous majority, it is relatively easy to adapt to our right-biased world, and they blend in with "real" right-handers. The about 10 percent practicing left-handers in our right-handed world might be the minority of strongly lateralized individuals who are unable to conform to the cultural right-hand bias. In a world entirely free of social, cultural, and infrastructural pressures against left-handedness, significantly more individuals might be practicing ambidexters or left-handers. In a very discriminatory society, as little as zero percent might practice left-handedness, although the

[955] Kushner, *On*, xiii.
[956] See, e.g., Bethe, "Zur"; Gaupp, "Über"; Jackson, *Ambidexterity*; Meyer, *Linkshändig?*; Marina Neumann, *Natürlich mit links: Zurück zur Linkshändigkeit – Befreiter leben mit der starken Hand* (Munich: Ariston, 2014); Miloš Sovák, *Pädagogische Probleme der Lateralität*, Beiträge zum Sonderschulwesen 16 (Berlin: Verlag Volk und Gesundheit, 1968); Zoche, *Ich sehe die Welt auch von der anderen Seite!*. See also Bernard Mazoyer et al., "Gaussian Mixture Modeling of Hemispheric Lateralization for Language in a Large Sample of Healthy Individuals Balanced for Handedness," *PLOS One* 9, no. 6 (2014), https://doi.org/10.1371/journal.pone.0101165. McManus called the argument that there are as many left-handers as right-handers "a statistical game," which is often based on specifically developed questionnaires and strict inclusion and exclusion criteria; Ian C. McManus, E-mail to Tabea Cornel, February 28, 2019.

underlying distribution of manual *preference* (as opposed to habit or practice) might be the same. This theory would explain why the percentage of practicing left-handers in the United States has risen from probably 3 percent in the late nineteenth century to 10 percent in the twentieth century,[957] and why the incidence of left-handedness seems so much lower in cultures that seem socially conservative from a "Western" point of view.[958]

Fifth, the sex-related puzzles in handedness research might have cultural explanations. One persistent problem for handedness researchers has been the higher incidence of left-handedness among men than women. A recent meta-study suggested that there are 25 percent more left-handed men than women, but this might be due to the fact that men and boys in industrialized societies find it easier to resist the pressure to be right-handed than girls and women, or boys might be given more leeway and not be pressured into right-hand-usage at all.[959]

Similarly, the maternal effect (that is, that children are more likely to inherit left-handedness from their mother than from their father) might be an artifact of gendered education. After unsuccessfully trying to account for this effect in their theories of the inheritance of handedness (Chapter 3), psychologists have suggested that the maternal effect might be due to underreported rates of maternal left-handedness[960] or prospective mothers' cheating on their left-handed partners and secretly conceiving children with right-handed men.[961] An alternative explanation for this effect is that, on average,

[957] Ian C. McManus et al., "Science in the Making—Right Hand, Left Hand III: Estimating Historical Rates of Left-Handedness," *Laterality* 15, 1–2 (2010), https://doi.org/10.1080/13576500802565313.
[958] See footnote 6.
[959] Iris E. C. Sommer, "Sex Differences in Handedness, Brain Asymmetry, and Language Lateralization," in Hugdahl; Westerhausen, *The Two Halves of the Brain*.
[960] Marian Annett, "Left-Handedness as a Function of Sex, Maternal Versus Paternal Inheritance, and Report Bias," *Behavior Genetics* 29, no. 2 (1999), https://doi.org/10.1023/A:1021608522152; Marian Annett, interview by Tabea Cornel.
[961] Ian Christopher McManus, interview by Tabea Cornel.

mothers in heterosexual relationships in industrialized countries still carry more than half of the child-rearing responsibilities. If left-handed mothers encourage left-handedness in their children, the manual preference of an oftentimes absent father would affect the child's handedness less than that of the oftentimes present mother.

Finally, and of that I am sure, handedness is not in the brain. In contemporary industrialized cultures, it is part identity and part embodied behavior that depends on the number of hands we possess, the habits we have acquired, and the socio-cultural environment in which we live. I do not wish to deny that there are neural processes and maybe even structures that reflect our hand preference and manual habits. However, the idea that what we do with our hands is caused by what our brain is and does is a gross oversimplification. More than that, it is one instance of dehumanizing neuro-centrisms that make us project all things human onto our brains (or onto one facet of the brain multiple). With the idea that handedness is in the brain, we would accept the doctrine of "[b]rainhood, … a historically contingent resource, born to uphold and make plausible a redefinition of personhood" from the late seventeenth century.[962] Admittedly, this doctrine has brought us groundbreaking therapies for neurological conditions and psychiatric illnesses, but also racial science and neurosexism. Let us be weary of claims that something is in the brain when we can clearly see it at work outside of the skull.

[962] Vidal and Ortega, *Being*, 231.

APPENDIX

A. Analysis $C1_a$: Topic Models in C1, 2 Topics, 200 Words

	Topic 1_a	**Topic 2_a**
1	motor	brain
2	left	patients
3	cortex	study
4	brain	left
5	right	right
6	hand	using
7	activation	subjects
8	task	age
9	functional	cortex
10	subjects	group
11	study	studies
12	language	volume
13	areas	matter
14	stimulation	temporal
15	cortical	may
16	area	analysis
17	hemisphere	data
18	using	differences
19	gyrus	motor
20	analysis	frontal
21	movements	imaging
22	activity	regions
23	human	also
24	movement	changes
25	also	cortical
26	studies	cerebral
27	data	effects
28	visual	results
29	fmri	mean
30	frontal	used
31	tasks	significant
32	used	white
33	regions	cognitive
34	results	clinical

35	two	test
36	time	asymmetry
37	temporal	children
38	patients	human
39	may	time
40	control	memory
41	imaging	found
42	one	mri
43	parietal	psychiatry
44	processing	functional
45	different	associated
46	response	lobe
47	effect	control
48	found	controls
49	within	showed
50	magnetic	normal
51	group	one
52	cerebral	disease
53	effects	two
54	condition	healthy
55	changes	anterior
56	performance	reported
57	mean	schizophrenia
58	showed	function
59	observed	gyrus
60	can	university
61	performed	magnetic
62	primary	stimulation
63	test	effect
64	conditions	groups
65	inferior	performance
66	posterior	however
67	stimuli	compared
68	however	years
69	differences	scores
70	anterior	diffusion
71	activated	images
72	handedness	table
73	neurosci	total
74	neural	hemisphere
75	region	values
76	fig	research
77	participants	patient

78	compared	measures
79	present	increased
80	stimulus	size
81	subject	disorder
82	function	region
83	contralateral	activity
84	tms	correlation
85	responses	performed
86	superior	number
87	ipsilateral	area
88	shown	can
89	(fig	disorders
90	bilateral	participants
91	three	different
92	speech	present
93	table	cerebellar
94	signal	score
95	res	posterior
96	premotor	higher
97	system	neurol
98	images	observed
99	mapping	sex
100	number	system
101	involved	greater
102	lateralization	response
103	spatial	areas
104	use	resonance
105	hemispheric	within
106	figure	neurology
107	information	women
108	level	symptoms
109	role	men
110	associated	related
111	related	level
112	right-handed	previous
113	signicant	blood
114	words	multiple
115	neurophysiol	verbal
116	evidence	regional
117	stroke	autism
118	university	language
119	activations	evidence
120	asymmetry	statistical

121	lesion	shown
122	learning	three
123	previous	difference
124	reported	new
125	well	first
126	muscle	well
127	auditory	analyses
128	word	los
129	trials	gray
130	across	tdcs
131	individual	con
132	increased	pain
133	thus	current
134	similar	use
135	neuroimage	findings
136	difference	although
137	presented	following
138	normal	association
139	dominance	right-handed
140	following	obtained
141	mri	eeg
142	patient	lower
143	significant	corpus
144	training	development
145	memory	prefrontal
146	amplitude	structural
147	contrast	connectivity
148	experiment	fig
149	action	significantly
150	although	depression
151	representation	methods
152	middle	tensor
153	pattern	sample
154	healthy	scale
155	cognitive	volumes
156	anatomical	reduced
157	lobe	res
158	maps	epilepsy
159	network	neural
160	lateral	callosum
161	sensory	journal
162	new	high
163	dominant	figure

164	intensity	signicant
165	part	lesions
166	cerebellum	model
167	sma	image
168	resonance	based
169	size	individuals
170	somatosensory	superior
171	frequency	neuroimage
172	sensorimotor	increase
173	arm	inhibition
174	revealed	relationship
175	first	including
176	neurol	method
177	based	relative
178	connectivity	assessment
179	recovery	treatment
180	humans	inferior
181	statistical	negative
182	<96>	parietal
183	pet	medical
184	whether	levels
185	research	case
186	increase	impairment
187	sulcus	handedness
188	blood	cingulate
189	values	syndrome
190	cingulate	early
191	complex	neurosci
192	patterns	correlations
193	model	measured
194	case	role
195	semantic	included
196	central	comparison
197	second	processing
198	transcranial	bilateral
199	prefrontal	cerebellum
200	comparison	less

B. Analysis $C1_b$: Topic Models in C1, 25 Topics, 50 Words

	Topic 1_b	**Topic 2_b**	**Topic 3_b**	**Topic 4_b**	**Topic 5_b**
1	activation	brain	brain	patients	con
2	cortex	patients	blood	disease	los
3	motor	study	cerebral	left	que
4	brain	imaging	study	right	del
5	pain	left	changes	brain	para
6	functional	right	subjects	patient	copaxone
7	study	using	flow	motor	pacientes
8	cortical	group	glucose	clinical	una
9	swallowing	controls	metabolic	test	por
10	subjects	control	using	memory	las
11	areas	frontal	metabolism	study	tratamiento
12	imaging	data	regional	parkinson<92>s	placebo
13	fmri	magnetic	effects	apraxia	como
14	gyrus	subjects	studies	also	trastornos
15	area	matter	data	neurology	estudio
16	right	resonance	significant	hand	fue
17	left	differences	cognitive	atrophy	debe
18	using	temporal	regions	may	durante
19	analysis	used	pet	normal	datos
20	signal	analysis	differences	cognitive	grupo
21	activated	spectroscopy	mean	writing	entre
22	regions	white	analysis	neurol	inyecci
23	task	anterior	may	progressive	fueron
24	cingulate	<96>	0	mirror	estudios
25	human	studies	values	performance	sin
26	studies	regions	results	sclerosis	acetato
27	stimulation	der	cortex	controls	reacciones
28	activity	naa	frontal	showed	lugar
29	primary	healthy	also	temporal	riesgo
30	images	diffusion	used	impairment	menos
31	also	results	time	time	sobre
32	cerebral	clinical	response	age	mayor
33	changes	functional	group	scores	glatiramero
34	tasks	test	social	verbal	tratados
35	data	also	human	cerebral	enfermedad
36	sensory	age	activation	multiple	nicos
37	may	gaba	volume	control	uso
38	intensity	mri	1	group	lesiones

39	tongue	compared	size	cortex	est
40	time	measures	normal	cortical	este
41	anterior	inferior	can	dementia	lisis
42	group	cortex	cbf	years	tiempo
43	frontal	found	increase	speech	sujetos
44	magnetic	die	two	limb	estos
45	region	gyrus	activity	using	periodo
46	temporal	may	different	two	total
47	control	lobe	left	lesions	educaci
48	results	time	effect	university	ser
49	hemisphere	two	emission	score	participantes
50	contralateral	showed	right	mean	dos

	Topic 6b	**Topic 7b**	**Topic 8b**	**Topic 9b**	**Topic 10b**
1	stimulation	patients	right	brain	motor
2	learning	brain	left	asymmetry	hand
3	tdcs	functional	handedness	language	lesion
4	right	motor	hand	left	cortex
5	task	connectivity	hemisphere	autism	monkeys
6	effects	imaging	asymmetry	functional	recovery
7	brain	stroke	brain	right	monkey
8	effect	study	left-handed	study	brain
9	activity	cortex	preference	regions	spinal
10	pain	cortical	right-handed	cortex	dexterity
11	participants	analysis	lateralization	lateralization	area
12	left	using	hemispheric	hemisphere	stroke
13	study	fmri	patients	asymmetries	cortical
14	subjects	pain	task	area	cord
15	motor	function	cerebral	gyrus	per
16	cortex	clinical	left-handers	differences	population
17	hand	changes	may	handedness	(fig
18	emotional	group	dominance	human	movements
19	time	areas	one	volume	neurons
20	training	studies	group	subjects	also
21	significant	results	subjects	using	areas
22	performance	left	right-handers	studies	corticospinal
23	studies	regions	laterality	cerebral	ipsilesional
24	anodal	fmr	speech	group	older
25	using	data	asymmetries	temporal	regions
26	sham	healthy	studies	posterior	number
27	data	coherence	language	cortical	study
28	stimuli	activation	side	networks	data

29	results	cognitive	study	surface	time
30	one	activity	also	analysis	may
31	condition	subjects	tasks	size	developed
32	response	network	use	age	use
33	mean	significant	results	planum	manual
34	transfer	test	visual	auditory	grip
35	control	also	human	hemispheric	two
36	emotion	can	participants	leftward	following
37	used	recovery	significant	connectivity	using
38	two	found	two	found	functional
39	responses	task	normal	structural	one
40	sequence	controls	differences	anatomical	macaque
41	may	multiple	hemispheres	region	observed
42	patients	mri	auditory	also	primary
43	also	right	found	anterior	used
44	activation	used	individuals	asd	present
45	memory	lesion	data	frontal	total
46	prefrontal	different	left-handedness	imaging	cent
47	changes	correlation	evidence	may	countries
48	current	time	dominant	processing	contralesional
49	facial	magnetic	groups	sex	control
50	increased	one	control	matter	case

	Topic 11$_b$	**Topic 12$_b$**	**Topic 13$_b$**	**Topic 14$_b$**	**Topic 15$_b$**
1	cortex	language	activation	patients	matter
2	vestibular	stimulation	gyrus	schizophrenia	brain
3	nucleus	brain	brain	study	white
4	cortical	mapping	task	brain	volume
5	stimulation	patients	left	psychiatry	diffusion
6	brain	surgery	frontal	group	left
7	area	functional	cortex	disorder	study
8	areas	resection	right	subjects	age
9	right	cortical	functional	volume	imaging
10	thalamus	tumor	temporal	right	right
11	human	0	regions	children	using
12	study	motor	inferior	studies	tensor
13	nuclei	patient	subjects	left	mean
14	gyrus	areas	tasks	using	human
15	thalamic	left	study	controls	asymmetry
16	anterior	intraoperative	visual	depression	corpus
17	within	errors	processing	differences	dti
18	left	frontal	superior	may	callosum

19	lateral	study	areas	significant	images
20	connections	cortex	fmri	age	temporal
21	posterior	neurosurg	activated	cortex	subjects
22	functional	sites	memory	symptoms	mri
23	also	gyrus	language	frontal	fasciculus
24	region	temporal	middle	associated	lobe
25	fig	surgical	area	analysis	data
26	medial	speech	word	healthy	analysis
27	using	tumors	semantic	clinical	differences
28	hemisphere	area	using	disorders	regions
29	projections	using	analysis	control	cortex
30	one	naming	studies	matter	used
31	two	duffau	parietal	scores	gray
32	regions	imaging	neural	gyrus	studies
33	data	also	speech	negative	tract
34	studies	results	prefrontal	score	tracts
35	cells	magnetic	anterior	response	cerebral
36	somatosensory	neurosurgery	words	groups	values
37	temporal	used	stimuli	amygdala	results
38	results	glioma	activations	prefrontal	tractography
39	system	rtms	condition	found	volumes
40	neurons	hemisphere	cingulate	adhd	image
41	visual	can	occipital	results	children
42	ventral	function	activity	scale	frontal
43	connectivity	within	images	cognitive	also
44	parietal	regions	also	regions	sex
45	primary	preoperative	data	data	group
46	cerebral	gliomas	posterior	also	changes
47	dorsal	mri	(ba	temporal	area
48	monkeys	awake	imaging	imaging	hemisphere
49	neurol	performed	group	anterior	size
50	part	electrical	used	used	anisotropy

	Topic 16b	**Topic 17b**	**Topic 18b**	**Topic 19b**	**Topic 20b**
1	alpha	response	brain	language	brain
2	eeg	cortex	cortex	patients	cortex
3	activity	visual	study	activation	cerebellar
4	task	left	activity	brain	left
5	time	brain	participants	left	action
6	brain	stimuli	task	fmri	tool
7	right	task	left	study	motor
8	motor	subjects	visual	functional	use

9	movement	right	using	right	regions
10	visual	stimulus	subjects	task	hand
11	cortical	auditory	functional	subjects	tools
12	left	analysis	right	using	actions
13	performance	study	human	frontal	parietal
14	data	processing	time	temporal	cerebellum
15	<88>	data	effects	imaging	activation
16	two	using	data	areas	right
17	control	responses	also	dominance	study
18	analysis	functional	activation	analysis	functional
19	study	activation	control	lateralization	also
20		temporal	cortical	area	human
21	tasks	activity	studies	results	using
22	significant	time	pmid	studies	frontal
23	used	meg	analysis	age	words
24	one	spatial	motor	data	language
25	also	two	neural	children	hemisphere
26	results	attention	connectivity	epilepsy	studies
27	participants	areas	food	group	areas
28	target	used	used	used	premotor
29	power	effects	response	hemisphere	processing
30	differences	evoked	fmri	mri	planning
31	cortex	different	medline	gyrus	posterior
32	different	fmri	neurosci	test	neural
33	cognitive	tactile	differences	migraine	involved
34	frontal	amplitude	responses	cortical	region
35	using	effect	stimulation	showed	inferior
36	beta	human	within	cortex	representations
37	studies	fig	crossref	may	objects
38	first	results	alcohol	images	may
39	contractions	subject	phase	also	neurosci
40	smoking	found	number	magnetic	results
41	electrode	shown	results	activations	others
42	amplitude	source	parietal	ifg	object
43	cerebellar	cortical	regions	regions	analysis
44	subjects	mean	university	clinical	participants
45	human	also	cognitive	tasks	used
46	may	stimulation	may	memory	can
47	second	signal	cerebral	healthy	visual
48	electrodes	studies	one	mean	one
49	phase	memory	processing	cerebral	response
50	band	frequency	effect	performed	control

	Topic 21_b	Topic 22_b	Topic 23_b	Topic 24_b	Topic 25_b
1	patient	motor	brain	eeg	motor
2	left	hand	area	activity	stimulation
3	right	movements	left	sleep	tms
4	aphasia	movement	cortex	power	cortex
5	memory	left	reading	subjects	hand
6	temporal	cortex	right	changes	excitability
7	case	right	areas	frequency	mep
8	patients	activation	surface	study	left
9	lobe	task	cortical	motor	transcranial
10	lesions	brain	length	brain	magnetic
11	frontal	subjects	test	cortex	inhibition
12	brain	areas	visual	time	muscle
13	test	activity	words	coherence	right
14	language	area	posterior	band	cortical
15	lesion	control	also	analysis	subjects
16	epilepsy	study	effects	cortical	effects
17	visual	premotor	hemisphere	right	study
18	normal	parietal	human	force	rtms
19	verbal	functional	non-words	data	effect
20	showed	sma	gyrus	beta	brain
21	neurology	tasks	normal	task	amplitude
22	neuropsychological	analysis	regions	meg	intensity
23	cerebral	condition	two	human	changes
24	seizures	imagery	frontal	movement	time
25	hemisphere	arm	found	sensorimotor	human
26	clinical	conditions	mean	conditions	task
27	naming	performance	word	alpha	training
28	also	using	study	two	test
29	cases	bimanual	anterior	values	using
30	reported	two	illusion	hand	muscles
31	seizure	data	illusions	left	mean
32	may	human	temporal	neurophysiol	sici
33	anterior	ipsilateral	analysis	hemisphere	stimulus
34	stroke	fmri	may	using	ihi
35	posterior	performed	data	clin	fdi
36	onset	used	eld	onset	emg
37	speech	also	one	source	meps
38	syndrome	results	fig	amplitude	neurophysiol
39	impaired	visual	using	hz)	hemisphere
40	neglect	primary	effect	used	interhemispheric
41	thalamic	sequence	functional	subject	performance
42	impairment	studies	cerebral	response	corticospinal

43	damage	activated	region	condition	evoked
44	following	action	can	studies	used
45	cognitive	contralateral	studies	peak	may
46	however	time	used	bilateral	coil
47	bilateral	hemisphere	parietal	electrode	ipsilateral
48	cortex	execution	vibration	signals	contralateral
49	words	regions	subjects	ipsilateral	force
50	semantic	cortical	results	electrodes	plasticity

C. Analysis $C1_c$: Keywords-in-Context Search in C1 for "handedness," Length 10

The following table presents 625 results, the first 10 percent of overall 6,251 results.

	Keywords in Context
1	ages condence interval was years years handedness was assessed using the edinburgh handedness inventory since we
2	years years handedness was assessed using the edinburgh handedness inventory since we are measuring volumes of brain areas
3	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia petrides m
4	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia
5	frackowiak rs cerebral asymmetry and the effects of sex and handedness on brain structure a voxelbased morphometric analysis of normal
6	fatigue score mean sd handedness rightleftc fmrisdmt behavioral measures
7	since first attack bage at first attack cbased on dutch handedness questionnaire donly correct trials enormalized thalamic volume thalamic
8	schmidt participants also completed the following questionnaires a dutch handedness questionnaire van strien b centre for epidemiological studies depression
9	pedsql score no differences were observed between groups in handedness dutch handedness questionnaire score or socioeconomic status bsmss score
10	no differences were observed between groups in handedness dutch handedness questionnaire score or socioeconomic status bsmss score behavioral performance
11	van strien j w the dutch handedness questionnaire rotterdam faculty of social sciences fsw department of psychology
12	motor cortex excitability during a simple motor task relationships with handedness andmanual performanceexp brainres civardi c cavalli a naldi
13	excitability and in transcallosal inhibition in relation to degree of handedness plos one e de gennaro l cristiani r bertini
14	g ferrara m fratello f romei v rossini pm handedness is mainly associated with an asymmetry of corticospinal excitability and
15	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia priori a oliviero a
16	donati e callea l bertolasi l rothwell jc human handedness and asymmetry of the motor cortical silent period exp brain
17	their modulation by task context and by interindividual differences in handedness represents one of the least understood facets of the functional
18	years righthanded healthy volunteers were recruited for this study the

	handedness of each subject was evaluated using the edinburgh handednessscaling questionnaire
19	the handedness of each subject was evaluated using the edinburgh handednessscaling questionnaire oldeld the mean laterality index using the handedness
20	handednessscaling questionnaire oldeld the mean laterality index using the handedness questionnaire was no subject had a history of
21	a common right and left hemisphere activations independently of handedness identied by a conjunction of dh and ndh effects supporting
22	no effect of the lateralization scores as measured by the handedness tests on the group ndings the main results of
23	zilles k asymmetry in the human motor cortex and handedness neuroimage ashe j force and the motor
24	activations in humans grasprelated areas depend on hand used and handedness plos one ee binkofski f fink gr geyer s
25	neurosci hammond g correlates of human handedness in primary motor cortex a review and hypothesis neurosci biobehav
26	cerebral cortex new york ny marian a handedness in families ann hum genet marshall mm
27	rehabil martin k jacobs s frey sh handednessdependent and independent cerebral asymmetries in the anterior intraparietal sulcus and
28	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia palesi f tournier jd
29	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science shibuya k kuboyama n tanaka j
30	volkmann j schnitzler a witte ow freund h handedness and asymmetry of hand representation in human motor cortex j
31	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia friston kj
32	then excluded from the study the laterality quotient for righthandedness according to the item inventory of the edinburgh test was
33	avect this bilateral cortical activation pattern of vestibular areas the handedness of the subjects and the side of the stimulation there
34	oldweld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia guldin wo
35	years of age with a mean iq range participated handedness was assessed on the annett handedness scale annet and
36	mean iq range participated handedness was assessed on the annett handedness scale annet and premorbid iq was estimated using the
37	genetic control sulcal and gyral anatomy and asymmetries associated with handedness are not bartley et al steinmetz et al
38	iowa city community all were righthanded scores on the oldeldgeschwind handedness inventory men mean sd women mean
39	women mean sd with no lefthandedness in rstdegree relatives healthy and with no history of neurological
40	sex less sexually dimorphic than other major lobes and age handedness we

	need to better understand the less correlated with other
41	participated for introductory psychology course credit and monetary remuneration handedness scale range chapman chapman participants were
42	l j chapman j p the measurement of handedness brain and cognition coan j a
43	and a left hand preference as determined by a handedness questionnaire patients in the acute and chronic stage of their
44	of cerebral asymmetries frontooccipital correlation sexual dimorphism and association with handedness arch neurol a brocklandt
45	of control and autism populations edinburgh handedness verbal iq performance iq fmri laterality index
46	groupmatched by age table compares group demographics of age handedness receptivelanguage function verbal intelligence quotient iq and performance iq of
47	and control populations there was a slight trend toward decreased righthandedness in the autism group which was not statistically significant in
48	cognitive neurologic or neuropsychiatric conditions were excluded assessments handedness the edinburgh handedness inventory a standardized assessment of hand preference
49	neuropsychiatric conditions were excluded assessments handedness the edinburgh handedness inventory a standardized assessment of hand preference was performed for
50	score between and in which represents strong lefthandedness and represents strong righthandedness iq verbal iq viq
51	in which represents strong lefthandedness and represents strong righthandedness iq verbal iq viq and performance iq piq were
52	number of subjects exhibiting scores between and edinburgh handedness inventory or between and functional mr imaging fmri
53	mr imaging fmri laterality index in which represents strong righthandedness and represents strong lefthemispheric language dominance fig
54	of hand preference showed a slight nonsignificant trend toward decreased righthandedness whereas the language laterality observed with the fmri laterality index
55	disord bryson se autism and anomalous handedness in coren s ed left handedness amsterdam the netherlands elsevier
56	se autism and anomalous handedness in coren s ed left handedness amsterdam the netherlands elsevier colby km
57	netherlands elsevier colby km parkison c handedness in autistic children j autism child schizophr
58	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia semel e
59	in this study dominant hand was determined by the edinburgh handedness inventory the present study was approved by the clinical
60	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia fadiga
61	history of neurological or psychiatric illness participated in the study handedness was assessed by the edinburgh handedness inventory the subjects

62	participated in the study handedness was assessed by the edinburgh handedness inventory the subjects were recruited from the kansai area
63	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia patton jh
64	participants apparatus and stimuli fourteen pure righthanded hn handedness inventory all participants mean se
65	operated a computer mouse with their right hand the hn handedness inventory is a revised version of the edinburgh inventory
66	ratonfl crc pp flowers k handedness and controlled movement british journal of psychology
67	hatta t nakatsuka z handedness inventory in ohno d ed papers on celebrating rd birthday
68	oldfield rc the assessment and analysis of handedness the dinburgh inventory neuropsychologia pelli
69	roy ea mackenzie c handedness effects in kinesthetic spatial location judgements cortex
70	used to note the age gender socioeconomic status education and handedness information was obtained by directly questioning to subjects socioeconomical status
71	demographic variables was undertaken with chisquare analyses for gender and handedness volumetric dierences of the pituitary glands of the patients with
72	all patients and controls were females socioeconomic status education and handedness all subjects were righthanded were not signicantly dierent between groups
73	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia delorme
74	possible neurological disorders no drugs were allowed except birthcontrol pills righthandedness was assessed with the van strien questionnaire
75	before wada testing the observers were aware of the patient handedness and of their histories of epilepsy information that would be
76	r female l r handedness was assessed using the edinburgh scale experimental setup
77	and and therefore is likely not related to handedness or task difculty this study showed a spatial reduction
78	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia cox rw
79	this study and paid for participation the laterality quotient for handedness according to the item inventory of the edinburgh test was
80	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia pompeiano o manzoni d
81	laterality effect in free viewing conditions the influence of sex handedness and response bias brain and cognit dec
82	motor abilities and motor network laterality may be due to handedness hand preference was assessed using the edinburgh handedness inventory oldeld
83	due to handedness hand preference was assessed using the edinburgh handedness inventory oldeld the relationship between total paness and

	edinburgh
84	inventory oldeld the relationship between total paness and edinburgh handedness score was not signicant r p
85	p in addition the degree of righthandedness was compared with motor network connectivity to determine whether connectivity
86	whether connectivity may reect the degree of hand preference edinburgh handedness score was not signicantly related to mean connectivity within either
87	lhrh r p to determine whether handedness affects the relationship between lateralized connectivity and paness partial correlation
88	relationship between lateralized connectivity and paness partial correlation controlling for handedness was performed the r value for this relationship was
89	the correlation between lateralized connectivity and paness without controlling for handedness was and the p value was suggesting that
90	was and the p value was suggesting that handedness had little effect on this brainbehavior relationship to ensure
91	of righthanded children hand preference as assessed by the edinburgh handedness inventory oldeld was not signicantly related to childrens lateralized
92	function between the two hemispheres examination of the relationship between handedness may also help to distinguish these possibilities there was no
93	zilles k asymmetry in the human motor cortex and handedness neuroimage barnes ka cohen al power jd nelson
94	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science konczak j timmann d the effect
95	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia picard n strick pl
96	noll dc small sl lateralization of motor circuits and handedness during nger movements eur j neurol sun ft
97	t walsh ca molecular approaches to brain asymmetry and handedness nat rev neurosci suskauer sj simmonds dj caffo
98	volkmann j schnitzler a witte ow freund h handedness and asymmetry of hand representation in human motor cortex j
99	vol pp april neurobiology direction of handedness linked to hereditary asymmetry of a sensory system mouse
100	abstract studies on the role of heredity in the transmission ofhandedness in nonhdp mammals bave so far led to the isolation
101	were bred demonstrate an opposite shift in the distribution of handedness a right or left dominance of the whisker pad predicts
102	whisker padassociated with a change in the circuitry that governs handedness or alternatively are there two gene sets responsible for the
103	that we reportone that causes whiskeredness and another that causes handedness many explanations have been proposed to account for human
104	many explanations have been proposed to account for human handednessan expression of brain asymmetryranging from purely cultural to purely genetic
105	a better understanding ofhereditary mechanisms and the brain substrate of handedness is not known it is difficult to arrive at a

106	explanation such difficulties can be circumvented by using animals because handedness is not confined to our species mice exhibit a
107	may indeed be associated with the direction of paw preference handedness in mice a contribution of potential interest for animal
108	strains allowed us to test whether direction and strength of handedness are associated with the direction ofan observable leftright asymmetry ofa
109	ofmice to possibly discriminate between genotypic and phenotypic factors influencing handedness we not only tested mice that expressed the patterns for
110	whiskers r rostral d dorsal lateralized in terms ofstrength ofhandedness than are male mice refs and nonpublished personal
111	by small circular barrels were not taken into account handedness was determined by using the pawpreference test designed by collins
112	min subsequent sessions took less time two parameters define handedness direction and strength the number of right paw entries rpe
113	number of left paw entries lpe measures the direction of handedness whereas the number of preferred paw entries ppe serves as
114	entries ppe serves as a measure of the strength of handedness ppe ilpe rpejlpe rpe x
115	because lpe rpe the direction and strength ofhandedness were compared in the seven groups of mice in every
116	to rpethe parameter we chose to express the direction of handednesswe found that of the matrices were normally distributed
117	the newmankeuls test direction as well as strength of handedness was recorded at the end of every behavioral session in
118	oap results and discussion analyzing the direction of handedness we demonstrated that the rpe differed between groups f
119	other groups had no preference the differences in direction of handedness between oap apo and the other five groups were apparent
120	at the first session no difference for the direction of handedness was observed between groups at the second session occurring
121	the third fourth and fifth sessions the opposite directions of handedness demonstrated by the o ap and ap mice differed from
122	the phenotype was the alldetermining factor associating the direction of handedness with whisker asymmetry we analyzed the pawpreference in animals that
123	and apo interestingly these animals did not demonstrate bias for handedness fig this result would seem to indicate that the
124	in classes and were considered as dextral the handedness distributions of all groups were compared by using the x
125	evolution in succeeding test sessions of the direction of handedness in ap o ap v and aps e a and
126	shifted to the right in the nor mice leftand righthandedness were found about equally distributed collins reported similar
127	in mice of other inbred strains however the handedness distribution of nor mice resembles that of collins lo line
128	lo line obtained by mating ambidextrous mice whereas the handedness of ap

	aps apos and ap was distributed similarly to
129	ap was distributed similarly to that in nor mice the handedness of ap mice was shifted about one class toward the
130	evolution in succeeding test sessions of the strength of handedness ppe in the same mice whose evolution of direction is
131	segments represent sems with respect to the strength of handedness defined by ppe we did not find a difference between
132	ap mice in succeeding test sessions exhibit opposite directions of handedness it has been reported that the strength of handedness
133	handedness it has been reported that the strength of handedness is influenced by hereditary factors and that
134	hereditary factors and that the direction of handedness is influenced by environmental factors even by teaching
135	by teaching the present study associates the direction of handedness with a genetically determined asymmetry of a neuronal system the
136	system the question remains whether the association between whiskeredness and handedness is made at the level of the wiring of the
137	the whisker padand brain centers responsible for the expression of handedness in the latter case two gene sets would be linked
138	another set that is responsible for a given direction of handedness we thank p g h clarke n jeanpretre r
139	rsj cerebral asymmetry and the effects of sex and handedness on brain structure a voxelbased morphometric analysis of normal
140	functional magnetic resonance imaging evidence of functional lateralization related to handedness neurosci lett frank gk kaye wh carter cs
141	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia onoda k kobayakawa t
142	were normal in all patients on visual inspection the edinburgh handednessinventory laterality quotientsrevealed righthand mum possible score cutoff showed
143	servedasacontrol grouptable germanwasthe primary language of all subjects the edinburgh handedness inventory laterality quotients ranged from to mean
144	table patients age at duration handedness wada overall seizure of epilepsy
145	table healthy controls controls age yr sex handedness lq m m
146	and right tle did not differ significantly with respect to edinburghhandedness laterality quotient mann whitneyutestp iq mannwhitneyutest p
147	patientsitis importantto stress that the patient groups are comparable regarding handedness age intelligence age at epilepsy onset duration of epilepsy and
148	controls patients and controls did not differ in edinburgh handedness laterality quotient mannwhitney u test p and
149	in one patient with right tle and was associated with lefthandedness younger age at epilepsy onset and early precipitating injury thus
150	oldfield rc the assessment and analysis of handedness the edinburghinventory neuropsychologia loring d lee
151	brain size hatazawa et ai gender and handedness scanned twice in a single day

	the
152	ranged from to more than years of schooling handedness was determined by the edinburgh handedness questionaire oldfield
153	years of schooling handedness was determined by the edinburgh handedness questionaire oldfield twelve subjects the ampm group were
154	oldfield rd the assessment and analysis of handedness the edinburgh inventory neuropsychiatry phelps me huang sc
155	al ipsilateral meps are related to the degree of handedness bernard et al when tms was used to generate
156	neurosci bernard ja taylor sf seidler rd handedness dexterity and motor cortical representations j neurophysiol bihel
157	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science lacroix s havton la mckay h yang
158	cm all were righthanders as determined by the edinburgh handedness inventory item version mean laterality quotient
159	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia keel
160	all subjects were consistent righthanders according to the edinburgh handedness inventory edi we studied healthy females mean sdage
161	research article laterality of interhemispheric inhibition depends on handedness tb umer e dammann f bock
162	springerverlag abstract there is some evidence that handedness is related to lateralisation of excitability in the motor system
163	interval intracortical inhibition sici and facilitation sicf in relation to handedness in right rh and left handed lh subjects
164	and sicf showed no diverences between hemispheres or dependency from handedness we hypothesize that ihi is a function of handedness perhaps
165	from handedness we hypothesize that ihi is a function of handedness perhaps rexecting predominant usage of the dominant hand while lateralisation
166	other factors introduction there is some evidence that handedness has an inxuence on motor cortex excitability using transcranial
167	of the white matter underneath the precentral sulcus related to handedness b chel et al at closer inspection tms
168	there was no hemispherical diverence of ihi in relation to handedness or hemisphere on the other hand resting motor thresholds rmt
169	in experiments and healthy subjects were studied handedness was tested using the edinburgh handedness inventory edi subjects were
170	healthy subjects were studied handedness was tested using the edinburgh handedness inventory edi subjects were considered rh if the edi score
171	hemisphere left vs right hemisphere and a between groups factor handedness rh vs lh absolute mean mep amplitudes of conditioned meps
172	there was no signiwcant evect for the between groups factor handedness and no interaction of these factors fig analysing both
173	indicates that hemispheric diverences of motor thresholds are independent from handedness test mep intensities used over the right hemisphere right

174	group indicates that laterality of ihi between hemispheres depends on handedness fig post hoc tests only showed trends towards more
175	wnd signiwcant hemispherical diverences of sici and sicf related to handedness isi ms fig interhemispheric
176	this study shows that asymmetries of ihi depend on handedness the inhibitory drive from the dominant hemisphere is generally stronger
177	m as compared to dpm motor thresholds were independent from handedness but lateralised with higher thresholds for the right hemisphere there
178	the right hemisphere there was no lateralisation or dependency on handedness for sici and sicf fig short interval intracortical
179	ihi and handedness in this study hemispherical asymmetry of ihi depended on
180	in this study hemispherical asymmetry of ihi depended on handedness this asymmetry with stronger ihi from the dh to the
181	ms did not wnd a dependency of ihi on handedness or hemispherical dominance table however at isis of
182	there are albeit weak interhemispheric diverences of ihi related to handedness if lateralisation of interhemispherical inhibitory drive is a function
183	sicf were not lateralised moreover there was no relation to handedness this is inline with wndings of cincinelli et al
184	table studies where ihi was investigated in relation to handedness result interstimuluscoils cp intensity flow tp intensity flowreference intervals direction
185	no diverence in lh muscle no diverence related to handedness mm wgure rmt ap rmt ap de
186	mm wgure rmt pa rmt pa b umer handedness interaction of eight et al this study stimulus parameters
187	rmt and amt were higher in right hemispheres regardless of handedness which is in line with most previous studies macdonell et
188	of hand preference this does not support the idea that handedness is the most crucial factor determining motor thresholds findings
189	the majority of previous studies only one factor eg handedness or coil distance to the motor cortex was investigated however
190	results of threshold diverences are inxuenced by factors other than handedness including the distance between the head surface and motor cortex
191	of the sensorimotor cortex during wnger movements in relation to handedness asymmetric hemispheric activation was reported for complex wnger movements but
192	kl ppel et al thus it appears that handedness becomes more relevant if more complex cortical networks are engaged
193	during motor performance as a corollary it is possible that handedness is not rexected in basic properties of the motor system
194	together in this study laterality of ihi was related to handedness whereas thresholds and sici and sicf were not thus intracortical
195	intracortical parameters restricted to one hemisphere are not depended on handedness while ihi as a parameter of interhemispheric control probably is
196	interhemispheric control probably is conclusion ihi depends on handedness

	with a more pronounced inhibitory drive from the motor dominant
197	pairedpulse transcranial magnetic stimulation evects of hemispheric laterality gender and handedness in normal controls j clin neurophysiol chen r
198	in motor cortex rexects the direction and the degree of handedness proc natl acad sci usa de gennaro l
199	g ferrara m fratello f romei v rossini pm handedness is mainly associated with an asymmetry of corticospinal excitability and
200	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science kl ppel s van eimeren t glauche
201	chel c weiller c siebner hr the evect of handedness on cortical motor activation during simple bilateral movements neuroimage
202	cros d chiappa kh physiological motor asymmetry in human handedness evidence from transcranial magnetic stimulation brain res triggs
203	volkmann j schnitzler a witte ow freund h handedness and asymmetry of hand representation in human motor cortex j
204	was previously reported in behavioral data individual handedness was assessed by comparing bimanual performance hand dominance test hdt
205	posthoc ttests to account for the effect of age and handedness individual values for age and hdt handedness scores were added
206	of age and handedness individual values for age and hdt handedness scores were added as covariates to the onefactor repeatedmeasures anova
207	similar to the comparison of gabacr concentrations age and hdt handedness scores were included in the analysis as covariates in case
208	addition we corrected the respective correlations for age the hdt handedness scores and the individual cortical grey matter volume within the
209	doijournalponet individual hdt handedness scores as covariates yielded a significant difference between gabacr concentrations
210	and condition eo ec eceo with age and individual hdt handedness score included as covariates yielded no significant main effects for
211	correlations we additionally partialized out the effect of age hdt handedness score and respective individual cortical grey matter volume in line
212	subjects in the present study were classified as righthanded handedness might be an explanation for the unilateral correlation however correlations
213	correlation however correlations largely remained significant even after correcting for handedness this finding suggests that handedness alone is unlikely to account
214	significant even after correcting for handedness this finding suggests that handedness alone is unlikely to account for the differences between left
215	account for the differences between left and right sensorimotor cortices handedness however is known to lead to asymmetries with respect to
216	size in future studies to further elucidate the effect of handedness on gabaergic concentrations in sensorimotor cortices a general limitation
217	we measured mostly righthanded subjects so that an influence of handedness cannot be excluded the abovementioned studies do not report handedness
218	handedness cannot be excluded the abovementioned studies do not report handedness of their subjects making a direct comparison difficult gaetz

219	volkmann j schnitzler a witte ow freund h handedness and asymmetry of hand representation in human motor cortex journal
220	skills in vj indicates that questions relating language dominance and handedness may have been formulated incorrectly rather than looking for dichotomous
221	mirror movements all subjects were righthanded according to the edinburgh handedness table patient demographics age type of
222	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia ridding mc sheean
223	b which determinants can best explain the differences the subjects handedness or the side of the lesioned ear or both c
224	patients were strongly righthanded based on a laterality quotient for handedness of or according to the item inventory of
225	oldfeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia ptito m matteau i
226	activations in humans grasprelated areas depend on hand used and handedness chiara begliomini cristian nelini andrea caria wolfgang grodd umberto
227	been identified whether activity within this circuit varies depending on handedness has yet to be investigated methodologyprincipal findings we used
228	used functional magnetic resonance imaging fmri to explicitly test how handedness modulates activity within human graspingrelated brain areas rightand lefthanders subjects
229	study conclusionsignificance data are discussed in terms of an handednessindependent role for the right dpmc in monitoring hand shaping the
230	the performance of precision grip movements which varies depending on handedness and the involvement of the cerebellum in terms of its
231	compelling evidence of specific grasping related neural activity depending on handedness citation begliomini c nelini c caria a grodd w
232	activations in humans grasprelated areas depend on hand used and handedness plos one e doijournalpone editor eric warrant lund
233	how the neural circuit underlying grasping modulates with respect to handedness a basic feature of the human motor behavior to date
234	of asymmetries in hand use that defines left and right handedness to our knowledge there are no published studies that
235	grasping tasks is always contralateral to the hand modulated by handedness and the used hand or always located in the same
236	hand or always located in the same hemisphere regardless of handedness therefore here we studied the kinematics and fmri activation patterns
237	by rightor lefthanded participants an analysis of variance anova with handedness righthanders lefthanders as a betweensubjects factor and performing hand rh
238	sulcus aip and the cerebellum main effect of handedness when contrasting activity related to handedness independently from the used
239	main effect of handedness when contrasting activity related to handedness independently from the used hand righthanders rhrighthanderslhlefthandersrhlefthanderslh significant differential activity

240	contrast testing for differences between rh and lh independently from handedness righthandersrhlefthandersrhrighthanderslhlefthanderslh revealed significant activity within both the anterior and posterior
241	motor and dorsal premotor cortices see table interaction handedness by performing hand the interaction between handedness and performing hand
242	interaction handedness by performing hand the interaction between handedness and performing hand righthandersrhrighthanderslhlefthandersrhlefthanders lh revealed significant differential activity within
243	table brain regions showing significant effects for the anova handedness by performing hand cluster level voxel level mni
244	mri results group statistical map resulting from the interaction between handedness and performing hand the contrast righthandersrhrighthanderslhlefthandersrhlefthanderslh revealed significant effects on
245	demonstrated then we may not expect differences related to handedness for the considered kinematic variables alternatively if the results that
246	left hand to perform precision grasp movements therefore violating handedness then we may expect the left hand to behave less
247	the left than with the right hand the interaction between handedness and performing hand was significant for movement duration f
248	a and closing time b graphical representation for the interaction handedness by hand for movement duration c and the amplitude of
249	hand however as outlined below depending on the relationship between handedness and the hand used distinguishable neural and kinematic patterns were
250	the pattern of dpmc activity for the interaction between handedness and hand mirrors the pattern obtained for the same interaction
251	similar in both hemispheres but differs depending on hand and handedness in particular an increase of bilateral aip activity was evident
252	anatomical observation of differences in interhemispheric connections in relation to handedness and it might also suggest differences in the functional
253	key areas involved in the control of grasping depending on handedness crucially they extend the current human neuroimaging literature in three
254	had no neurologic or psychiatric history or any motor pathology handedness righthandedness lefthandedness was assessed by using a test of manual
255	no neurologic or psychiatric history or any motor pathology handedness righthandedness lefthandedness was assessed by using a test of manual dominance
256	neurologic or psychiatric history or any motor pathology handedness righthandedness lefthandedness was assessed by using a test of manual dominance
257	the experiment was conducted by using a mixed eventrelated design handedness righthanders lefthanders was the betweensubjects factor type of action g
258	withinsubjects variable corrected for sphericity and equal variance assumed

	and handedness righthanders lefthanders served as a betweensubjects variable the resulting spmt
259	lefthanded dominance men women mean age years handedness was determined using a test for manual dominance none
260	specialization for the visual control of action is independent of handedness j neurophysiol gonzalez cl whitwell
261	whitwell rl morrissey b ganel t goodale ma left handedness does not extend to visually guided precision grasping exp brain
262	behavioural experiment across trials was entered into an anova with handedness righthanders lefthanders as a betweensubjects factor and performing hand rh
263	healey jm liederman j geschwind n handedness is not a unidimensional trait cortex
264	interhemispheric asymmetry of the human motor cortex related to handedness and gender neuropsychologia solodkin a
265	noll dc small sl lateralization of motor circuits and handedness during finger movements eur j neurol
266	s the lefthander syndrome the causes and consequences of lefthandedness new york free press umilta ma brochier
267	the degree of face selectivity in the rh varies with handedness also consistent with the precedence of language and the subsequent
268	been proposed to bridge the genetics of hemispheric dominance and handedness and while we do not review these exhaustively a few
269	relevance for instance a generic trait of asymmetry such as handedness which may be genetically determined for example see refs
270	understanding of the nature of hemispheric dominanceaswell asitsunderlyingbasisand relationship to handedness is clearly needed but is beyond the scope of this
271	cortex is larger in individuals who have less lateralization in handedness also the callosal crosssectional area is proportionally larger for left
272	cerebral lateralization of faceselective and bodyselective visual areas depends on handedness cereb cortex maurer u d
273	mcmanus ic the inheritance of lefthandedness ciba found symp discussion
274	the ontogenesis of language lateralization and its relation to handedness neurosci biobehav rev knecht s
275	knecht s et al handedness and hemispheric language dominance in healthy humans brain pt
276	when more is less associations between corpus callosum size and handedness lateralization neuroimage witelson sf
277	all lesions were in the right hemisphere or to the handedness all patients were righthanded a physiological comparisons across subjects was
278	a second factor of asymmetry in cortical activation is the handedness of the subjects the activation was stronger in the nondominant
279	vestibular neuritis participated in the study the laterality quotient for handedness according to the item inventory of the edinburgh test was
280	oldfield rc the assessment and analysis of handedness the edinburgh inventory

	neuropsychologia salmaso d
281	oldeld salmaso and longoni was for strong righthandedness in volunteers and in one volunteer the local
282	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia paus t location
283	the result of spinal excitability modulations most likely related to handedness j neurol neurosurg psychiatry keywords motor thresholds
284	neurosurg psychiatry keywords motor thresholds sex diverences pallidotomy handedness internal capsule there are recognised diverences between the functions
285	understand these sex related diverences it has been claimed that lefthandedness is more prevalent in men and women seem to function
286	geschwind n patterns of pyramidal decussation and their relationship to handedness arch neurol macdonnell ral shapiro be
287	ral cros d chiappa kh physiological motor asymmetry in human handedness evidence from transcranial magnetic stimulation brain res
288	from the wrist lateralization of motoneuronal excitability in relation to handedness in normal subjects int j neurosci kim
289	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science geschwind n levitsky w human brain
290	j asymmetrical processing of tachistoscopic inputs in undergraduates across sex handedness feldside and fxation instructions percept mot skills
291	genettawadley a swirskysacchetti t sex diverences and handedness in hemispheric lateralization of tactilespatial functions percept mot skills
292	asymmetry in men and women bilateral diverences in relation to handedness in men j comp neurol strauss
293	novel correlations with clinical features beyond the established association of lefthandedness early seizure onset and vascular pathology with atypical language cluster
294	pathology with atypical language cluster analysis identified an association of handedness with frontal lateralization early seizure onset with temporal lateralization and
295	and pediatric volunteers were reported previously inclusion criteria were righthandedness on the edinburgh handedness inventory score and normal mri
296	were reported previously inclusion criteria were righthandedness on the edinburgh handedness inventory score and normal mri the study was
297	for gender age years early seizure onset years old handedness focus and underlying pathology to reduce comparisons and determine whether
298	patients with atypical language dominance more likely to have atypical handedness left and mixed dominance early seizure onset and abnormal mri
299	activation patterns are considered supplementary tables and handedness for level comparisons both methods found more frequent atypical
300	for level comparisons both methods found more frequent atypical handedness when ifg was right lateralized a priori groups chisquare
301	activation rightlateralized ifg patients had the greatest proportion of atypical handedness ifg lateralization perhaps due to proximity to motor cortex may

302	proximity to motor cortex may be more related to atypical handedness than wa lateralization factors underlying motor dominance determination may underlie
303	handedness dexterity and motor cortical representations jessica a bernard stephan
304	october bernard ja taylor sf seidler rd handedness dexterity and motor cortical representations j neurophysiol
305	published october doijn motor system organization varies with handedness however previous work has focused almost exclusively on direction of
306	however previous work has focused almost exclusively on direction of handedness right or left as opposed to degree of handedness strength
307	of handedness right or left as opposed to degree of handedness strength in the present study we determined whether measures of
308	we determined whether measures of interhemispheric interactions and degree of handedness are related to contraand ipsilateral motor cortical representations participants completed
309	contraand ipsilateral motor cortical representations participants completed a battery of handedness assessments including both handedness preference measures and behavioral measures of
310	representations participants completed a battery of handedness assessments including both handedness preference measures and behavioral measures of intermanual differences in dexterity
311	of imeps correlated with ihtt there were no relationships between handedness or lateralization of dexterity and symmetry of contralateral motor representations
312	ihtt was positively correlated with multiple measures of laterality and handedness these ndings demonstrate that degree of laterality of dexterity is
313	are transcallosally transmitted introduction it is known that handedness is related to the organization of the sensorimotor system for
314	al however the majority of work investigating relationships between handedness neuroanatomy and behavior has evaluated direction of handedness left vs
315	relationships between handedness neuroanatomy and behavior has evaluated direction of handedness left vs right as opposed to degree of handedness how
316	of handedness left vs right as opposed to degree of handedness how strongly handed one is although there is evidence to
317	solodkin et al organization of motor cortex and handedness motor cortex physiology is related to handedness for example
318	cortex and handedness motor cortex physiology is related to handedness for example leftand righthanders show different functional acti address for
319	used transcranial magnetic stimulation tms to investigate the relationship between handedness and motor cortical representations cicinelli et al triggs et
320	leftand righthanders however these studies did not consider degree of handedness nor did they investigate ipsilateral motor representations interhemispheric communication
321	did they investigate ipsilateral motor representations interhemispheric communication and handedness the poffenberger paradigm pp marzi

	poffenberger is
322	cherbuin and brinkman ab observed a relationship between ihtt and handedness thus although ihtt is related to direction of handedness it
323	and handedness thus although ihtt is related to direction of handedness it remains unclear whether there is a relationship across the
324	it remains unclear whether there is a relationship across the handedness spectrum corpus callosum and handedness the corpus callosum
325	a relationship across the handedness spectrum corpus callosum and handedness the corpus callosum is the main conduit for information
326	consistent righthanders li or higher suggesting that degree of handedness may also relate to speed and accuracy of interhemispheric interactions
327	colleagues examined callosal size in relation to degree of handedness in a large sample they found that less strongly handed
328	whether or not there are differences in callosal morphometry among handedness groups at least some of the evidence suggests a neuroanatomical
329	text in sum it is clear that direction of handedness left or right is related to m organization speed and
330	to be determined however particularly in relation to degree of handedness although research employing functional neuroimaging has looked at degree of
331	although research employing functional neuroimaging has looked at degree of handedness dassonville et al lutz et al to our
332	motor cortical representations and ihtt across the full range of handedness and laterality of dexterity based on prior work looking at
333	at functional activity in the primary motor cortex across the handedness spectrum dassonville et al kim et al siebner
334	of imeps and ihtt supporting the interrelatedness of degree of handedness and laterality interhemispheric interactions and the existence of ipsilateral motor
335	separate days on day participants completed a battery of handedness assessments the edinburgh handedness inventory item score oldeld
336	participants completed a battery of handedness assessments the edinburgh handedness inventory item score oldeld to provide a selfreport measure
337	item score oldeld to provide a selfreport measure of handedness tapping circles and tapping squares from the hand dominance
338	three trials were completed for each hand while the edinburgh handedness inventory assesses preferred hand use our other measures assess dexterity
339	not be ltered out statistical analyses relationships between handedness measures and interhemispheric communication were assessed using linear regression analyses
340	the number of imeps was investigated in relation to both handedness measures and cud in these cases poisson regression models were
341	are no relationships between the symmetry of contralateral representations and handedness although mixed handed individuals show more ipsilateral meps fig
342	fig a distribution of scores on the edinburgh handedness inventory for all participants b distribution of scores on edinburgh
343	inventory for all participants b distribution of scores on edinburgh handedness inventory for the subset of tms participants fig ad

344	a relationship between contralateral motor cortical representations and degree of handedness contrary to the ndings of dassonville and colleagues given
345	et al our study included a wide range of handedness and our data indicate that only those that are less
346	ndings and they underscore the importance of considering the entire handedness and laterality spectrum it is also not clear whether these
347	and laterality spectrum it is also not clear whether these handedness effects arise during development or are a function of extended
348	of the direction of transfer from dominant to nondominant hemisphere handedness has not been considered either although bisiacchi and colleagues
349	indicates that patterns of interhemishperic communication may differ across the handedness and laterality spectrum furthermore the differential pattern of the
350	differential pattern of the domcud and noncud correlations across the handedness and laterality spectrum may reect differing patterns of interhemispheric interactions
351	had the fastest cud although we see no relationship with handedness more bilateral representations are indicative of faster ihtt leftlateralized individuals
352	single hemisphere processing resulting in a negative cud human handedness is the most obvious instance of motor laterality additionally differences
353	additionally differences in brain structure and function are manifest across handedness groups sainburg views hand preference as an important underlying
354	al however how this pattern generalizes to mixed handedness is unclear although our data provide some insight if in
355	data provide some insight if in the cases of mixed handedness neither hemisphere is specialized for a particular task then efcient
356	that patterns of communication between the hemispheres vary across the handedness spectrum acknowledgments the authors thank a bosma s
357	pe zillies k asymmetry in the human motor cortex and handedness neuroimage annett m handedness and cerebral
358	cortex and handedness neuroimage annett m handedness and cerebral dominance the right shift theory j neuropsychiatry
359	r d seidler chase c seidler r degree of handedness affects intermanual transfer of skill learning exp brain res
360	activation in motor cortex reects the direction and degree of handedness proc natl academy of sci usa
361	curcio g ferrara m fratello f romei v rossini pm handedness is mainly associated with an asymmetry of corticospinal excitability and
362	oliva a regis j salamon g khalil r effects of handedness and sex on the morphology of the corpus callosum a
363	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science koeneke s lutz k herwig
364	when more is less associations between corpus callosum size and handedness lateralization neuroimage lutz k koeneke s
365	oldfeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia poffenberger at

366	nervous centers arch psychol sainburg rl handedness differential specializations for control of trajectory and position ecs and
367	bloem br schwaiger m conrad e longterm consequences of switching handedness a positron emission tomography study on handwriting in converted lefthanders
368	p noll dc small sl lateralization of motor circuits and handedness during nger movements eur j neurol
369	ral cros d chiappa kh physiological motor asymmetry in human handedness evidence from transcranial magnetic stimulation brain res
370	volkmann j schnitzler a witte ow freund hj handedness and asymmetry of hand representation in human motor cortex j
371	j sainburg rl interlimb transfer of visuomotor rotations depends on handedness exp brain res wassermann em pascualleone
372	woerner w wittling ra schweiger e wittling w effects of handedness and gender on macroand microstructure of the corpus callosum and
373	rare case of a patient jnr with history of mixed handedness developmental dyslexia dysgraphia and attentional deficits associated with a klippeltr
374	the lateralization of language to the left hemisphere and right handedness induces a random hemispheric lateralization and intrahemispheric localization of language
375	thus analysis of these cases irrespective of the patients handedness is interesting because it would provide a better understanding of
376	remaining nine activities of the chapman and chapman questionnaire of handedness there was no family history of lefthandedness learning disabilites
377	questionnaire of handedness there was no family history of lefthandedness learning disabilites or inherited neurocutaneous syndromes on an interview with
378	years handedness rightmixed mixed wechsler adult intelligence
379	in the right hemisphere of patients who had pathological lefthandedness congenital right hemiparesis but normal language due to discrete left
380	review and hypothesis brain annett m handedness and cerebral dominance the right shift theory journal of neuropsychiatry
381	neuropsychological society bishop d v m handedness and developmental disorder hove uk lawrence erlbaum associates boatman
382	l j chapman j p the measurement of handedness brain and cognition chee m w l
383	d l saslow e henry r the pathological lefthandedness syndrome brain and cognition satz p strauss
384	varghakhadem f ogorman a watters g aphasia and handedness in relation to hemispheric side age at injury and severity
385	abstract lateralization of cortical functions such as speech dominance handedness and processing of vestibular information are present not only in
386	be correlated with the hemispherical dominance as determined by the handedness it is located mainly within the right hemisphere in right
387	rats follows a strong left hemispheric dominance independent from the handedness of the animals these ndings support the idea of an

388	were revealed as important functional aspect it was demonstrated that handedness the side of the vestibular stimulation and the direction of
389	the concept of lateralized vestibular dominance in dependency of the handedness in humans could once more be delineated as previously shown
390	al o dkvist et al the concept of handedness was not considered in any of these studies furthermore the
391	incomplete the data on the functional context of hemispherical specialization handedness and vestibular processing in animal models are fragmentary over
392	forelimb in rodents became evident in a series of studies handedness as such is nowadays an accepted concept in rodents biddle
393	were found to inuence hemispheric specialization as expressed by the handedness of the animals schaafsma et al however the question
394	to determine if this dominance correlates with the presence of handedness in the animals methods animals twelve male
395	weight g six righthandedfooted six lefthandedfooted the assessment of handednessfootedness will be described below were provided housing with equal daily
396	of a resulting nystagmus in the animals testing of handedness handedness of the animals was evaluated by a food
397	resulting nystagmus in the animals testing of handedness handedness of the animals was evaluated by a food deprivation test
398	and included in the analyses results testing of handedness of the tested rats six showed a pure
399	same side as the leftsided vestibular stimulation independent of the handedness six clusters were identied on cortical level of which
400	three factors the side of the stimulated ear the subjects handedness and the direction of induced vestibular symptoms the stronger activation
401	as well as in the hemisphere in accordance with the handedness right hemisphere in right handers and left hemisphere in left
402	hemisphere in the processing of vestibular information independently of the handedness in rats furthermore we showed that left vestibular input was
403	animals left hemisphere and that the development of speech and handedness in humans may represent processes that lead to reorganization within
404	janzen et al three factors are of relevance handedness is a strong inuencing factor on the cortical vestibular representation
405	in right handers ie contralateral to the left hemisphere for handedness and speech dominance three explanations are possible the vestibular
406	process of specialization of cortical functions inducing the lateralization of handedness and speech dominance into the opposite hemisphere other
407	areas as well as the lateralization of speech dominance and handedness to the opposite hemisphere the lateralization of the vestibular
408	cortical system followed the development and lateralization of speech and handedness of the rats in the present study were
409	out a specialization of one hemisphere with respect to the handedness within the group of animals the central processing of vestibular
410	eales ba the degree of lateralization of paw usage handedness in the mouse is

	dened by three major phenotypes behav
411	ziehr je eales ba genetic variation in paw preference handedness in the mouse genome brandt t dieterich m
412	neurosci collins rl on the inheritance of handedness i laterality in inbred mice j hered collins
413	mahler l kalbitzer j heinz a bermpohl f understanding lefthandedness dtsch arztebl int janzen j schlindwein p bense
414	least months years weakness of the upper extremities right handedness and spinemri showing or more levels of cervical spinal
415	for tr and for cm groups handedness before the stroke was evaluated using edinburgh handedness inventory oldeld
416	cm groups handedness before the stroke was evaluated using edinburgh handedness inventory oldeld all subjects were righthanded before stroke except
417	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia page sj gater dr
418	converselycomparedwithnhsddwomenhsddwomenshowedhigheractivationinth emedialfrontalgyrusbaandtherightinferiorfrontalgyrusbatheauthorsinterpretedth eseactivationsinbaandbaasindicatingthathsddwomenallocatedsignicantlymoreat tentiontomonitoringandorevaluatingtheirresponsestoeroticstimulithannhsddwo mendidwhichmayinterferewithnormalsexualresponsetheseresultsifreplicatedare importantbecausetheyprovidenewinsightsintothepossibleprocessinganomaliesa ssociatedwithhsddandmayhavedirectimplicationsforsexualmedicinenonetheless despitethesecompellingresultsfurtherfmristudiesarenecessarytoconrmandreneth ebrainnetworkinvolvedinhsddinwomenbecausearnowetalusedsportstimuliasam aincontrolconditionforthedesireevokedbyeroticstimulionecannotassertwhethert heirresultscanbegeneralizedwithothertypesofcontrolstimulialthoughtheirstudyi ncludedwhattheycalledrelaxationstimulitheirmainstatisticalanalysesofinterestfo cusedonthecomparisonbetweenthebrainactivationduringeroticvssportsvideoseg mentsfurthermorebecauseallthedifferentvideosegmentspresentedinarnowetalsst udydidnothavethesamedurationeroticminutessportsminutesrelaxationminuteitis difculttoensurethatcomparablebrainactivationtookplaceduringalltheirvideoseg mentsalsomanydifferentthoughtsandbrainmechanismsmayoccurduringthosemi nutesofpresentationoftheeroticsegmentsotherthanthoseunderlyingsexualdesirep ersethusoneneedstotestshorterpresentationoferoticstimuli finallythereisoneadditionallimitationinarnowetalsstudygiventhewellknowneffe ctofhormonesonsexualdesireandonbrainmechanismstheauthorstestedwomenon oralcontraceptivesandwomenoffcontraceptivesduringtheirlutealphasewhichbeg insafterovulationwiththeformationofthecorpusluteumandcontinuesuntilmenstru ationbeginsienormallybetweenanddaysfromthebeginningofthelastmenstrualcyc leandwomenonoralcontraceptivesbetweenanddaysfollowingtherstdayoflastmen sestoaddresstheseexperimentallimitationsoneneedstotestamorehomogeneousgr oupofcyclingwomenegwomenofforalcontraceptivesanduseanexperimentaldesig nthatpresentsparticipantswithsimilarcategoriesofstimuliegpicturesoferoticvsno neroticmenthatvaryasafunctionoftheirdesirablelevelsegdesirablevsnondesirable ratherthanasafunctionoftheirattributessportsvshumanbeings hereweusedsuchanexperimentaldesigninfmritotestwhetherwomenwithhsddcom

	paredwithwomenwithouthsddshoweddistinctivepatternsofbrainactivationsinresponsetovisualeroticmalestimuli materials and methods participants atotalofhealthyheterosexualsexuallyactivewomenmeanage yearswhoweredatingengagedormarriedparticipatedinthepresentstudyallparticipantswererecruitedviayerstheexperimentalprocedurewasthenexplainedtoeligibleparticipantsincludingtheuseoferoticandnoneroticstimuliallparticipantsprovidedwritteninformedconsenttoparticipateintheexperimentwhichwasapprovedbythelocaluniversityinstitutionalreviewboardallparticipantswererighthandededinburghhandednessinventorywithnormalmenstrualcyclenormalorcorrectedtonormalvisionnomedicationandnochemicaldependencynoneoftheparticipantshadpriororcurrentneurologicorsymptomsofpsychiatricdisordersasascertainedbyadetailedanamnesisandastructuredclinicalinterviewincludingthebriefpsychiatricratingscalebprsandthehospitalanxietyanddepressionscalemoreovertheanamnesisdidnotrevealanyhistoryofpsychiatricdisorderstraumaticbraininjurywithlossofconsciousnessepilepsyneurologicimpairmentgynecologicaldisordersordegenerativeneurologicillnessnoneoftheparticipantshadanycontraindicationformriscanningasassessedbythelocaluniversityprescanscreeningform toensurenormalmenstrualcyclefunctioningacertiedpsychologistnrfromthepsychosomaticgynecologyandsexologyunitofthelocaluniversityhospitalperformedadetailedstructuredinterviewwitheveryparticipanttheexclusioncriteriawerethefollowingitheuseoforalcontraceptiveswithinthepreviousmonthsiimenstrualcyclesthatwerelongerthandaysorshorterthandaysorthatwereirregulariiicurrenttreatmentwithanabolicsteroidsorpsychoactivemedicationsivorahistoryofneurologicorpsychiatricdisorderstheinclusioncriteriawerethefollowinginouseoforalcontraceptivesiinormalmenstrualcyclesbetweenanddays iiinosteroidorpsychoactivemedicationsandivnohistoryofneurologicorpsychiatricdisorders inadditionweassessedthelevelofparticipantssexualdesireusingadetailedstructuredinterviewontheirsexualhistoryanddesirethisinterviewprovidedinsightsintotheparticipantsfeelingsabouttheirsexualdesireitsintensityfrequencyandsatisfactionthisinterviewwasbasedonthedsmivandontheinternationalconsensuscommitteecriteriaandwasusedtodeterminethediagnosisofhsddnotablythecriterionofpersonaldistresswasclearlyassessedinordertomakethediagnosisofhsddtoassessthewomenssubjectiveexperienceaboutsexualdesirewiththeirpartnerweaskedeveryparticipanttocompletestandardquestionsaboutwhetherandtowhatdegreetheyfeltsexualdesirewiththeirpartnerforinstanceweusedquestionsthatwerepartofthestandardizedfemalesexualfunctioningindexfsfiaselfreportmeasureofsexualfunctioningthathasbeenvalidatedonaclinicallydiagnosedsampleofwomenwithfemalearousaldisorderthenparticipantswerescheduledforthefmriscanningsessionseebelowforfurtherdetailsbecauseagrowingnumberofstudieshasshownhormonaluctuationsasevidencedbywomensmenstrualcycletoinuencesexualdesirecerebrallateralityandalsothebrainactivationsduringtheviewingoferoticstimuliallparticipantshadtheirfmriscanningsessionatthesameperiodoftheirmenstrualcycleiewithintherstdaysoftheirmenstrualcycleiemensesaphasethatoccurspriorthephasesofthemenstrualcyclesuchastheovulatoryphasethatareknowntomodulatesexualdesire women with no hsdd nhsdd participants

419	redoutejstoleruspugeatmcostesnlavenneflebarsddechaudhcinottilpujoljfbrainprocessingofvisualsexualstimuliintreatedanduntreatedhypogonadalpatientspsychoneuroendocrinology ferrettiacaulomdelgrattacdimatteormerlaamontorsifpizzellavpompaprigattiprossinipmsaloniaatartaroaromanigldynamicsofmalesexualarousaldistinctcomponentsofbrainactivationrevealedbyfmrineuroimage arnowbamillheiserlgarrettalakepolanmgloverghhillkrlightbodyawatsoncbannerlsmarttbuchanantdesmondjewomenwithhypoactivesexualdesiredisordercomparedtonormalfemalesafunctionalmagneticresonanceimagingstudyneuroscience kawabatahzekistheneuralcorrelatesofdesireplosonee jeonggwparkkyoungkanghkkimhjseojjryusbassessmentofcerebrocorticalregionsassociatedwithsexualarousalinpremenopausalandmenopausalwomenbyusingboldbasedfunctionalmrijsexmed parkkseojjkanghkryusbkimhjjeonggwanewpotentialofbloodoxygenationleveldependentboldfunctionalmriforevaluatingcerebralcentersofpenileerectionintjimpotres hamannshermanranolanclwallenkmenandwomendifferinamygdalaresponsetovisualsexualstimulinatneurosci ortiguesbianchidemichelifthechronoarchitectureofhumansexualdesireahighdensityelectricalmappingstudyneuroimage gastauthcollombhetudeducomportementsexuelchezlesepileptiquespsychomoteursannmedpsychol freemonfrnevisahtemporallobesexualseizuresneurology oldeldrctheassessmentandanalysisofhandednesstheedinburghinventoryneuropsychologia venturamagreenmfshaneralibermanrptrainingandqualityassurancewiththebriefpsychiatricratingscalethedriftbusterintjmethodspsychiatrres zigmondassnaithrpthehospitalanxietyanddepressionscaleactapsychiatrscand associationapeddiagnosticandstatisticalmanualofmentaldisorderstheditionwashingtondcdsmiv mestoncmvalidationofthefemalesexualfunctionindexfsfiinwomenwithfemaleorgasmicdisorderandinwomenwithhypoactivesexualdesiredisorderjsexmaritaltherrupphajamestwkettersonedsengelaubdrjansseneheimanjrneuralactivationintheorbitofrontalcortexinresponsetomalefacesincreasesduringthefollicularphasehormbehav heisterglandistregardmschroederheisterpshiftoffunctionalcerebralasymmetryduringthemenstrualcycleneuropsychologia altemusmwexlerbeboulisnchangesinperceptualasymmetrywiththemenstrualcycleneuropsychologia kimuradsexandcognitioncambridgemassabradfordbookmitpress brovermandmvogelwklaiberelmajcherdsheadpaulvchangesincognitivetaskperformanceacrossthemenstrualcyclejcompphysiolpsychol rodecwagnermgunturkunomenstrualcycleaffectsfunctionalcerebralasymmetries neuropsychologia
420	subjects all these individuals were in the upper quartile of lefthandedness range from to mean sd
421	sd as indicated by the revised edinburgh handedness inventory oldeld this

	sample was of critical importance because
422	participants in this group were in the upper quartile of righthandedness but typically did not show extreme righthand preference as evaluated
423	not show extreme righthand preference as evaluated by the edinburgh handedness inventory oldeld mean edinburgh laterality index range
424	and gesture lateralization are not specic to lefthanders but are handednessindependent see also chiarello et al consistent with this assumption
425	the relationships observed for gesture are universal ie are not handednessdependent and more importantly that there are some parallels with the
426	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia oliveira j brito
427	achten e cerebral lateralization of praxis in rightand lefthandedness same pattern different strength hum brain mapp
428	with no history of neurological psychiatric or auditory symptoms edinburgh handedness inventory laterality quotients oldfeld ranged from to
429	samples of subjects each matched on gender age and handedness individual subject spms from the semantic decisiontone decision comparison were
430	samples of subjects matched to this sample on age handedness and gender discussion this fmri study sought to
431	oldfeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia pardo jv fox pt
432	in md and when using gender gaf iq and handedness simultaneously as nuisance regressors in fa md and
433	were not dependent on other diagnoses in our study population lefthandedness was more common in the adhd group a notion also
434	with adhd were lefthanded but no association was found between handedness and age gender inattentiveness score hyperactivityimpulsivity score comorbid psychiatric problems
435	coordination problems score or parental characteristics in our study handedness could contribute to the results but given the nearly statistically
436	not alter the results when using gender gaf iq and handedness simultaneously as nuisance regressors signicantly diering clusters between the groups
437	ghanizadeh a lack of association of handedness with inattention and hyperactivity symptoms in adhd j atten disord
438	subjects were righthanded as conrmed by the edinburgh inventory of handedness oldeld they were naive to the experimental purpose of
439	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia oostenveld r fries p
440	m leonard and k m heilman morphologic cerebral asymmetries and handedness the pars triangularis and planum temporale arch neurol no
441	this study were righthanded according to a modied italiantranslated edinburgh handedness inventory oldeld and naive to the specic purpose of
442	s oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia parlow se kinsbourne m
443	et al asymmetry in the human primary somatosensory cortex and handedness

	neuroimage pmid ss
444	years male right central cavernoma were studied according to edinburgh handedness inventory oldfeld all subjects were righthanded mean range
445	oldfeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia paiva ws fonoff et
446	any history of neuropsychiatric disease were included in this study handedness was assessed by edinburgh handedness inventory the study had prior
447	were included in this study handedness was assessed by edinburgh handedness inventory the study had prior approval by the ulbhopital erasme
448	problems or solving spatial relational problems interestingly when analyzed by handedness lefthand motor activity interfered more with the two spatial tasks
449	were participants all were righthanded as assessed by the edinburgh handedness inventory oldfield participants were volunteers from various undergraduate classes
450	signing a letter of informed consent participants were assessed for handedness with the edinburgh handedness inventory participants were told that they
451	informed consent participants were assessed for handedness with the edinburgh handedness inventory participants were told that they would learn to play
452	ldfeld r c the assessment and analysis of handedness the edinburgh inventory neuropsychologza vlkki j vrntanen s
453	of them maintained that they wereingoodhealth subjects also completeda standardized handedness survey oldfeld to insure that they were all right
454	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia plailly j bensa m
455	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia louis dn
456	practical class with the aid of abbreviated versions of the handedness questionnnaire and the dichotic listening test described below in order
457	two carousels hand preference was measured with the edinburgh handedness inventory oldfield and was scored to yield a
458	psychophysik leipzig breitkopf and hartel flowers k handedness and controlled movement british journal ofpsychology
459	bulletin hicks re kinsbourne m human handedness in asymmetrical function of the brain ed m kinsbourne new
460	oldfield r c the assessment and analysis of handedness the edinburgh inventory neuropsychologia weber
461	adapted version of the edinburgh inventory for the assessment of handedness cohen oldeld augmented laterality index mean sd
462	somatosensory cortex cereb cortex cohen ms handedness questionnaire wwwbrainmappingorgsharededin burghphp september
463	asymmetry of hand representation in human primary somatosensory cortex and handedness clin neurophysiol jung p klein jc
464	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia olry r
465	g m peterson mechanisms of handedness in the rat comp psychol monogr

466	analyzed healthy righthanded volunteers aged years handedness was assessed using the edinburgh recipient of a welcome
467	medium provided that the original work is properly attributed handedness inventory oldfield the second study included healthy righthanded
468	diffusion measures from the arcuate fasciculus connections age sex and handedness were regressed out using spss and residuals were standardized for
469	medline oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia crossref medline ordaz sj
470	tumors mostly large ones of the left hemisphere signs of lefthandedness were detected in those patients in only half of the
471	to be righthanders but had two or more signs of lefthandedness eg they constantly applied a handset to the left ear
472	results of fmri dichotic listening test and questionnaire for determining lefthandedness were compared with pre and postoperative examination aimed at detecting
473	side detected according to the fmri data had signs of lefthandedness according to the annettes questionnaire but considered themselves righthanders it
474	and one cases respectively all three patients had signs of lefthandedness according to the questionnaire however all of them showed a
475	this group of patients was not homogeneous in terms of lefthandedness three out of patients were righthanders had relatives with
476	three out of patients were righthanders had relatives with righthandedness and showed a positive cre in the dichotic nn
477	righthanded in half of the cases and had signs of lefthandedness in another half only the presence of large and relatively
478	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia ortigue
479	as thetadelta slowing she was lefthanded confirmed by the edinburgh handedness inventoryl and there was no family history of lefthandedness the
480	edinburgh handedness inventoryl and there was no family history of lefthandedness the neurologic examination otherwise revealed no abnormalities particularly there was
481	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia markowitsch hj
482	indicating no incipient dementia the edinburgh inventory test showed righthandedness in all subjects lq meansd all the recruited people
483	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia sadato n
484	be explained by asymmetries in skill performance the degree of handedness or interhemispheric interactions the latter was measured by a doublepulse
485	wiley online library wileyonlinelibrarycom key words attention functional laterality handedness laterality of motor control magnetic resonance imaging functional motor cortex
486	the right hand as well as to the degree of handedness finally we tested the hypothesis that functional asymmetries of the
487	the inclusion criteria for fmri and tms research degree of handedness was

	determined using the item version of the edinburgh handedness
488	handedness was determined using the item version of the edinburgh handedness inventory oldeld all participants were strongly righthanded habib et
489	regression analysis regression between lici and ihi performance and handedness it was hypothesized that activation of the ipsilateral motor
490	models were set up between lici and libehavliihi and an handedness index as directly derived from the oldeld score lioldeld bonferroni
491	by ndht would correlate with interhemispheric inhibition behavioural asymmetries or handedness results summary see supp info table iii i a linear
492	with lici finally the correlation between lici during ndht and handedness level lioldeld reached signicance for pmd in the absence of
493	this pattern could not be explained by the degree of handedness or the differential motor performance of both hands nor does
494	asymmetries in ipsilateral bold response and the extent of right handedness were detected this nding requires further conrmation since our subject
495	the notion that lefthemisphere motor dominance is observed irrespective of handedness kim et al verstynen et al fifth
496	et al motor asymmetry or lateralization of language and handedness dassonville et al suggests that hemispheric asymmetries might be
497	movement is a universal feature rather than an aspect of handedness furthermore since the neural substrates for highprecision movements such
498	as measured during restisometric contraction to movement performance or to handedness we argue that the left hemisphere contains action representations that
499	interhemispheric asymmetry of the human motor cortex related to handedness and gender neuropsychologia astaev sv shulman gl stanley
500	hr munchau a laterality of interhemispheric inhibition depends on handedness exp brain res bohlhalter s hattori n wheaton
501	in motor cortex reects the direction and the degree of handedness proc natl acad sci usa de gennaro
502	g ferrara m fratello f romei v rossini pm handedness is mainly associated with an asymmetry of corticospinal excitability and
503	sobiecka b kozub j grabowska a brain correlates of righthandedness acta neurobiol exp wars haaland ky harrington dl
504	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science kloppel s van eimeren t glauche v
505	buchel c weiller c siebner hr the effect of handedness on cortical motor activation during simple bilateral movements neuroimage
506	eur j neurosci lemay m leftright dissymmetry handedness ajnr am j neuroradiol li a yetkin fz
507	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia petit l zago l
508	noll dc small sl lateralization of motor circuits and handedness during nger movements eur j neurol stephan ke
509	volkmann j schnitzler a witte ow freund h handedness and asymmetry of hand

	representation in human motor cortex j
510	study the subjects were assessed as righthanded by the edinburgh handedness inventory oldweld all participants were scored as strongly righthanded
511	oldweld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia ozgoren m basareroglu c
512	noll dc small sl lateralization of motor circuits and handedness during wnger movements eur j neurol stam cj
513	with years of education and no family history of lefthandedness salmaso longoni she suffered from a vascular
514	and training of hand dominance iv developmental problems associated with handedness journal of genetic psychology ireland w w
515	ireland w w on mirrorwriting and its relation to lefthandedness and cerebral disease brain kuzuya m yamamoto
516	schott g d schott j m mirror writing lefthandedness and leftward scripts archives of neurology schwoebel
517	consent was obtained from all subjects before the study the handedness of the subjects was assessed using the edinburgh inventory
518	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia brott t
519	by guest on october right handedness native english speaker single unilateral lefthemisphere ischemic infarct
520	verb generation task all subjects were righthanded native english speakers handedness was assessed by the edinburgh inventory the protocol was
521	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia loenneker t
522	can produce dti images with similar parameters but not identical handedness of the subjects was assessed by the edinburgh handedness inventory
523	identical handedness of the subjects was assessed by the edinburgh handedness inventory oldeld only the subjects who were strongly righthanded
524	only the subjects who were strongly righthanded with a handedness index greater or equal to were included in study
525	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia pajevic s pierpaoli c
526	nonvalval years t p and handedness valval nonvalval t p
527	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia abler
528	functional magnetic resonance imaging of motor cortex hemispheric asymmetry and handedness science rao sm binder jr
529	noll dc small sl lateralization of motor circuits and handedness during finger movements eur j neurol
530	k uvebrant p wiklund lm von wendt l pathological lefthandedness revisited dichotic listening in children with left vs right congenital
531	used to assess iq the psychological corporation the edinburgh handedness inventory was used to determine participants handedness oldfield all
532	the edinburgh handedness inventory was used to determine participants

	handedness oldfield all experimental and control subjects scored in the
533	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia orr sp metzger lj
534	screening visit handedness lr r r education
535	controls demographic sex n mf handedness n rl education y
536	the institute of psychiatry research ethics committee because sex and handedness influence language laterality the study contained only righthanded male subjects
537	connectivity identified in this article varies with hemisphere sex or handedness are questions for future study from associationist to connectionist
538	female p handedness ehi score t
539	or chisquared bnt boston naming test ehi edinburgh handedness inventory nat northwestern anagram test ppvt peabody picture
540	and healthy control subjects were matched for age gender and handedness frontal aslant tract the frontal aslant tract connects
541	a large sample population that was homogeneous for age and handedness to evaluate in a sex model a new classification with
542	wwwajnrorg ilar results have not been reported for handedness but morphometric variations have been described the aim of
543	a large sample population that was homogeneous for age and handedness to evaluate in a sex model a new classification of
544	to exclude as an experimental variable the known relationship between handedness and the laterality of certain cerebral structures although this design
545	this design implies that the potentially important relationshipbetween degree of handedness and morphologic variants was not studied we wished to study
546	the basis of reports in literature to observe variations handedness was assessed by asking which hand the subject used for
547	subjects by using the italian revised version of the edinburgh handedness inventory adapted by salmaso and longoni the questionnaire was selfreported
548	included only righthanded subjects in view of the fact that handedness is known to influence the morphometry of the hmc but
549	not been reported interhemispheric differences of the hmc correlated with handedness have been described in terms of asymmetry of the depth
550	although we did not investigate correlations between morphologies and handedness whether morphologic variants of the hmc and their interhemispheric combinations
551	between the anatomic variants of the hmc and differences in handedness the validation of this hypothesis requires further study correlating hmc
552	oldfield rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia salmaso d
553	volkmann j schnitzler a witte ow et al handedness and asymmetry of hand representation in human motor cortex j
554	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia pagani e filippi m
555	salespdflibcom functional lateralization of human gustatory cortex related to

	handedness disclosed by fmri studya b cerfhd d lebihanc pf
556	accordance with a wholemouth stimulation a striking lateralization related to handedness was found in a lower part of the insula this
557	i tjj cerf et al lateralization handedness table t number of gustatory activations of inferior and
558	and lefthanded subjects activation in inferior insulae significantly depends on handedness p x lefthanded subjects exhibit activation in right inferior
559	gustatory projection more interestingly a strong lateralization related to handedness was found in a lower part of the insula figure
560	b psic ltris bravo v sr arturo pinto g handedness in children with and with out dyslexia a frequency
561	with and with out dyslexia a frequency distribution of handedness and its relations with minor signs of neurological dysfunction was
562	functions with subsequent expression on verbal language reading ability and handedness key woeu handedness cerebra dysfonction and reading disability
563	on verbal language reading ability and handedness key woeu handedness cerebra dysfonction and reading disability l docente e investigador
564	gaddes wh cerebral dominance handedness and laterality en wh gaddes ed learning disabilities and brain
565	annef m a model of the inheritance of handedness and cerebral dominance nature london
566	annett m genetic and non genetic influences on handedness bchav genet b annetr m
567	annetr m the rightshift theory of handedness lateroidad manu y dislexi and developmental language
568	rz p pathological lefthandedness an explanatory note cortex satz p
569	p orsini di sasow w and hnuy r the pathological lefthandedness syndrome brain and cognition geschwind n
570	cognition geschwind n and behan p lefthandedness association with immune disease migraine nd developmental learning disorder proc
571	a study on cerebral dominance with regard to speech and handedness in chinese j formosan med assoc
572	we carefully matched the subject groups by age gender education handedness estimated premorbid intelligence and hematocrit the two hiv groups were
573	the experiment all subjects were righthanded based on the edinburgh handedness inventory oldeld none of the participants had a
574	oldeld rc the assessment and analysis of handedness the edinburgh inventory neuropsychologia oliveri m rossini pm
575	research article degree of handedness avects intermanual transfer of skill learning cori chase
576	to study functional specialization and hemispheric interactions in relation to handedness this literature has not evaluated whether degree of handedness impacts
577	to handedness this literature has not evaluated whether degree of handedness impacts learning and intermanual transfer because handedness scores are related

578	whether degree of handedness impacts learning and intermanual transfer because handedness scores are related to factors that might inxuence intermanual transfer
579	brain we tested whether degree of handedness is correlated with transfer magnitude we had groups of left
580	intermanual transfer were inxuenced by either direction andor degree of handedness participants exhibited faster sensorimotor adaptation with the right hand regardless
581	hemisphere during learning may inxuence intermanual transfer magnitude keywords handedness learning transfer sequence learning sensorimotor adaptation
582	sequence learning sensorimotor adaptation motor introduction handedness is associated with lateralization of behavioral prowciency and structural and
583	to study functional specialization and hemispheric interactions in relation to handedness this literature has yielded complex patterns of intermanual transfer that
584	handed individuals making it diycult to interpret the role of handedness in intermanual transfer even though the studies do typically evaluate
585	and direction whether one is right or left handed of handedness there are several reasons to believe that degree of handedness
586	handedness there are several reasons to believe that degree of handedness may play an important role in intermanual transfer however first
587	demonstrated that there is a relationship between the degree of handedness and the laterality of functional brain activation in the primary
588	of the current study was to determine whether degree of handedness plays a role in intermanual transfer we predicted that less
589	al reported to be the locus of degree of handedness evects therefore we expected that degree of handedness would have
590	degree of handedness evects therefore we expected that degree of handedness would have a similar impact on transfer of both types
591	to the motorically constant sequence would depend on degree of handedness but that transfer to the spatially constant sequence would not
592	substantial evorts to recruit individuals with a broad range of handedness scores in order to test our hypothesis the mean handedness
593	handedness scores in order to test our hypothesis the mean handedness score oldweld scaled from to for the
594	and ranged from to the mean handedness score for the left handed participants was sd
595	michigan participants wlled out an activity questionnaire and the edinburgh handedness inventory oldweld and then performed an intermanual transfer of
596	end of this initial ballistic movement we conducted a handedness left or right by order dom to non or non
597	of learning and transfer were both tested for correlation with handedness scores correlations were evaluated using onetailed tests to determine whether
598	responses than the mean the data were subjected to a handedness left or right by order dom to non or non

599	transfer measures were both tested for correlation with degree of handedness correlations were evaluated using onetailed tests to determine whether less
600	task there was a near signiwcant diverence in degree of handedness for the two groups with the right handed participants tending
601	however there was a good distribution across the range of handedness scores in both groups in a couple of instances
602	their performance did not fig individual handedness scores are presented for each participant the absolute value score
603	were therefore removed from analyses as noted below does handedness avect learning and transfer of sensorimotor adaptation the de
604	hand regardless of whether they were left or right handed handedness order block interaction f p there
605	participants between the magnitude of learning and the degree of handedness right handers r f p left
606	hand regardless of whether they were left or right handed handedness order block interaction f p there
607	participants between the magnitude of learning and the degree of handedness right handers r f p left
608	relationship between the magnitude of de transfer and degree of handedness r f p fig a
609	with these participants showing bet fig a plots handedness scores x axis versus the magnitude of de transfer y
610	de values indicate more transfer less strongly handed individuals lower handedness scores showed more intermanual transfer of learning b plots handedness
611	handedness scores showed more intermanual transfer of learning b plots handedness scores x axis versus the magnitude of iee transfer y
612	iee values indicate more transfer less strongly handed individuals lower handedness scores tended to show more intermanual transfer of learning
613	relationship between the magnitude of iee transfer and degree of handedness r f p fig b
614	combined r f p does handedness avect learning and transfer of sequences the response time
615	across participants there were no signiwcant interactions of block with handedness or order indicating that all participants learned the sequence at
616	there was a relationship between the magnitude of learning and handedness for the right handed participants r f
617	the magnitude of transfer to the spatially constant sequence and handedness for the right handed participants r f
618	the current study we investigated whether direction and degree of handedness avect intermanual transfer of skill learning we hypothesized that less
619	same variables for left handed participants fig a plots handedness scores x axis versus the magnitude of sequence learning y
620	time values indicate more learning less strongly handed individuals lower handedness scores exhibited more sequence learning b plots handedness scores x

621	individuals lower handedness scores exhibited more sequence learning b plots handedness scores x axis versus the magnitude of transfer to the
622	time values indicate more transfer less strongly handed individuals lower handedness scores exhibited better transfer of learning supported by the
623	at wrst glance it is curious that degree of handedness predicts sensorimotor adaptation transfer for only left handed participants while
624	right handed participants however previous literature demonstrates an interaction between handedness and the type of measure used to assess hemispheric interactions
625	determine eyciency of hemispheric interactions they found that degree of handedness was diverentially associated with hemispheric interactions for right and left

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