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Positive Psychology and Men: The Tell-Tale Heart

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Gender differences are often overlooked or minimized in research regarding well-being. Men and women respond differently to stress, such that men experience higher risk of cardiovascular events. Yet despite their greater potential to benefit, men seem to exhibit less interest and participation than women in activities shown by research to enhance well-being. Heart rate variability provides a sensitive and reliable index of well-being and adaptability both at rest and across various stressors. Research suggests that heart rate variability is influenced not only by physiological processes, but also cognitive and emotional processes, which differ between men and women. Neurological factors underlying these differences may suggest future directions for improving well-being in men.

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Positive Psychology and Men: The Tell-Tale Heart

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Abstract

Gender differences are often overlooked or minimized in research regarding well-being. Men and women respond differently to stress, such that men experience higher risk of cardiovascular events. Yet despite their greater potential to benefit, men seem to exhibit less interest and participation than women in activities shown by research to enhance well-being. Heart rate variability provides a sensitive and reliable index of well-being and adaptability both at rest and across various stressors. Research suggests that heart rate variability is influenced not only by physiological processes, but also cognitive and emotional processes, which differ between men and women. Neurological factors underlying these differences may suggest future directions for improving well-being in men.
Positive Psychology and Men: The Tell-Tale Heart

The goal of Positive Psychology, according to founder Martin Seligman (2011), is to increase well-being to the point of flourishing in terms of positive emotion, engagement, relationships, meaning, and accomplishment. Positive Psychology emphasizing universal human strengths (Peterson & Seligman, 2004) and broadly applicable interventions for increasing positive feelings and relationships, savoring what is best in life, building positive organizations, and pursuing that which makes life worth living. The approach of emphasizing what is good about people, families, and organizations has drawn a tremendous response from the public. There is great value in affirming that what is best about us as humans can be experienced by each of us, regardless of such factors as gender, ethnicity, nationality, location, or socioeconomic status. This is a message of unity and hope. It can be energizing to emphasize what is common over what divides us. To that message, however, we should add the notion that within this unity there are patterns of variation. These variations are an important – but often ignored – strength.

Evolution favors sexual reproduction, so it is only natural that men and women differ in important ways. Baumeister (2010) suggests that what differentiates men and women the most is not in what they can or cannot do, but in what they want to do. When behavioral patterns coincide with groups as fundamentally different as men and women, and when they indicate potentially significant differences in how we respond to or approach our world, then it is our obligation to explore and understand those differences.
Gender fundamentally differentiates people in a wide range of areas of interest to Positive Psychology, including responses to positive and negative stressors. The quality and nature of human responses to experience are rooted in the physiology of the heart-brain connection. The reciprocal messages between the heart and the brain influence the way we think, feel, and act (Thayer & Lane, 2009). These responses differ greatly among individuals and between groups, not only at rest but also when triggered by internal and external stressors. These responses are managed by complex networks in the brain and nervous system, and reveal themselves in subtle changes in the rhythm of the heart.

This paper describes important physiological processes governing the heart-brain connection and argues that, although often ignored, there are important gender differences in these processes which may have useful implications for adapting Positive Psychology for men. In fact, these differences suggest that techniques and principles of positive psychology may be especially beneficial to men, not only to help men flourish, but also to reduce potential health threats. The interventions and techniques of positive psychology, however, often appeal more to women. By understanding underlying physiological processes, we may better tailor interventions and information to appeal especially to those who may need it most. The purpose of this paper is to contribute in some small way to that goal by exploring the current research on gender differences in the heart-brain connection, and to use those findings to promote the many benefits of Positive Psychology to a male audience.
The first part of this paper describes an important objective measure of the heart-brain connection known as heart rate variability (HRV) which has been linked to positive health and well-being outcomes. The processes governing HRV, which include the ANS along with certain areas of the brain which are thought to be associated with cognitive and emotional processing, are also described. Terms and abbreviations used throughout are summarized in the Appendix. The second part of this paper reviews the current literature on gender differences in HRV. The final part discusses how the findings reviewed apply to positive psychology, with suggestions for future directions the field.

The Tell-Tale Heart

The heart is reciprocally linked to the emotion processing centers of our brain (Thayer, Hansen, Saus-Rose, & Johnsen, 2009), and its rhythms not only reflect but also influence our moment-by-moment physical, emotional, and cognitive adaptations to our experience (Hagemann, Waldstein, & Thayer, 2003; Thayer & Lane, 2009). For example, when we simply breathe or we are aroused by strong emotion, the rhythm of the heart speeds up to distribute oxygenated blood in the former case or prepare us to take action in the latter. When we exercise self-control, the rhythm slows to conserve energy.

The heartbeat itself is the result of a supremely sensitive dynamically balanced feedback and control mechanism. The heart does not beat in a perfectly even rhythm, and in fact an even heart rhythm is a reliable predictor of mortality (Thayer & Lane, 2000). In a healthy heart beat, the time interval between beats, or inter-beat interval (IBI) varies within a certain range, with
both the range and degree of variance differing greatly from person to person. Our overall well-being, as well as evanescent experiences such as actual or perceived safety or threat, moments of concentration and self-control, bursts of joy or sadness, and obsessive thoughts leave their traces in minute changes in the beat-to-beat intervals of the heart. This pattern of change, known as heart-rate variability (HRV), provides a unique window into the ability of an individual to adapt to their inner and outer environment. Greater HRV, especially when at rest, is associated with a variety of positive states. The factors underlying these associations and contributing to HRV are described in the next section.

The Autonomic Nervous System

At the broadest level, the speed and rhythm of the heart beat is largely under the control of the autonomic nervous system (ANS), which takes care of the automatic functions of the body, such as breathing and digestion. Though popularly thought of as a system that operates unconsciously, the ANS interacts with and reciprocally influences brain areas responsible for processing of conscious awareness and emotion (Thayer & Brosschot, 2005). The ANS is composed of two opposing but dynamically balanced systems: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The muscle tissue of the heart is connected by nerves to both the SNS and PNS (Thayer, 2002). The SNS stimulates energy for taking action, whereas the PNS inhibits the SNS and restores the body to rest. Healthy functioning depends on the interplay between both systems.
Generally speaking, the SNS provides the resources necessary for vigorous physical activity, particularly in response to threat. Activation of the SNS above resting levels results in what is often called the “fight or flight” response, which includes increased heart rate and blood pressure, faster shallower breathing, and constriction of blood flow to the digestive system (Cannon, 1932). Notably, recent research suggests that “fight or flight” may be more descriptive of the stress response in men, since further effects of SNS activation in men, but not women, include dilation of the blood vessels in the legs and increased output of the stress hormone cortisol (Dart, Du, & Kingwell, 2001). Women seem to respond to stress more through withdrawal of PNS activation rather than increases in SNS activation (Dart et al., 2001). Taylor, Klein, Lewis, Gruenwald, Gurung, and Updegraff (2000) have characterized women's stress response as being oriented toward nurturing and engaging in relationship, in some ways an opposite response to that of men.

The tonic or resting activity of the SNS provides a baseline ability to respond to challenges or threats, however even this level is too high for normal everyday functioning (Thayer & Lane, 2000). It must be inhibited and its effects offset, and that is the role of the PNS. The input of the PNS acts to slow breathing and heart rate, increase blood flow to the digestive system, reduce inflammation, and allow repair and healing of the body. The PNS is also known as the “rest and digest” system.

The SNS and PNS both supply nerves to the heart (Thayer & Lane, 2000). The PNS connects to the heart through the cardiac branch of the vagus nerve. The vagus nerve is the
primary nerve in the parasympathetic nervous system, and connects all the major organs of the body as well as certain muscles in the face and neck. The vagus includes both efferent connections and afferent connections. Efferent nerve connections send messages out from the brain to the body. Afferent nerves send signals from the body back to the brain, providing feedback and information about the organ or tissue on which they originate. The efferent cardiac vagus provides inputs to the heart which, as we shall see in the next section, reflect not merely baseline physiological needs, but also cognitive and emotional processing in the brain.

The influence of the PNS relative to the SNS is called parasympathetic tone, or *vagal tone*, after the vagus nerve. While the SNS is like the gas pedal on a car, speeding things up, the PNS corresponds to the brakes (J. F. Thayer, MAPP 600 lecture, September 10, 2010). Temporary increases in SNS activity are a normal part of everyday functioning, and the PNS is relatively adept at subsequently reducing activation to maintain equilibrium. However, under prolonged levels of internal or external stress, chronic activation of the SNS may occur. A prolonged high level of tonic SNS activity is a health risk, associated with negative outcomes such as inflammation, high blood pressure, and cardiovascular events (McEwen, 1998). SNS activation has both anti-inflammatory and inflammatory effects. Acetylcholine, the neurotransmitter of the PNS, has an anti-inflammatory effect on tissues.

The heart thus receives continuous input from the SNS, prompting it to go faster, as well as continuous input from the PNS, prompting it to slow down. The inputs from the SNS are relatively stable and slow to change, taking up to several seconds to take effect. The inputs from
the PNS via the cardiac vagal nerve, however, alter constantly and very quickly – within milliseconds (Thayer & Lane, 2000). The SNS and the PNS can vary completely independent from each other, such that heart rate and HRV can increase due to activation in the SNS, withdrawal or decrease in inhibition from the PNS, or some combination of the two. Likewise, heart rate and HRV can decrease due to increased PNS activity or reduced SNS activity. Finally, the SNS and PNS can be simultaneously coactivated, which may involve a change in HRV without a corresponding change in the heart rate.

It is the speed of the PNS, changing levels perhaps multiple times within a single heartbeat, that makes HRV such a sensitive indicator. As we shall see in the following section, the meaning and importance of HRV lie in the origins of the inhibitory influence of the PNS: the neural processes by which we respond to and make sense of the constant flow of our experience.

**Quantifying Heart Rate Variability**

Heart rate is typically measured with an electrocardiogram (ECG). Figure 1 shows one such beat-to-beat interval. Most measures of heart rate variability derive from measures of heart rate, and quantify the amount of variation in inter-beat intervals (IBI). Importantly, higher HRV values have been associated with greater overall physiological and psychological well-being, and lower values have been associated with pathology and mortality (Thayer & Lane, 2000).

The most thorough and invasive process involves measuring the intrinsic heart rate, that is, the rate the heart beats at rest without the effects of either the SNS or the PNS. This is accomplished by administering drugs which block these influences. The drug atropine blocks the
inputs of the vagus nerve to the heart, leaving the heart under the influence of the SNS. Since the SNS acts to increase heart rate and reduce HRV, the increase in heart rate and decrease in HRV under atropine blockade reflects the relative influence of the PNS versus the SNS (Berntson et al., 1994). Thus larger increases in heart rate and larger decreases in HRV under atropine blockade reflect higher PNS influence, whereas smaller increases in heart rate and smaller decreases in HRV reflect lower PNS influence.

However a completely accurate picture of balance in the autonomic control of the heart must exclude the influence of the SNS as well, since an individual with relatively lower SNS activation, for example, will have higher HRV despite lower PNS influence. The drug metoprolol blocks the inputs of the SNS. By blocking both SNS and PNS, intrinsic heart rate and heart-rate variability can be measured, separting out the independent effects of the SNS and the PNS. This precisely reveals the causes underlying HRV and thus provides the most accurate picture of autonomic control of the heart (Berntson et al., 1994). The intrinsic heart rate is faster than the normal resting heart rate, which is under the combined influence of the SNS and PNS. This suggests that the inhibitory power of the PNS is mostly responsible for the tonic or resting heart rate under normal conditions (Thayer et al., 2009).

A common, far less invasive and more precise technique to quantify HRV is the Root Mean Squares of Successive Differences (RMSSD). Heart rate is measured and described above, and the differences between adjacent beats within a given period are each squared, divided by the sample size, and then square rooted (Task Force of the European Society of Cardiology, 1996).
A popular but controversial method is called Respiratory Sinus Arrhythmia (RSA). This method takes advantage of a reflex initiated by specialized nerves in the lungs called baroflex receptors. When we inhale, these nerves are mechanically stimulated by the stretching of our lungs (Appelhans & Leuken, 2006). The baroflex receptors then fire messages that result in the withdrawal of vagal input to the heart. When the lungs are expanded, there is less parasympathetic input and therefore the heart rate increases. When we breathe out, the baroflex receptors stop firing and vagal input is restored. Measuring the change in the heart rate from peak to peak across the respiratory cycle thus gives an indication of the amount of influence the PNS exerts on the heart rate, similar to the atropine blockade. Since a single breath usually encompasses several heartbeats, RSA is often divided into frequency spectra corresponding to the known or suspected sources of influence. Most researchers agree that the high-frequency spectrum (HF-HRV) is solely the result of PNS influence since it reflects events that take place in less than a second. The low frequencies are presumed to result from a mix of PNS and SNS influences, while the very low frequencies are usually attributed solely to the SNS.

Many studies – including some reviewed below – use RSA. However, RSA has certain shortcomings. Berntson, Cacioppo, and Grossman (2007) point out that this measure is influenced by factors that have nothing to do with the ability of the PNS to slow the heart. For example, the rate and depth of breathing can alter the amount of vagal withdrawal, and simultaneous influence by the SNS cannot be ruled out. While they accept that monitoring
respiration can mitigate the effects from rate and depth of breathing, not all studies monitor respiration.

The complexity of the variation, that is, the relative predictability of the pattern of change in the inter-beat interval (IBI), is also of interest. Approximate Entropy (ApEn), derived from nonlinear dynamic systems theory, captures this complexity and may in fact be a more precise and reliable predictor of well-being (Snieder, van Doornen, Boomsma, & Thayer, 2007). Unlike RSA and RMSSD, which both focus on the size of the variations in IBI and their amount of difference from the average, ApEn looks at a series of IBI changes to see how complex the pattern of change is. Based on the previous IBI changes in the series, ApEn indicates how hard it is to predict the size and direction of the variation in the next IBI. More chaotic, that is to say, less predictable, sequential IBI differences correlate with higher vagal tone and measures of well-being. Of the studies reviewed here, ApEn has been used only by a few researchers, but its predictive ability seems to corroborate the notion that the human heart and brain may best be described in terms of complex system dynamics, in which unpredictable variability within a range are the hallmark and measure of the adaptability of a system (Thayer & Brosschot, 2005).

A resting or tonic measure of HRV gives a good overall picture of the balance in the ANS and generally predicts phasic responses to stressors. However, there is a great deal of variability among individuals in response under stress, and as we shall see, much variability between genders.
Measurement of SNS activity is also of interest. Most researchers use one of two methods to measure SNS activity. The first method is the pre-ejection period (PEP), which measures the speed of the contraction of the left ventricle (Berntson et al., 1994). Lower numbers represent faster contractions and thus increased SNS activation. The second measure uses RSA, as described previously. Since the high-frequency component shows parasympathetic influence and the low-frequency unit responds to SNS activation, the ratio of the low-frequency component to the high-frequency components (LF/HF) is taken to represent the relative influence of the SNS on the overall measure of RSA. Lower numbers represent decreased SNS activation.

**Positive and Negative Correlates of HRV**

HRV reflects more than just physiological responses, or to take another perspective, it reveals how intertwined and interdependent our physiological, emotional, and cognitive functions are, especially regarding control of the heart. Thayer, Ahs, Fredrikson, Sollers, & Wager (2010) used brain imaging to correlate cognitive processing with HRV. Hagemann, Waldstein, & Thayer (2009) linked HRV to our emotional processing system. Since HRV reflects both cognitive and emotional processes and is easily measurable, it gives us a way to investigate individual responses to positive and negative events as well as differences between individuals and groups.

More importantly, tonic HRV correlates with many outcomes of interest to Positive Psychology, including self-regulation (Thayer & Lane, 2000, 2009); better self-reported marital quality (Smith et al., 2010); greater optimism (Oveis et al., 2009); cognitive reappraisal of
negative experiences (Denson, Grisham, & Moulds, 2011; Urry, van Reekum, Johnstone, & Davidson, 2009); increased concentrations of acetylcholine, which has anti-inflammatory effects and inhibits tumor necrosis factor (Thayer, 2009); increased attention in a startle response paradigm (Heponiemi, Ravaja, Elovainio, Naatanen, & Keltikangas-Jarvinen, 2006); greater likelihood of orienting toward novel stimuli (Jöhnsson and Sonnby-Borgström, 2003); better cardiovascular, endocrine, and immune recovery after stress (Weber et al., 2010); and control over negative emotions (Ahs et al., 2009). Kok and Fredrikson (2010) showed that higher HRV led to greater benefits from positive experiences, including social benefits such as improved relationships.

Tonic HRV is negatively correlated with cardiovascular events (Thayer & Lane, 2000); obesity (Duncker, Rea, & Rebolledo, 2010); blood levels of C-reactive protein (CRP), a marker of inflammation (Thayer, 2009); nighttime plasma fibrinogen levels, especially in women (Känel, Thayer, & Fischer, 2009); anxiety (Brosschot, Van Dijk, & Thayer, 2007); and post-operative pain (Ledowski, Stein, Albus, & MacDonald, 2011).

Across these outcomes, tonic HRV is positively associated with beneficial outcomes and negatively related to detrimental outcomes. In terms of phasic HRV, however, there are some complex associations that remain unexplained in a review of the current literature. The exercise of self-control is associated with increases in HRV (Thayer & Lane, 2000, 2009), whereas emotions such as happiness, sadness, and disgust (Lane, McRae, Reiman, Chen, Ahern, & Thayer, 2009) and cognitive tasks involving working memory (Nugent, Bain, Thayer, Sollers, &
Drevets, 2011) are associated with decreases in HRV. Surprisingly, pain sensitivity is unrelated to tonic high-frequency RSA, but is correlated with the sympathetically influenced low-frequency band of RSA (Appelhans & Leuken, 2008).

Smith et al. (2010), in line with Baumeister, Gailliot, DeWall and Oaten (2006), propose that cardiac self-control is a limited resource which can be depleted through use, as when responding to stress. For example, they found that increases in HRV during self-control are followed by decreases in HRV as compared to the baseline, but only for women (Smith et al., 2010). More research is needed to understand the parameters and adaptive value of some of these responses.

**The Importance of Inhibition**

The autonomic nervous system is in a dynamic balance in which, under normal conditions, the PNS dominates over the SNS, resulting in relatively low heart rate and high HRV. This is appropriate for safe situations in every day life, and a high level of PNS influence is necessary for long term health. Vagally mediated dominance of the PNS is associated with positive health conditions (Thayer & Lane, 2000), whereas both weakened vagal control and increased SNS influence are associated with pathological states and mortality (Weber et al., 2010). At the same time, to survive and thrive requires the ability to act quickly and vigorously at times, in response to positive and negative internal and external events. Responses are not limited to extreme events, however. Even low-valence and ambiguous information is processed
whether we are consciously aware of it or not, producing measurable changes in both heart rate and HRV (Johansson & Sonnby-Borgstrom, 2003).

The ability to transition quickly between states of low and high arousal in response to our evaluation of events is provided by the antagonistic interaction of the SNS and the vagally mediated PNS. The overall dynamic range, that is, the extremes the system is capable of, corresponds to vagal tone, and is indexed by HRV. A review of the literature found no discussion of negative outcomes associated with too little SNS activation. Too much vagally mediated PNS activation, a state known as bradycardia, can result in severe health problems, but is caused by factors generally unrelated to those which contribute to high HRV in the healthy range (Ufberg & Clark, 2006). The current literature is clear that negative tonic states are associated primarily with the relative dominance of the SNS, through increased SNS activation, reduced vagally mediated PNS activity, or some combination of the two.

A model of the interaction between the PNS and SNS can be found in a nuclear reactor. The SNS corresponds to the fissile material, while the PNS corresponds to the control rods and the cooling system. The control rods are used to slow down the activity of the fissile material and prevent its nuclear reaction from getting out of control while still producing enough heat. When the control rods are withdrawn even somewhat, the system generates more heat. When the rods are inserted further in, the reaction slows down and the system generates less heat. If the control rods are too few, then the system runs chronically too hot, and the fuel is spent more quickly. If the control rod mechanism is too slow, then the system cannot raise or lower the amount of
energy it is producing in time to meet demand, and thus fuel is wasted in going from high
demand to low demand, or else demand is not met when going from low-demand to high-
demand states. The quicker the mechanism, the more responsive and efficient it is in meeting the
outside demands efficiently. Extended periods of withdrawal of the control rods, however, runs
the risk of a meltdown. Most reactors are designed with a fail-safe system that lets the control
rods drop completely into the core, stopping the reaction in case of any problem.

This analogy is only partial, however. Humans differ in that the ANS is designed to
default to a high-energy state (SNS) ready to respond to immediate threats to survival. Like a
meltdown, this state cannot be maintained for long without severe costs. In addition, a nuclear
reactor is a stand-alone system that has nowhere to go and nothing to do. It is not designed to
interact with or adapt to changes in its surroundings. In fact engineers go to great lengths to
isolate the reactor from any uncontrolled changes. People, on the other hand, are constantly
adapting not only to the demands placed on them by their environment, but also to their own
thoughts, memories, cognitions, emotions, goals, and even their own assessment of themselves.

As we have seen, most of the variation in the ANS is provided by the vagally mediated
PNS. And as we shall see, the variation in the vagal input to the heart is not only physiological,
but is determined by the entire spectrum of human cognitive and emotional experience. Recent
theoretical models and data suggest that the heart appears not to be just a pump, but rather an
integral part of our cognitive and affective system. Thayer and Lane (2000) propose that control
of autonomic, emotional, and cognitive functions are integrated in a single complex system. In
their Neurovisceral Integration Model (NIM), elaborated in Thayer and Brosschot (2005), they propose that the health of this regulatory system is maintained not by unchanging inputs from each component, but rather “through variability in the dynamic relationship among system elements. Thus, patterns of organized variability, rather than static levels, are preserved in the face of constantly changing environmental demands” (p. 1051). Control of the entire system thus depends on the balance as well as the range of variability in the SNS and PNS.

To understand the NIM, consider that each component in a complex system has its own range of variability. Taken together, the combined range of the possible states of the system as a whole defines its ability to respond efficiently and effectively across a range of challenges and demands. When a system component varies within a wide range of values, then any associated components are supported (or limited) by the availability of that range, on whatever basis those two components interact. Systems whose components have greater ranges can thus cope with a broader range of external situations. By the same token, if a system component has a narrow range of variability, then that component limits the dynamics of any systems or components that depend on it.

In our nuclear reactor example, ideally the control rods and cooling system are well-matched to the amount of fissile material so that the system can run safely for a long time. The amount of fissile material can vary, meaning a more or less powerful reactor. Likewise, the size, number, and speed of the control rod mechanisms can vary, meaning a more (or less) safe and responsive system. Just as the SNS takes time to ramp up and slow down, changing the amount
of fuel in a reactor to add to or decrease its power certainly takes longer than raising or lowering the control rods. So variability is relatively limited on the SNS side. But corresponding to the PNS, the control rod system allows the reactor to generate more heat on a fairly quick basis in response to the need for more power, and then return the system to a safe resting level. The larger and quicker the response from the PNS, therefore, the quicker the system is able either to make energy available on demand or return the system to rest, ready to respond to the next challenge. The inability to quickly return to baseline is associated with various chronic maladaptive states such as anxiety (Brosschot, Pieper, & Thayer, 2005).

Thayer and Brosshchot (2005) propose that the opposing forces and qualities of the SNS and PNS allow the ANS to find the most efficient and effective means of responding to situational demands:

These demands can be conceived in terms of energy regulation, such that points of relative stability represent local energy minima required by the situation. Because the system operates 'far from equilibrium,' the system is always in search of local energy minima to minimize the energy requirements of the organism. Consequentially, optimal system functioning is achieved via lability and variability in its component processes, to allow the flexible regulation of local energy expenditure. (p. 1051)

Of course, humans beings are far more complex than nuclear reactors and thus our internal control mechanisms can be expected to be commensurately more complex. We have drives and goals, and we have to instantly sift through a flood of information, select the salient
details from the flow available to us, and make adaptive interpretations about what is going on and predictions about what is going to happen. Interpretation and evaluation are of the utmost importance, and shortcomings in these areas (as shown by studies of brain-damaged patients) can have important consequences. We would not want to lift the control rods out or push the control rods in based on a misinterpretation of the current situation. Adding an additional layer of complication, men and women differ at the neurological level where these interpretations and evaluations take place.

**Integrated Control by Physiological, Cognitive and Emotional Processes**

Thayer and Lane suggest that the SNS and PNS are themselves regulated by a coordinated network of neural structures in the brain, known as the Central Autonomic Network (CAN). The activities of the CAN are central to Thayer and Lane's (2000) NIM, which proposes that the inhibitory framework of the PNS functionally and structurally overlaps with the attention, emotion and reward processing centers of the brain. Since the basis of cardiac vagal regulation lies in inhibition, and since the activity of the vagus correlates with cognitive and emotional processing, it follows, according to the NIM, that tonic vagal regulation would correlate with higher-order processes such as self-regulation and control over negative emotions such as worry and anger. Such regulation of emotions has been shown to depend on the same ability to adjust levels of arousal that are indexed by HRV (Gross, 1998, as referenced in Appelhans & Leuken, 2006).
The CAN is comprised of multiple regions in the cortex: the medial prefrontal and insular cortices; the limbic system, including the anterior cingulate cortex, hypothalamus, and central nucleus of the amygdala; and the brainstem, including the periaqueductal gray matter and the nucleus of the solitary tract (Appelhans & Leuken, 2006). All the components of the CAN communicate reciprocally (Thayer & Lane, 2000). The CAN receives inputs from the outside environment through the sensory processing areas of the brain, as well as inputs directly from the internal organs (Benarroch, 1993, as cited in Appelhans & Leuken, 2006).

The CAN is responsible for monitoring our physiological, emotional and cognitive state, initiating responses including raising and lowering SNS and PNS activity, and monitoring and evaluating feedback in response to ongoing environmental changes. Having components in the brainstem, limbic system, and cortex, “the CAN is critically involved in integrating physiological responses in the services of emotional expression, responding to environmental demands, goal-directed behavior, and homeostatic regulation” (Appelhans & Leuken, 2006, p. 231). Although each component has specialized functions, the simplest emotional reaction involves processing across multiple components. For example, Liang, Zebrowitz, and Zhang (2010) used functional magnetic resonance imaging (fMRI) to measure responses to attractive and unattractive faces. They found increased blood flow in the anterior cingulate cortex, parts of the frontal cortex, amygdala, and caudate as well as other regions of the brain. Thus, the CAN coordinates the entire feedback loop of our conscious and unconscious experience, including our movements, thoughts, emotions, and inner organ functions.
The NIM suggests that HRV is controlled primarily by activity in the prefrontal cortex. The prefrontal cortex produces parasympathetic outputs proceeding downward through the other neural structures of the CAN, including the anterior cingulate cortex, which is associated with attention control and processing of emotions and emotional expressions; the amygdala, which is associated with threat responses, suppression of parasympathetic outputs and stimulation of sympathetic output; the hypothalamus, which together with the pituitary and adrenal glands controls the output of the stress hormone cortisol; and the nucleus of the solitary tract, where the vagus nerve originates (Thayer & Lane, 2000, 2009).

The output of the CAN, synthesized from internal and external inputs including attention control, directly influences heart rate and HRV through the activation of the vagus nerve. Given the nearly instantaneous timescale of HRV response, this accounts for the unique power of HRV to reflect the processes of the CAN, including cognitive effort and emotion regulation in near-real time (Thayer & Brosschot, 2005; Thayer & Lane, 2000). The heart is thus in synchrony with those processes that feed into the CAN, supporting the changing demands for blood supply and blood pressure.

There is no evidence so far, however, that high HRV itself directly influences attention, cognition, or emotion. However Thayer, Hansen, Saus-Rose, and Johnsen (2009) have hypothesized that tonic HRV is an independent variable providing inputs into those processes. They point to findings supporting a genetic influence on HRV, and propose the possibility that
HRV represents an endophenotype – a mediator between genes and behavior, directed by a common gene or genes (Thayer & Lane, 2009).

The findings of two twin studies on HRV neither clearly confirm nor clearly deny the possibility of an endophenotype. Wang et al. (2009) showed that separate genetic factors underlie tonic HRV versus HRV under stress. Snieder, van Doornen, Boomsma and Thayer (2006) found that only 40% of tonic HRV as measured by ApEn could be accounted for by genetic factors. Measurements of RSA appeared to be more heritable, but rose only to 48%. More research is needed to either support or discount Thayer et al.’s notion.

The notion of HRV as an independent variable contributing to health outcomes is attractive because of the possibility of designing therapies tailored to increasing HRV. Given the importance of feedback loops in dynamic systems, perhaps Thayer et al.’s endophenotype is composed of two factors that can each be considered as independent variables. The first factor would be the quality of higher-order processes in the CAN, reflected in adaptive capacities including cognitive and emotional regulation and optimism (Denson, Grisham, & Moulds, 2011; Oveis et al., 2009), and the absence of such maladaptive traits as anxiety and worry (Ahs et al., 2009). The second factor would be the degree of synchrony and quality of the signal sent back to the CAN from the heart by the cardiac vagal afferent nerves.

The efficiency of any feedback mechanism depends on the quality and timing of the instructions initiating the loop as well as the ability of the target systems to execute those instructions and provide timely, high quality feedback about their performance. Assuming that
the heart and vagus are in perfect shape, if the signal coming from the CAN is interrupted or diminished, as occurs in negative emotional states like anxiety, the performance of the heart will be limited by that input. If, on the other hand, the heart or the cardiac vagus nerve itself is unable to respond to the signal, or is unable to provide good and timely feedback to the CAN, then that would presumably alter the CAN's calculation of its next instruction.

According to this notion, then, HRV could be improved by three separate pathways: increasing the coherence of higher-order processes in the CAN, increasing the performance of the heart, or increasing the feedback of the cardiac vagal afferents themeselves. In fact there is evidence that all three pathways are effective. Increasing the quality of higher-order processes through meditation results in improvements in HRV (Ditto, Eclache, & Goldman, 2006; Tang et al., 2009) as does increasing the efficiency of the heart through aerobic conditioning (Hansen, Johnsen, Sollers, Stenvick, & Thayer, 2004). Finally, artificial stimulation of the afferent cardiac vagus nerve produces some of the same benefits associated with high HRV. Nemeroff et al. (2006) induced positive mood in cases of treatment-resistant depression through electrical stimulation of the cardiac vagal efferents. Effects on HRV, however, were not measured. Further support for the notion of HRV as an independent variable in well-being depends on more research into the effects of the feedback of the cardiac vagal nerve as well as the genetic determinants of heart capacity and higher-order capacities such as optimism and self-regulation. Knowing the extent to which HRV is only a result of top-down outflows from the prefrontal
cortex, or to what extent the CAN is influenced by cardiac vagal afferent feedback may suggest new ways to increase overall well-being.

Summary

In sum, the sympathetic nervous system and the parasympathetic nervous system counterbalance each other to maintain appropriate levels of energy for any given context, and to maintain restore the systems of the body. They are both under the influence of higher-order functions of the brain, including our conscious and unconscious evaluations of our surroundings and experience, and especially activity in the prefrontal cortex, which is associated with self-control and emotion regulation. At the same time, vagally mediated cardiac control over the heart by the parasympathetic nervous system may have a reciprocal influence on cognitive and emotional processes.

Potential of Using HRV to Study Gender Differences

Given the particular neural structures that are involved in the regulation of HRV, the Neurovisceral Integration Model has important consequences for the consideration of gender differences related to positive states associated with high HRV, as well as risks and negative outcomes associated with low HRV. As Dart, Du, and Kingwell (2002) noted in regard to potential gender differences:

Differences in the autonomic system may be due to differences in afferent receptor stimulation, in central reflex transmission, in the efferent nervous system and in post synaptic signaling. At each of these potential sites of difference, there may be effects due
to different size or the number of neurons, variations in receptors, differences in neurotransmitter content or metabolism as well as functional differences in the various components of the reflex arc.” (p. 678)

The next section surveys the existing literature on gender differences in both tonic HRV and across a range of different types of stressors. The often ignored but important differences between men and women, starting at a physiological level and extending to cognitive, emotional, motivational, and behavioral levels have important implications for studies and interventions in positive psychology.

**Gender and HRV**

Much research has been done regarding gender differences in tonic control of HRV. As mentioned previously, tonic HRV correlates with health and well-being. Most studies give evidence of greater tonic HRV in women, while men show a smaller decrease in HRV during stress. As we have seen, tonic HRV has great predictive power of the current and future well-being of individuals.

A few studies showed no significant gender differences in tonic HRV. Wang et al. (2009) found no gender differences in tonic RMSSD in a large sample of twins (N=735). In a longitudinal study of HRV, Li et al. (2009) measured HRV using RSSD and RSA at rest and during stress on 609 young adult subjects at an initial point and once again 1.5 years later. They found no significant effect of gender on tonic HRV.
Other studies have found numerous gender differences. Snieder, van Doornen, Boomsma, and Thayer (2007) found clear support for higher tonic HRV among women, using approximate entropy (ApEn) as a measure and carefully controlling for confounds. This study was significant in that it compared opposite-sex twins and also correlated the measure of ApEn to RSA to explore heritability of HRV. Heritability was found to be only moderate at 40%, indicating that other differences between the men and women, including the opposite-sex twins, are at work. The hormone estrogen has appeared to be associated with increased vagal tone in some studies, but this study failed to find any effect of estrogen, including influences from contraception and menopause. Based on earlier findings (Ahern et al., 2001), the authors speculate that the activity in the prefrontal cortex, along with the resulting inhibitory effects, may be greater in women than in men. Interestingly, monozygotic (identical) male twin pairs in this study ($n=43$) had ApEn correlation of only $r = .29$, whereas monozygotic female pairs ($n=47$) had an ApEn correlation of $r = .55$.

Sztajzel, Jung, and de Luna (2008) provide further confirmation for the notion that women have higher tonic vagal tone overall than men. In a study that was intended to establish the reproducibility of gender differences in vagal tone, the investigators took multiple continuous around-the-clock measures of HRV of a group of young men and women across two consecutive days. The researchers also included heart rate and the low-frequency to high-frequency ratio of RSA (LF/HF) as measures of sympathetic activation. Women were found to have higher HRV than men overall compared to men throughout the day, mainly due to lower SNS activity. This
study also confirmed that HRV varies independent of heart rate, supporting the notion of the ANS as a complex system, as proposed by Thayer and Lane’s (2000) NIM.

Von Kanel, Thayer, and Fischer (2009) examined HRV and plasma levels of fibrinogen in men and women during sleep. Plasma fibrinogen is associated with inflammation and hardening of the arteries, and independently correlates with many lifestyle factors such as smoking, amount of exercise, and obesity. Consistent with previous studies, women had higher levels of plasma fibrinogen than men, accounting for a variety of potential confounds including lifestyle and age. The authors also found a significant reverse correlation between RMSSD and plasma fibrinogen at night ($p < 0.001$). This correlation was significantly greater in women ($r = -.28$) than for men ($r = -.20$), such that lower vagal tone (as measured by RMSSD) correlated with higher plasma fibrinogen levels. Since men experience a higher incidence of cardiovascular disease relative to women despite lower levels of plasma fibrinogen, this finding could point to the presence of other cardiovascular risk factors in men, protective factors in women, or both. More research into these factors may lead to benefits for men in reducing their cardiovascular risk.

In another examination of gender differences in HRV related to sleep, Valladres, Eljammal, Motivala, Ehlers, and Irwin (2007) analyzed nighttime vagal tone during sleep in healthy non-obese adults. They sought to find autonomic correlates that might help explain the high incidence of negative cardiovascular events at the end of the sleep cycle and just after waking found in previous research. The researchers measured HRV using the high-frequency
component of RSA, controlling for reproductive hormones that may influence vagal control. Sympathetic activity was measured using the ratio of low-frequency to high-frequency (LF/HF) components. Over the course of the night, men were found to have lower RSA and higher sympathetic activation on average than women. In particular, men differed markedly from women during the rapid eye movement (REM) stages of sleep. Men experienced decreased RSA and large increases in sympathetic activation measured by LF/HF during these stages, whereas women experienced neither increases in sympathetic activation nor decreased RSA response. The increases in men did not correlate with other factors such as physical fitness, age, body-mass index, socio-economic status, or sleep quality. Increased sympathetic activation, as indicated previously, correlates with negative cardiac events, and REM sleep dominates the later stages of the sleep cycle near waking. Thus for men, increased cardiac risks in the late stages of sleep and first stages of waking may be at least partially due to these physiological responses.

If the findings of Valladres et al. are replicated, the question remains as to why men, and not women, undergo vagal withdrawal and sympathetic activation during REM sleep, and more importantly, whether anything can be done to reduce the risk of cardiovascular events. This may be a key area for positive psychology to explore in the future. Since sleep is by definition out of conscious control, this risk is unlike other controllable aspects of HRV. Some forms of meditation have been shown to reduce tonic SNS activity (Tang et al., 2009), and should be explored for their potential to mitigate risks associated with nighttime sleep rhythms in men.

**Gender Differences in HRV Across Types of Stressors**
As noted, tonic HRV has great predictive power for the future health of individuals and reveals some gender differences. HRV under stress is even more instructive, as it can reveal both individual and gender-based differences. In fact, studies show a surprising degree of gender differentiation in the neural pathways of the autonomic response to stress, including functional differences in several structures in the CAN. These areas are associated with responses to threat and reward as well as self-control and emotional processing, and thus present a unique and powerful perspective on differences between men and women in relation to well-being. Still, findings are mixed, and may depend upon a complex array of factors including gender, genetic, psychological, and social influences. Weber et al. (2010) found that larger reductions in HRV during a stressor correlated with better overall health and adaptability. Thus the larger a decrease in HRV one can muster during a stress response, as a result of some combination of SNS activation and PNS withdrawal, seems to indicate greater adaptability to that type of stress.

Gender differences in phasic HRV seem to depend on the type of stressor and whether the source of the stressor is external or internal. For example, Ruiz, Uchino and Smith (2006) found that, despite slightly lower baseline RSA, men showed greater increase in RSA and greater decrease in heart rate compared to women in response to a cold pressor task, which induces a strictly physiological reflex. This suggests that, at least for this one task, men recruit a more powerful vagally mediated PNS response. Men also seem to exhibit stronger responses to external stressors involving an emotional component. Jöhnsson and Sonnby-Borgström (2003) found that men responded with a greater increase in RSA than women when looking at pictures
of faces with angry expressions. However no comprehensive explanation of gender differences appeared in a review of the current literature.

In a large twin study \((N=735)\), Wang et al. (2009) found no gender differences in RMSSD. The study measured HRV during rest and under three types of stressors to determine the effects of ethnicity and gender on HRV during rest and under stress, and whether HRV under stress is determined by separate genetic influences. It was found that HRV under stress indeed has a different genetic basis than tonic HRV. This finding suggests that while tonic HRV generally predicts ability to respond to stress, there is a separate capacity for HRV under stress that is independent of any potential associated with tonic HRV. Thus, an individual may have a genetic predisposition to low tonic HRV and a separate genetic predisposition to high HRV under stress, or vice versa. The findings did not indicate any genetic association between HRV and gender.

Li et al. (2009) found that men have smaller decreases in both RSSD and RSA than women under a video game stressor. This outcome suggests that men may have a weaker PNS response to this type of task, since their vagal influence did not change as much as women's.

Ruiz, Uchino, and Smith (2005) investigated the effects of hostility and gender in relation to high-frequency RSA and parasympathetic response in a forehead cold-pressor task (2005). The task involves placing an ice-pack on the subject's forehead for three minutes. This is known to induce a strong autonomic reflex resulting in increased cardiac vagal outflow evidenced by heart rate deceleration and increased RSA. This reflex is mediated by the trigeminal nerve, a
cardiac vagal afferent located in the face, which connects to the nucleus ambiguus in the solitary tract where it excites the cardiac vagal efferent nerve (Gorini, Jameson, & Mendelowitz, 2009). This task was chosen because, despite the fact that it temporarily increases vagal tone, it is unpleasant and the authors expected it to provoke negative reactions from individuals high in trait hostility. They selected a group of 80 test subjects from an initial sample of 670, drawing from the upper and lower quartiles based on various measures of hostility. The group was selected to be evenly divided both by gender and by low or high hostility. The response to the task showed differences along both gender and hostility parameters. Overall, heart rate deceleration and RSA increase were both significantly greater in men than in women, with women's average change in both measurements amounting to less than 60% of men's. This indicates a greater range of vagal response in men compared to women.

The results became more complicated when considered by hostility level. Participants scoring in the upper quartile of hostility experienced diminished heart rate deceleration over time compared to the low-hostile group, however the results did not correlate with anger or hostility reported during the task. High-hostile individuals experienced an attenuated decrease in heart rate over the third minute compared to low-hostiles, indicating diminished vagal control. Against expectations, trait hostility predicted anxiety rather than state hostility during the task, with high-hostile women experiencing greater anxiety than high-hostile men. The researchers also found changes suggesting coactivation of the SNS, but only in hostile men. Total peripheral resistance (TPR) and cardiac output (CO) are determinants of blood pressure and thus signs of SNS
activation. High-hostiles had increased TPR and decreased CO, whereas low-hostile men had decreased TPR and increased CO. These findings suggest that trait hostility may take a larger toll on men than it does on women, reducing their capacity to respond rather than priming them for any potential action. However, the mechanisms involved remain unclear and require additional study.

The studies reviewed suggest that major components of the CAN, particularly the medial prefrontal cortex (mPFC) and the amygdala, differ either physiologically or functionally between the sexes. The mPFC is associated with emotion control, reward processing, and higher-order functions such as cognitive reappraisal (Urry et al., 2009). Nugent et al. (2011) conducted neuroimaging studies of gender differences in autonomic arousal during a stressful task in individuals with damage to the mPFC. They found that vagal activation in women with mPFC damage correlated with increased blood flow to the amygdala, while in men with mPFC damage there was no or a negative correlation. The prefrontal cortex and the amygdala are key areas in assessing safety and regulating emotion among other functions, so gender differences here could result in important differences in behavior and approach to experience. The authors hypothesized that gender differences in HRV would be reflected in increased blood flow under mild stress in particular areas of the CAN, including the anterior cingulate cortex (ACC), insula, and amygdala. HRV was measured via RMSSD and positron emission tomography (PET) scans were taken while the test subjects performed a visual fixation task, a handgrip task, and a cognitive task. Blood flow in the right amygdala differed between men and women on the visual fixation
and cognitive tasks. During visual fixation, blood flow in the right amygdala correlated with increased RMSSD in women. During the cognitive task women again showed a positive correlation between blood flow in the amygdala and RMSSD, while men showed a weak negative correlation between these two measures. Blood flow also differed in the left anterior insula in the cognitive task, with women again showing a correlation between blood flow and RMSSD, while men did not. Consistent with Li et al. (2009), men had a smaller decrease in RMSSD in response to stress, indicating that men engaged a smaller adaptive response under stress compared to women. Activity in the amygdala is reduced in men compared to women during stress, which may be consistent with the finding by Ruiz et al. (2005) that women experienced greater anxiety during stress than men. Based on these findings, Nugent et al. (2011) propose that several areas of the brain, including the amygdala, differ in function between men and women.

Buchanan et al. (2009) also found gender differences in the function of the medial prefrontal cortex (mPFC). The mPFC is associated with the modulation of the hypothalamus-pituitary-amygdala axis, the main stress-response unit of the brain. This neural region is associated with emotion regulation and interpretation of social cues and stressful events. An equal number of men and women with damage to the mPFC were subjected to one physiological stressor (standing up) and one social stressor, and the results were compared with a healthy control group and with a group with damage in other areas of the brain. Damage to the mPFC resulted in gender-specific outcomes, with bilateral damage to the mPFC resulting in increased
cortisol output in women and a reduction of cortisol output in men. This study also revealed that men in all three groups experienced increases in cortisol in response to the stressors, whereas only women with mPFC damage experienced increased cortisol. So the healthy functioning of the male mPFC initiated cortisol during stress, while the healthy function of the female mPFC did not initiate cortisol. This result may point to an inhibitory function present in the healthy and undamaged female mPFC that is not present in the healthy male mPFC, or a particular orientation toward increased sympathetic activation in healthy men compared to women during stress.

For the physiological stressor, men with mPFC damage experienced decreased HRV compared to healthy men, whereas women with mPFC damage did not experience decreased HRV compared to healthy women. As the frontal cortex is held to be the principal origin of PNS activation, this finding suggests that there may be a gender difference in the locus of control of responses to at least this one type of stressor. Similar to the cortisol finding, this points to a relative orientation toward SNS activation on the part of men as compared to women. The authors note that, “These findings suggest that reactions to stress may depend on different neural structures for men and women” (p. 57). Together with the neuroimaging studies of Nugent et al. (2011) involving the amygdala, these findings indicate fundamental differences in the way men and women process and respond to stressors in the brain areas related to emotion processing.

Contributing to the notion that men are more prone toward sympathetic activation under emotional stress, Jöhnsson and Sonnby-Borgström (2003) found that men responded with a
greater increase in RSA to external stimuli than women when looking at pictures of faces with emotional expressions, indicating increased attention by males. The authors showed pictures of a series of happy faces and angry faces for varying lengths of time to test subliminal, marginal, and conscious recognition of the faces. All subjects responded to the angry faces with reduced heart rate and increased RSA regardless of the time of exposure, possibly reflecting an increase in attention directed at the face. Increased focus and attention involves increased activity in the prefrontal cortex, which produces PNS activation, consistent with the observed results. However men showed a greater reaction than women to the angry faces, and men’s reaction increased with the length of time exposed to the picture whereas women's reaction decreased with exposure time. In this laboratory study, increased attention did not lead to emotional responses in the men, but the impact of happy and angry expressions in real life deserves more study both in and outside of the laboratory setting.

Heponemi, Ravaja, Elovainio, Näätänen, and Keltikangas-Järvinen (2006) measured correlations between gender, trait positive/negative affectivity and cardiac response to stressors. They found that being startled led to increased RSA for both sexes. Women who were high on trait positive affect, but no other group, showed smaller reductions in RSA under all stress conditions. A smaller decrease in RSA might equate to a more adaptive response to stress. Additionally, RSA was found to decrease during math and public speaking challenges. In women, more positive affect during the speech challenge led to a greater decrease in RSA. Men reported and expressed less positive affect during challenges, however their sympathetic
activation did not differ significantly from the women. The authors suggest that greater decreases in RSA by the women who reported higher positive affect during the speech indicate a more adaptive response. Decreased RSA indicates a relative increase in SNS influence, which as describe previously provides energy resources and a narrows attention to shut out irrelevant information. Positive emotion, indeed all strong emotion, correlates with decreased RSA even in non-stressful situations (Lane et al., 2009), and decreased RSA correlates with decreased self-regulation, which would seem to be maladaptive in the context of public speaking. More research into positive emotions during stress could provide a resolution.

Recently, Denson, Grisham, and Moulds (2011) conducted an experiment on the effects on HRV when using cognitive reappraisal to manage anger. Cognitive reappraisal is “an example of an antecedent-focused strategy, and entails adopting a neutral perspective on a situation prior to the event in order to attenuate its emotional impact” (Denson, Grisham, & Moulds, 2011, p. 14). The test subjects were instructed to use cognitive reappraisal prior to watching an anger-inducing video whose content was matched to self-reported social and political views. The instructions included directions to “view the video with the detached interest of an impartial observer or a mediator of a debate” (p. 17). A control group was given no instruction, and a third group was told to suppress any emotions they experienced. The reappraisal group showed largest increase in HRV, least anger, and largest HR reduction during the video. Five minutes after the video, however, the test group's HRV had returned to their pre-video baseline, the suppression group's HRV was below baseline, but the control group's HRV
was actually higher than it was before the video. The authors contend that this task reflects emotion regulation as opposed to mental effort, which might be consistent with the increased HRV shown in the suppression condition. Suppression may be a less-effective or maladaptive form of emotion-regulation. Though the tactic of reappraisal is successful, it is nonetheless complex and composed of more than one cognitive task. The task essentially involves a redefinition of one's own role from participant to witness. Further research is needed to understand not only the neural machinery involved in this shift, but also the range of situations in which it might be considered adaptive. Finally, the researchers purposefully chose a female population for this experiment in order to compare their results with previous research on cognitive reappraisal, so its effectiveness for men are unknown.

Ahs and colleagues (2009) used positron emission tomography (PET) to correlate HRV with blood flow in the brains of men and women with social phobias during stress. The goal of the study was to see whether areas of the brain known to be involved with tonic cardiac vagal regulation were also involved during stress. Participants included fifteen men and thirteen women diagnosed with social phobias with pronounced public speaking anxiety. There was a range of intensity of the phobia across individuals, though all met the DSM-IV criteria for social phobia. The subjects were given a public speaking task, intended to induce stress and negative emotions. The researchers found, as in tonic regulation, that HRV correlated with increased blood flow in the prefrontal cortex, the anterior cingulate cortex, and the right caudate nucleus. Gender differences were found in the correlation of HRV to blood flow in the caudate nucleus.
Blood flow in this area was similar in men and women, however men showed a higher correlation between HRV and increased blood flow. The caudate nucleus has been associated with reward motivation and learning (Ahs et al., 2009). The authors suggest that gender differences in dopamine transmissions within this region may relate to the relative risk for cardiac disease in men.

**Summary**

Women seem to benefit from higher resting HRV as well as from an absence of risk-related sympathetic activation. Men and women exhibit differences in cognitive and emotional processing, however, which are reflected in HRV during different types of stress. These differences may depend on the type of stress and whether the source of stress is internal or external. Though these trends have emerged, more research is needed to understand the many social, emotional, and physiological influences that impact men and women differently. Since HRV is such a sensitive and easily measured index, there is great potential for further experimentation to explore gender differences especially in emotional and cognitive processing. Thus HRV may be an important tool to use in future studies examining gender differences in well-being.

**Gender and Positive Psychology**

As an index of not only physiological but also cognitive and emotional processes, HRV may be particularly well-suited for studying gender differences in emotion and during stress,
based on the array of studies reviewed above. In this final section, implications for Positive Psychology are suggested.

As longevity statistics show, men are at a disadvantage compared to women (U.S. Census Bureau, 2007). Men generally live longer – though still not as long as women – and happier lives through participation in marriage, though Smith et al. (2010) hypothesize that these gains come at the expense of their partners. Positive Psychology seeks to describe the very knowledge and habits that support flourishing, so it would seem on its face to be inherently interesting for men. The problem, however, is that it seems to be women rather than men who are flocking to the interventions and techniques offered by the field. Interventions are validated, but little consideration is given to potential gender differences, beginning with the under-representation of male participants often included in studies. As of this writing, women are overwhelmingly the most interested audience for Positive Psychology. In the University of Pennsylvania Masters of Applied Positive Psychology (MAPP) class of 2011, women outnumbered men two to one. The visitors to authentichappiness.org, one of the leading Positive Psychology websites, are over 60% female (M. L. Kern, personal communication, July 29, 2011). If, as Seligman suggests (MAPP 600 lecture, September 8, 2010), the good is what we prefer, then there may indeed be separate standards or at least different orientations toward flourishing for men and women. The possibility exists that men on average are not as interested in or cannot easily relate to the notions of Positive Psychology as currently promulgated.
Baumeister (2010) points out that even in our advanced society there are many dangerous jobs that someone has to perform, and overwhelmingly more men than women perform these jobs. For example, men make up 87% of the construction work force (Wulfhorst, 2009). Baumeister suggests that this difference is due to a relative preference by men to focus on income gain over their own personal safety, as compared to women, who focus on cultivating a safe emotional environment for themselves and their families. Working with the daily possibility of injury or death requires the suppression of some feelings, rather than the cultivation of their awareness (Baumeister, 2010). It may be that many men truly are more interested in traditional masculine pursuits and responsibilities such as addressing threats and ensuring the safety of their families and communities than in cultivating positive emotion. In any case, recent research suggests that men undertake these tasks from a somewhat different emotional and physiological perspective than women.

The field of Positive Psychology draws its authority from its research orientation and its emphasis on evidence-based descriptions of what is healthy and beneficial, but the message may not always be accurate for everyone since we often lump diverse groups together. To our credit, we emphasize that one size does not fit all, and no activity or intervention will fit with every person. In her book *The How of Happiness*, Sonja Lyubomirsky (2008) addresses this issue head on not only by acknowledging the variation in effectiveness of interventions across individuals, but also by providing a means to determine which interventions are more likely to be effective for particular individuals.
When groups differ in systematic ways, we should directly acknowledge and explore those differences. In order to fulfill its highest potential, the field of Positive Psychology should explore and discover the sources and potentials of well-being as they manifest in both men and women. Men have particular vulnerabilities to stress due to an inherently different stress-response system that seems to overreact compared to the threats in modern society. On the one hand, men may need different types of interventions. On the other hand, the findings must be presented in terms and venues that appeal to men in order to promote their adoption.

There is great potential for applying positive psychology to men. As the previously mentioned findings on marriage suggest, men do better in that state than on their own. Future research and interventions could focus on other types of supportive relationships and the skills and motivation needed to create and maintain them. Given their higher SNS activity, interventions which help to reduce SNS activation, such as meditation, are also appropriate. Promising signs for the promotion of meditation appeared at the Second World Congress of the International Positive Psychology Association in Philadelphia, July 23-26, 2011. The closing event featured a panel of researchers presenting findings on a host of benefits related to meditation, however none of the researchers presented results based on gender.

It may be possible, as suggested earlier, that men may not take as great an interest in questions of well-being as women. Research on this question would also be helpful.

Conclusion
At least some emotional and cognitive differences between men and women have their foundations in the physiology of the heart-brain connection and in the cognitive and emotion processing centers of the brain. Most gender differences are specializations that are adaptive from an evolutionary standpoint. Gender divergent responses to the same stimulus, therefore, may have an evolutionary advantage for the species. Men's tendency toward higher tonic sympathetic arousal is clearly a health risk, whereas women's higher vagal tone overall seems to convey benefits, perhaps including longer life. The differences summarized in this study suggest that men and women have equal abilities to control their cognitive, emotional, and cardiac responses, but they have different biases in processing the raw data of experience.

What remains unknown is the way these physiological differences translate into different influences and outcomes in the lives of men and women. Despite dramatic societal changes over the last century, men and women still have clearly distinct cultures. As noted earlier, one important divide between these cultures may simply be what men and women want (Baumeister, 2010). In combination with various collaborators, Thayer suggests that HRV is not merely reactive, but also responds to goal-directed thoughts and feelings (Hagemann et al., 2002; Thayer & Lane, 2009). So HRV may play some role in the types of goals we formulate and pursue and how we evaluate our progress toward them. Since the current interventions and approaches of Positive Psychology seem to be doing well for women, a possible future direction for research that may especially benefit men may lie in researching the effects of motivation and reward on HRV. Such research may reinforce stereotypes, or it may produce surprising results that lead
men to flock to new or old positive interventions. In either case, men will be armed with better knowledge of both their strengths and their vulnerabilities.
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### Appendix: Glossary of Terms

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<tr>
<th>Abbr</th>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>PNS</td>
<td>Parasympathetic nervous system</td>
<td>Part of the nervous system responsible for calming, quieting and performing maintenance work on the body.</td>
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<tr>
<td>ANS</td>
<td>Autonomic nervous system</td>
<td>The part of the nervous system controlling automatic functions such as breathing, heart rate, and digestion. Comprises the sympathetic nervous system and the parasympathetic nervous system, which offset each other to adapt to the inner and outer needs of the organism.</td>
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<tr>
<td>SNS</td>
<td>Sympathetic nervous system</td>
<td>Part of the nervous system responsible for speeding up heart rate and blood pressure in response to stress.</td>
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<tr>
<td>CAN</td>
<td>Central Autonomic Network</td>
<td>A coordinated network of neural structures in the</td>
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brain, including the medial prefrontal and insular cortices; the limbic system, including the anterior cingulate cortex, hypothalamus, and central nucleus of the amygdala; and the brainstem, including the periaqueductal gray matter and the nucleus of the solitary tract.

HRV  Heart rate variability  The variation in the beat-to-beat intervals of the heart

IBI  Inter-beat intervals  The time in milliseconds from the peak of one ventricular contraction to the next.

NIM  Neurovisceral Integration Model  Theory that cognitive and emotional processes in the prefrontal cortex, amygdala, insula, and anterior cingulate cortex drive changes in heart rate and other autonomic functions.