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Understanding Anticipatory Time Perception in Consumers' Time-Related Decisions

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Abstract

Anticipatory time (e.g., prospective duration into the future) is one of the key pieces of information to be processed in intertemporal decisions - decisions requiring a tradeoff between smaller sooner and larger delayed outcomes. Extensive research has examined human and animal perception of time as it is currently passing (i.e., experienced time) and time that has already passed (i.e., retrospective time). However, the nature of anticipatory time perception and its role in consumers' judgment and decision making have been largely neglected. In my dissertation, I aim to demonstrate that considering subjective anticipatory time estimates offers a new perspective to understand intertemporal decisions. For this purpose, first, I propose that both diminishing sensitivity to longer time horizons (i.e., how long individuals perceive short time horizons to be relative to long time horizons) and the level of time contraction overall (i.e., how long or short individuals perceive time horizons to be overall) contribute to how much individuals discount the value of delayed outcomes, and, then, examine factors influencing intertemporal decisions by changing subjective time perception. Specifically, in the first and third essays, I demonstrate that sexually arousing images and auditory tempo (which has been shown to influence judgment of elapsed time) influence anticipatory time perception and subsequent intertemporal preferences. These results indicate that anticipatory time perception shares the property of perceptual inputs (e.g., people process anticipatory time as if they "perceive" elapsed time). In the second and fourth essays, I demonstrate that cognitive information available at the time of judging anticipatory time such as spatial distance and perceived life span influence individuals' intertemporal preferences by changing their subjective perception of anticipatory time, which suggests that anticipatory time perception also has the property of embodied cognitions. Taken together, my dissertation incorporate both time perception research and consumer research on time-related judgment and decision making and sheds light on both domains.

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ABSTRACT

UNDERSTANDING ANTICIPATORY TIME PERCEPTION IN CONSUMERS' TIME-RELATED DECISIONS

B. Kyu Kim
Advisor: Gal Zauberman

Anticipatory time (e.g., prospective duration into the future) is one of the key pieces of information to be processed in intertemporal decisions - decisions requiring a tradeoff between smaller sooner and larger *delayed* outcomes. Extensive research has examined human and animal perception of time as it is currently passing (i.e., experienced time) and time that has already passed (i.e., retrospective time). However, the nature of *anticipatory* time perception and its role in consumers' judgment and decision making have been largely neglected. In my dissertation, I aim to demonstrate that considering subjective anticipatory time estimates offers a new perspective to understand intertemporal decisions. For this purpose, first, I propose that both *diminishing sensitivity* to longer time horizons (i.e., how long individuals perceive short time horizons to be relative to long time horizons) and the level of *time contraction* overall (i.e., how long or short individuals perceive time horizons to be overall) contribute to how much individuals discount the value of delayed outcomes, and, then, examine factors influencing intertemporal decisions by changing subjective time perception. Specifically, in the first and third essays, I demonstrate that sexually arousing images and auditory tempo (which has been shown to influence judgment of elapsed time) influence anticipatory time perception and subsequent intertemporal preferences. These results indicate that anticipatory time perception shares the property of perceptual inputs (e.g., people process anticipatory time *as if* they "perceive" elapsed time). In the second and fourth essays, I demonstrate that cognitive information available at the time of judging anticipatory time such as spatial distance and perceived life span influence individuals' intertemporal preferences by changing their subjective perception of anticipatory time, which suggests that anticipatory time perception also has the property of embodied

cognitions. Taken together, my dissertation incorporate both time perception research and consumer research on time-related judgment and decision making and sheds light on both domains.

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INTRODUCTION

The most well documented phenomenon in the intertemporal choice literature would be that individuals discount the value of delayed consumption more heavily when delaying an immediate consumption (e.g., from today to tomorrow) than when delaying the same consumption over an equal delay starting at a later date (e.g., from 30 days from today to 31 days from today). While hyperbolic discounting has been documented extensively in the past three decades of intertemporal choice literature, still relatively little is known about what psychological mechanism is responsible for the sub-optimal decision making from it. Recently, some researchers argue that the cause of hyperbolic discounting may be not rooted in time-dependent discounting per se (i.e., rewards delayed from present is discounted at a higher rate than rewards delayed from some point in the future), but more deeply in how people perceive time (Kim & Zauberman, 2009; Zauberman, Kim, Malkoc, & Bettman, 2009). That is, people show hyperbolic discounting not because they apply different discount rates for delayed rewards at different points in time, but simply because they perceive the delay from present to be subjectively longer than the delay of equal length in the future.

Although such a role of subjective time perception in hyperbolic discounting has been demonstrated both theoretically and empirically in many intertemporal choice articles recently (e.g., Ebert & Prelec, 2007; Killeen, 2009; Kim & Zauberman, 2009;

Read, 2001; Takahashi 2005; Zauberman et al., 2009), this is only one instance of how subjective time perception explains discounting-related phenomena. That is, *when individuals' subjective time perception is considered, many phenomena of intertemporal preference can possibly be explained by how long or short decision makers perceive anticipatory time (i.e., prospective duration in the future) to be.*

In my dissertation, building on the recent efforts to explain hyperbolic discounting using individuals' subjective time estimates, I aim to propose a general framework and provide empirical support demonstrating the mediating role of subjective time perception in various intertemporal choice phenomena. For this purpose, first, I introduce a model of perceived-time-based account of temporal discounting, and then present four empirical essays in which individuals' subjective time perception plays a key role in driving their intertemporal preferences. In the following sections, I start with a review of recent findings in intertemporal choice research, and introduce my perceived-time-based model of temporal discounting.

HYPERBOLIC DISCOUNTING

Hyperbolic discounting[1] (as opposed to its alternative, exponential discounting) is inconsistent with the assumptions of a standard normative economic model: even a utility maximizing individual who would patiently opt for superior but delayed rewards over inferior but sooner rewards can be worse-off by switching her preference as the options

[1] As both immediate and delayed consumption get closer to the present, people tend to assign progressively greater weight to the immediate consumption relative to the delayed consumption. To denote this tendency, researchers use various terms, such as present bias (O'Donoghue & Rabin, 1999), decreasing impatience (Prelec, 2004), or hyperbolic discounting. Throughout this paper, we use the term hyperbolic discounting to denote not the specific functional form of discounting but this broad tendency.

get closer to the present (Kirby & Herrnstein, 1995; Strotz, 1955). Another important manifestation of hyperbolic discounting is that discount rates seem to decline as people consider their preferences for longer time periods. For example, Thaler (1981) demonstrated that to delay a $15 lottery winning for 3 months, people required an extra $15 (277% annual discount rate), but to delay the same amount for 1 year, four times as long, they required only an extra $45 (139% annual discount rate).

A substantial body of evidence of hyperbolic discounting has been accumulated in both human (Kirby & Herrnstein, 1995; Thaler, 1981) and lower animals (Ainslie, 1974; Mazur, 1984; Rachlin & Green, 1972), among normal people and substance abusers (Bickel, Odum, & Madden, 1999; Kirby & Petry, 2004), and for various types of outcomes, including time, money, health, job offers, and life-savings (Cairns & Van der Pol 1997; Chapman, 1996; Hesketh, Watson-Brown, & Whitely, 1998; Zauberman & Lynch, 2005). Moreover, various models with different functional forms have been proposed to model time-inconsistent discounting, such as a hyperbolic decay model with a single parameter (e.g., Mazur, 1984), a generalized hyperbola with two parameters (e.g., Loewenstein & Prelec, 1992), and a quasi-hyperbolic discount function (e.g., Laibson, 1997). That is, extensive effort has been dedicated to documenting the effect and to providing various functional forms to model the data. By contrast, relatively little is known about the psychological mechanisms underlying hyperbolic discounting: that is, why do individuals discount the value of delayed consumption at a different rate depending on when the delay happens? Why does individuals' impatience increase as they approach the actual consumption?

Many researchers have proposed various affective and cognitive mechanisms to explain why the same delayed consumption can be discounted differently depending on when the delay happens. Most of these explanations can be characterized as an attempt to explain what causes changes in the relative (de)valuation of outcomes over the 'same' delay depending on when the delay happens. For this reason, I denote these explanations as *perceived-value based accounts*, and contrast these explanations with the *perceived-time based account*, which centers on the perception of time rather than devaluation of outcomes.

Perceived-value based accounts. Some initial attempts to provide a psychological explanation for hyperbolic discounting attributed the tendency to low-level impulsive reactions toward immediately available rewards (Ainslie, 1974). Consistent with this approach, Loewenstein (1996) argued that excessive visceral influences of active drive states may explain hyperbolic discounting. Just as sensory proximity of positive stimuli creates strong appetitive responses toward the stimuli, temporal proximity to rewards (i.e., immediacy of consumption) could elicit steep devaluation of outcomes that are not immediately available. If excessive appetitive responses are generated only for immediate monetary outcomes but not for delayed ones, this affective process can explain why individuals discount the value of delayed consumption differently depending on when the delay happens. Other empirical studies showing the similar effects (e.g., Metcalf & Mischel, 1999; Van den Bergh, Dewitte, & Warlop, 2008; Wilson & Daly, 2003) shares this view that decision makers' appetitive responses influences how they perceive the value of immediate vs. delayed rewards.

Making a contrast to the visceral explanation of discounting, there exist more cognitive explanations of temporal discounting but still belonging to this perceived-value-based account. For instance, *Construal Level Theory* posits that changes in the mental representation between immediate vs. delayed consumptions may result in hyperbolic discounting by influencing decision weights given to the value of rewards and delay (Trope & Liberman, 2003). Supporting this view, participants who were primed to adopt a high-level construal were shown to reveal low degree of impatience for delayed rewards (e.g., Fujita, Trope, Liberman, & Levin-Sagi, 2006; Malkoc & Zauberman, 2006). In addition, how much resources individuals perceive to be available in the near vs. distant future is also shown to influence how much they discount the value of delayed outcomes (Zauberman & Lynch, 2005).

Perceived-time based account. While such perceived-value based accounts explain hyperbolic discounting by focusing on why individuals discount *the value of outcomes* per se at a different rate, recently researchers have suggested the importance of separating the perception of values from the *perception of delays* in temporal discounting (e.g., Ebert & Prelec, 2007; Killeen, 2009; Kim & Zauberman, 2009; Read, 2001; Takahashi 2005; Zauberman, et al., 2009). When the two processes are separated, hyperbolic discounting can be explained not by decreasing discount rates, but rather by diminishing sensitivity to longer time horizons. That is, individuals do not perceive time objectively - one year is not perceived to be subjectively as four times longer than 3 months. Due to such biased time perception, individuals can have *internally* a constant discount rate over subjective time while still discounting the value of delayed outcomes more heavily for earlier (or shorter) delays and reversing their preferences as options get closer to the present (i.e., still display hyperbolic discounting).

Obviously, this explanation makes strong claims about the perception of future time. Although diminishing sensitivity to experienced time (i.e., duration of time that has passed) is a well-known, heavily studied phenomenon in the psychology literature (e.g., the Weber-Fechner Law or Stevens' Power Law), it is not clear whether the same phenomenon would be observed in perceiving *anticipatory time* (i.e., future time that decision makers have not experienced but have to incorporate into intertemporal decisions). To examine diminishing sensitivity to future time, Kim and Zauberman (Kim and Zauberman, 2009; Zauberman, et al., 2009) directly measured participants' subjective time estimates for various future durations and found that a non-linear function (e.g., power function) fits time perception data than a linear function. Using the subjective time estimates, they further showed that participants' discount rates calculated based on calendar time revealed hyperbolic discounting, but when their subjective time estimates were accounted, the hyperbolic discounting was reduced to exponential discounting, confirming the role of subjective time perception as a cause of hyperbolic discounting.

A PERCEIVED-TIME-BASED DISCOUNTING MODEL

Building on the empirical findings that diminishing sensitivity to time is responsible for hyperbolic discounting, in this section, I propose a model that incorporates the role of subjective time perception in temporal discounting more generally.[2] Specifically, I suggest that not only diminishing sensitivity to time but also the overall level of time contraction (i.e., how long or short individuals perceive a given time horizon to be) can contribute to the greater degree of hyperbolic discounting.

To develop this model, I start with the following standard exponential discount function. This function has a constant discount rate *r* and is defined over continuous delay *t*.

$$D(t) = e^{-r \cdot t} \text{ ----- } (1)$$

I assume that 'true' internal discounting process (i.e., internal discounting not over objective time, but over subjective perception of objective time) is exponential, but I postulate that the values of delayed outcomes are internally discounted based not on calendar time *t* but rather on subjective estimates of the objective time *T*.

$$D(T) = e^{-R \cdot T} \text{ ----- } (2)$$

Equation (2) denotes the internal discounting process over *perceived* time *T*, where *R* is the *perceived-time based* discount rate (i.e., rate of discounting defined over the perceived time rather than calendar time)[3]. Next, to incorporate the non-linear scaling nature of time perception, I define *T* as a function of objective time as such:

$$T = \alpha \cdot t^{\beta} \text{ ----- } (3)$$

In Equation (3), *T* is the subjective perception of objective time *t*, α is capturing the *overall* level of time contraction, and β is capturing the degree of non-linearity (diminishing sensitivity to time). In most analyses of hyperbolic discounting, individuals

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[2] The same model is introduced in Kim & Zauberman (2009).

[3] In the equation (2), *R* reflects that rate of discounting in respect to perceived delays. We used *R* instead of *r* because *r* often refers to an annual compound discount rate measured over calendar time, as defined in equation (1). Although we see *R* is a measurable construct separately from the time perception parameters, in the current article, *R* is simply treated as the unexplained variance in intertemporal preferences after controlling for individual differences in time perception.

are assumed to perceive time accurately (e.g., $T = t$). In the above equation, the time contraction parameter α can be any positive number, while the β parameter is restricted to be positive numbers less than 1 to incorporate diminishing sensitivity to anticipatory time horizons.

When non-linear time perception is reflected in the discount function, observed intertemporal preference can be described with one parameter for the perceived-time based discount rate R and two parameters (α and β) for time perception as below.

$$D(t) = e^{-R\cdot\alpha\cdot t^{\beta}} \text{ ----- (4)}$$

Equation (4) represents hyperbolic discounting when $0 < \beta < 1$[4]. A similar power function has been used by several authors to model the role of diminishing sensitivity to time in hyperbolic discounting (e.g., Ebert & Prelec, 2007; Killeen, 2009). The current perceived-time based discount model in equation (4) is *theoretically* different from previous models in emphasizing the role of α parameter in driving hyperbolic discounting. That is, while previous models consider only the diminishing sensitivity to time as being responsible for the degree of hyperbolic discounting, I consider both how long or short individuals perceive delays to be overall (i.e., the α parameter) and the extent to which they show diminishing sensitivity to time (i.e., the β parameter).

One major issue to consider is whether the absolute value of the α parameter is a meaningful indicator in perception or an arbitrary scaling parameter. Similar issues have been heavily debated in the psychophysical scaling literature (for more details, see the

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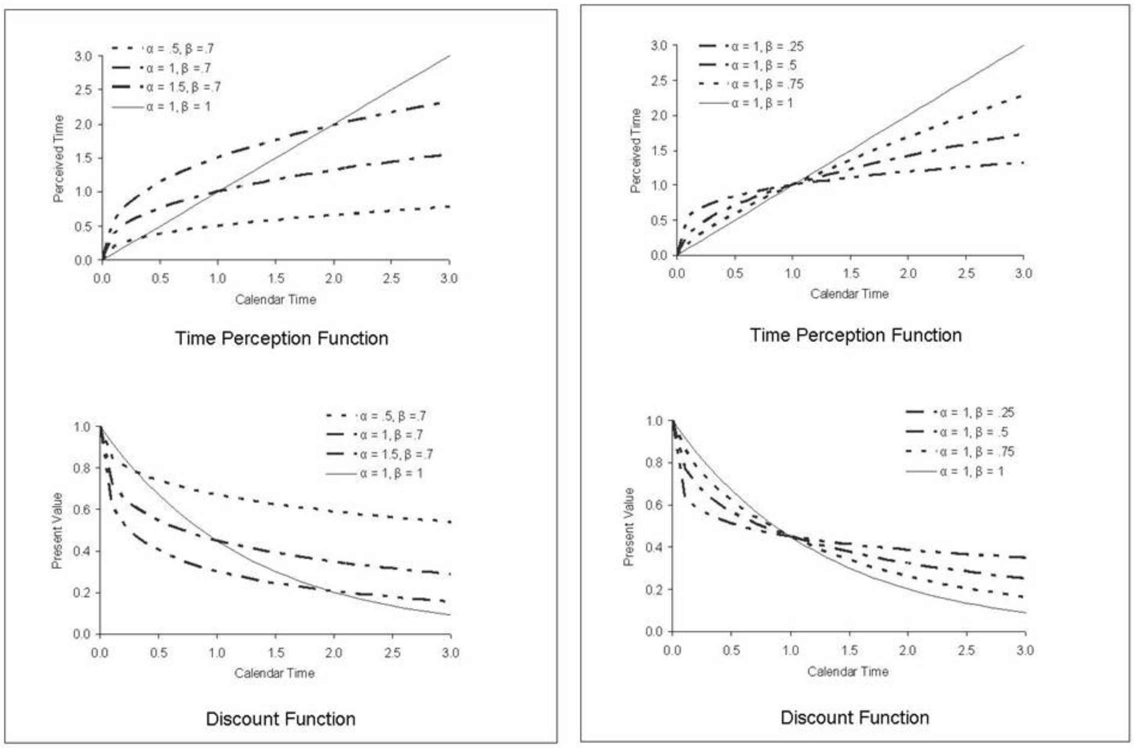
[4] Instantaneous discount rate over calendar time can be defined as $-\dfrac{D(t)'}{D(t)}$ (Laibson, 1997). When $\alpha > 0$, $0 < \beta < 1$, and $R > 0$, it is a decreasing function of t (e.g., $\alpha \cdot \beta \cdot R \cdot t^{\beta-1}$), indicating hyperbolic discounting.

debate between Mellers (1983) and Zwislocki (1983)). Despite this disagreement, I incorporated the *α* parameter into the discount function for the following reasons.

First, just as decreasing *β* parameter values contribute to greater deviations from exponential discounting, increasing *α* parameter values while holding the *β* parameter constant at less than 1 also induces a greater degree of hyperbolic discounting (e.g., a greater difference between discount rates measured at different times)[5]. Thus, trying to understand the *α* parameter's role is important. Figure 1 illustrates how changes in the *α* or *β* parameters uniquely induce a greater degree of hyperbolic discounting. The top graphs in Figure 1 (A) and (B), each depicts time perception functions at different values of *α*, holding *β* constant, and at different values of *β*, holding *α* constant (the solid line represents objective time perception). The bottom graphs show discount functions corresponding to the time perception functions (i.e., equation (4)), in which the perceived-time based discount rate, *R,* is set to be .8. As illustrated, either an increase in *α* or a decrease in *β* induces a greater degree of hyperbolic discounting, but in different ways. Consistent with prior research (Ebert & Prelec, 2007; Killeen, 2009; Kim & Zauberman, 2009; Zauberman et al., 2009), as *β* decreases, individuals become more impatient for delays happening earlier, and more patient for delays happening later. On the other hand, in this model, an increase in *α* also induces a greater degree of hyperbolic discounting over the entire time range by magnifying the difference between discount rates measured at different points in time.

[5] The difference in instantaneous discount rates measured at different point in objective time (t and $t + n$), $\alpha \cdot \beta \cdot R \cdot (t^{\beta-1} - (t+n)^{\beta-1})$, which indicates the degree of hyperbolic discounting, is an increasing function of α when $0 < \beta < 1$ and $R > 0$.

FIGURE 1. TIME PERCEPTION FUNCTIONS AND CORRESPONDING DISCOUNTING FUNCTIONS



(A) (B)

Figure 1 (A) depicts time perception functions and corresponding discounting functions at different values of the *α* parameter when *β* is fixed as.7. Figure 1 (B) Time perception functions and corresponding discounting functions at different values of the *β* parameter when *α* is fixed as 1. In both figures, the solid line indicates a hypothetical type perception and discount functions of when both parameter values are 1. (Kim & Zauberman, 2009).

Second, incorporating the *α* parameter provides a way to examine the different processes through which changes in time perception affect the degree of hyperbolic discounting. As illustrated in Figure 1, some manipulations could induce a greater degree of hyperbolic discounting not by influencing diminishing sensitivity to time (the *β* parameter) but rather by changing the degree of overall time contraction (the *α* parameter). For instance, previous research has demonstrated that male participants who rated attractive females revealed a greater degree of hyperbolic discounting in a delay discounting task of monetary outcomes compared to those who rated non-attractive females (Wilson & Daly, 2003). To test whether this effect is caused by changes in time perception due to the exposure to arousing images, Kim and Zauberman (2010a) had male heterosexual participants indicate their subjective perception of time horizons immediately after rating either photographs of Victoria's Secret models or photographs of landscapes. This research showed that changes in time perception mediated the impact of arousing images on hyperbolic discounting. More importantly, changes in time perception manifested themselves not as changes in diminishing sensitivity (β) but as overall changes in the level of time contraction (α). In particular, an increase in sexual arousal led participants to perceive all future durations as longer. Using a single non-linear scaling parameter to reflect time perception would not allow researchers to uniquely capture this process in time perception.

MEASUREMENT

To empirically test the proposed perceived-time-based model of temporal discounting, it is critical to measure individuals' subjective time estimates precisely and accurately. In Psychophysics, researchers have applied various cross-modality matching techniques, in which participants are asked to match the perceived magnitude of target stimuli with the perceived magnitude of the scale they are using to generate their responses (Stevens, 1995; Gescheider, 1985). This method, which was first developed by Stevens (1959), can be used to test the diminishing sensitivity to time horizons ($T = \alpha \cdot t^{\beta}$)

without requiring participants to make numerical estimation. For instance, researchers can validate whether participants' perception of loudness is non-linearly scaled by asking them to indicate the perceived magnitude of loudness with the perceived magnitude of vibration on their fingers. If participants' perception of a target stimulus (e.g., loudness) and the response stimulus (e.g., vibration) are both non-linearly scaled, the joint plot of the two perception modalities will be a linear function. If only their perception of a target stimulus is non-linearly scaled and that for the response stimulus is linear, then the joint plot will reveal a non-linear function. That is, when a stimulus that is shown to be scaled linearly is used as a response scale, then non-linear scaling that may exist in individuals' perception of a target stimulus can be plotted as it is without further functional transformation rooted in their response behavior. Among various stimuli that Stevens examined, human perception of line length was shown to be linearly scaled (Stevens, 1975). Therefore, when the perception of line length is used as participants' response scale, non-linear perception of a target stimulus can be captured without further functional transformation.

In my dissertation work, I implement a cross-modality matching technique to capture participants' diminishing sensitivity to time horizons using a variant of cross-matching between time perception and line length perception. Specifically, I use two types of line scales: 1) a fixed-length continuous line scale, and 2) a physically unbounded line scale. In the following section, I provide empirical results comparing the participants' responses using these line-perception-based scales in a time perception task along with other non line-perception-based scales such as a brightness-perception-based scale and numerical estimation (Kim and Zauberman, 2010b).

Non-numerical and numerical estimation of time perception. To compare the performance of various scales that can be used to measure the perceived magnitude of future time, I asked a group of undergraduate participants to estimate various lengths of anticipatory time horizons ranging from 1 month to 60 months presented in a random order for each participant (Kim and Zauberman, 2010b). They estimated these time horizons using five different magnitude estimation scales. Two of the scales were line-perception-based: one is a 150*mm* fixed-length line scale, and the other is a physically-unbounded line scale. A second class of scales required participants to match the perceived magnitude of surface brightness to the perceived magnitude of a target stimulus. The remaining two scales were numerical estimation scales: one involved directly assigning numbers to indicate the perceived magnitude of a target stimulus (e.g., one-month duration in the future), and the other involved indirectly assigning numbers by rotating a knob. In addition to examining these three different classes of scales, I compare whether having a modulus (i.e., assigning perception magnitude value to a given stimulus and using this value as a reference point) influences participants' responses in using these five different scales.

Fixed-length line scale. Zauberman et al. (2009) used a fixed-length line scale to measure anticipatory time perception. They provided participants a 180*mm* line with end-points labeled as '*Very Short*' on the left end and '*Very Long*' on the right end and asked them to mark the perceived magnitude of duration on the line. While there was a label at each end of this line scale as is the case for Likert-type scales, the wording of the labels wasshown not to influence participants' responses. For instance, participants showed similar response patterns regardless of the labels (e.g., '*Very Short – Very Long*', '*Instant – Distant'*, '*Near – Far*', '*Now – Forever'*, and *'Now – Eternity'*) and regardless of whether there were labels or not (see Zauberman et al. 2009). To further validate the use of this bounded scale, I asked participants to estimate various lengths of anticipatory durations ranging from 1 month to 60 months, and examined whether this scale is sensitive enough to reveal diminishing sensitivity to time, and whether using a modulus influences participants' responses (e.g., assign one-month duration to be 1/60 of the entire length of the line scale). As shown inFigure 2, this scale generated non-linear responses for future time horizons. In addition, there was no difference in responses with or without a modulus.

Physically-unbounded line scale. The second variant of the line-perception type scale is the physically unbounded scale. Although a fixed-length line scale reveals diminishing sensitivity to time horizons, there exists a limitation in using this line scale as a time perception measure: because the scale range is physically bounded, there may be a ceiling effect when participants' perceived magnitude of future time goes beyond the physical boundary of the line scale. To address this concern, Kim and Zauberman (2009) came up with a physically unbounded line scale, which is an application of the embroidery floss used in Psychophysics (e.g., participants are asked to cut the length of embroidery floss to indicate the perceived magnitude of stimuli they are estimating; Epstein & Florentine, 2006). At the beginning of each time perception task, this scale is presented as a small black, square shaped bar. When participants indicate their perceived magnitude of a given stimuli, they pull this square bar, which can be extended infinitely(when the length of the bar exceeded the physical boundary of the screen, the screen generated a scroll bar at the bottom of the screen to allow participants to look over the entire length of their response). Figure 2 shows participants' estimation of time horizons ranging from 1 to 60 months using this physically-unbounded scale. Just like the fixed-length line scale, this scale revealed diminishing sensitivity to longer time horizons but the exponent of a power function was greater than that drawn by using the fixed-length line scale. Similar to the fixed-line scale, there was no difference depending on the presence of a modulus (e.g., assign a one-month duration to be a certain length of the line scale).

Surface-brightness scale. This scale involves matching participants' perceived magnitude of future time horizons to their perceived magnitude of brightness of a given surface area. To develop this scale, I allowed the color of a squared-surface to vary gradually from white to black with 256 degrees of hexadecimal. Use of this surface-brightness scale revealed very similar results to line perception type scales. Participants' responses were non-linearly scaled against future time horizons, and there was no effect of having a modulus (e.g., assigning a one-month duration to be 1/60 of the change from white to black). This scale, however, requires further validation because I did not measure participants' perception of this 256 hexadecimal itself. Previous research showed that human perception of brightness is non-linearly scaled when it is a point source, and linearly-scaled when it is flashed briefly. If participants scale this surface-brightness scale non-linearly, and they perceive future time non-linearly, they should reveal a linear function in the joint plot of the magnitude estimates from the two modalities. Therefore, the non-linear scale shown in Figure 2 is a valid description of time perception only after confirming that participants perceive the brightness scale in a linear fashion.

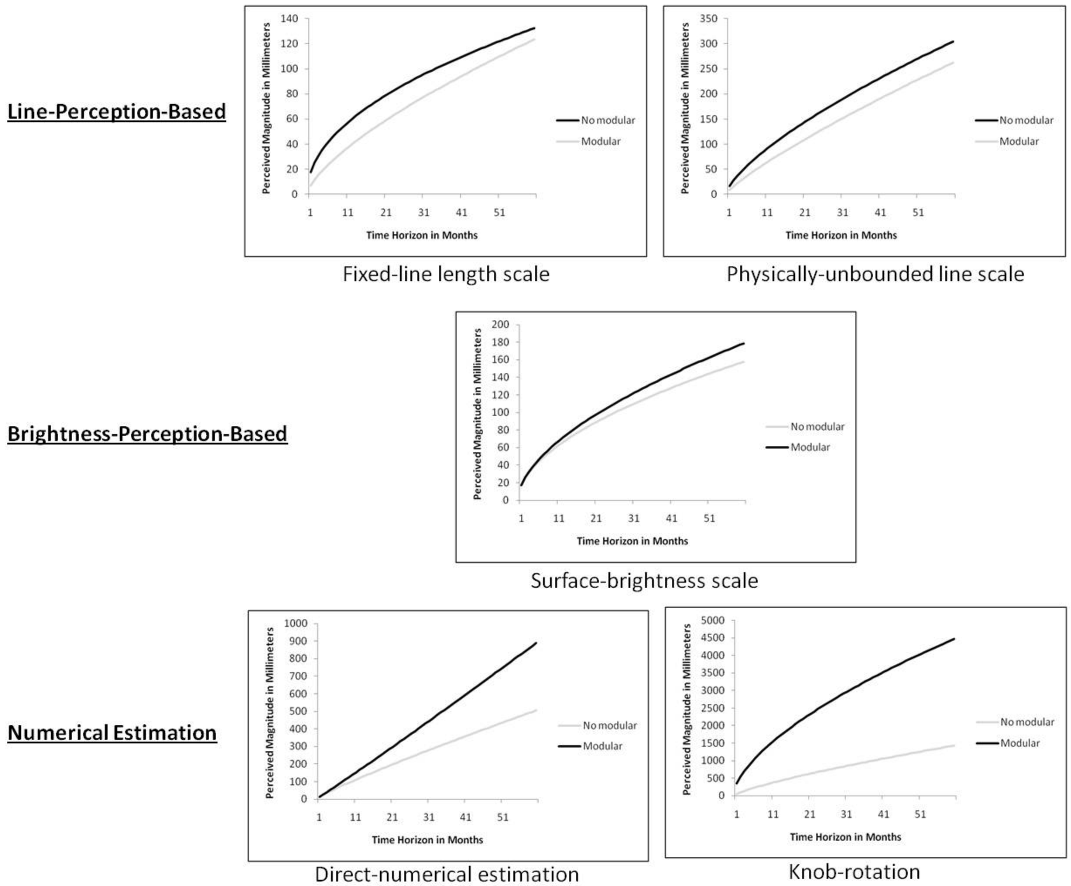
Direct-numerical estimation. The last type of scale is direct numerical estimation, in which participants assign a number to indicate their perceived magnitude of a given future time horizon. Because human perception of numbers is shown to be non-linearly scaled (i.e., people show diminishing sensitivity to larger numbers; Rule & Curtis, 1982), the joint plot of responses using this scale and the perceived magnitude of future time horizons should be linearly scaled. Results shown in Figure 2 confirm that this is the case. Participants did not show diminishing sensitivity to future time horizons by using the direct-numerical estimation method. In addition, the presence of a modulus did not affect participants' responses (e.g., assign a one-month duration to be the number 10).

Numerical estimation using a knob. Psychophysics researchers sometimes ask participants to turn a knob to provide a numerical estimate of the perceived magnitude of a target stimulus (Warren & Warren, 1958). Because rotating a knob does not involve perceiving additional stimuli beyond the target and response stimuli, participants' responses should theoretically be similar whether or not they use a knob to provide their numerical estimates. If participants must turn the knob multiple times (as might be the case when participants perceive the stimulus magnitude to be very large), however, a functional transformation in participants' responses may emerge not because of participants'perception of the stimulus, but simply because turning the knob is cumbersome and perhaps not as easy as providing a response on some other type of scale.

In using this knob-rotating scale, participants were instructed to rotate a virtual knob shown on a computer screen clockwise to increase or decrease numbers shown on the screen. Numbers displayed were multiples of 360 degrees. That is, if participants rotated a knob two times, a number, 720, appeared on the computer screen. Using this scale, I obtained similar results with and without a modulus (e.g., assign a one-month duration to be 1 rotation of a knob). For the functional form of the responses, however, this scale revealed non-linear scaling (see Figure 2). This result may imply that when scale usage involves physical activity, functional transformation in the psychophysical function can result from the ease of generating responses rather than from perception itself.

To summarize, I compared various types of scales that can be used to measure anticipatory time horizons. Among these scales, line-perception type scales capture diminishing sensitivity to future time and are not influence by the presence of a modulus. In a subsequent test of my perceived-time-based model of temporal discounting, I implement these line-perception based scales to measure participants' subjective perception of future time horizons.

FIGURE 2. PERCEPTION OF TIME HORIZONS USING VARIOUS MAGNITUDE ESTIMATION SCALES



EMPIRICAL EVIDENCE

The proposed perceived-time-based model makes specific predictions regarding the role of time perception in temporal discounting. First, it predicts that people perceive time non-linearly and the non-linear time perception is responsible for hyperbolic discounting. Second, it predicts that many other intertemporal preference-related phenomena other than hyperbolic discounting can also be attributed to the changes in the subjective time perception. The second prediction has not been examined in the literature, and, hence, is the key prediction I examine throughout four empirical essays I present in my dissertation. The first prediction, however, has been rigorously demonstrated both theoretically and empirically in a recent body of research (e.g., Ebert & Prelec, 2007; Killeen, 2009; Kim & Zauberman, 2009; Read, 2001; Takahashi 2005; Zauberman et al., 2009). In this section, I introduce one empirical study utilizing the physically-unbounded time perception scale to confirm this prediction.

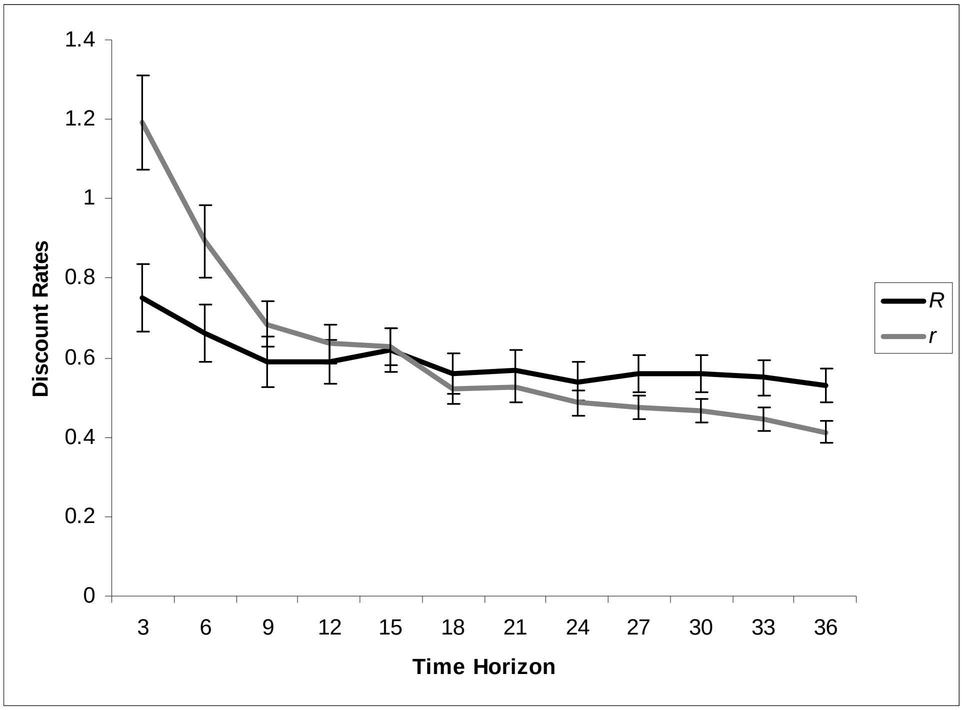
To examine diminishing sensitivity to future time, Kim and Zauberman (2009) utilized a physically-unbounded scale and asked participants to indicate the perceived magnitude of future durations ranging from 3 months to 36 months. They examined diminishing sensitivity by fitting a non-linear function $T = \alpha t^{\beta}$ and a linear function $T = \gamma + \delta t$, using maximum likelihood estimation, and found that a non-linear function $T = 1.05t^{.72}$ fit the data better than a linear function $T = 2.43 + .37t$ (*BIC* = 3062.8 versus 3128.8), confirming the diminishing sensitivity to longer time horizons.

In a subsequent study (Kim and Zauberman, 2009), participants' intertemporal preferences were elicited to indicate the amount of a $75 gift certificate delayed by the same durations (from 3 month to 36 months). They calculated the perceived-time based discount rate, *R* (i.e., a discount rate calculated based on the subjective unit time), by estimating time perception parameter values for each participant and controlling its impact on their intertemporal preferences. Specifically, they calculated each participant' idiosyncratic perceived-time based discount rate, *R*, using the perceived-time-based discount function ($D(t) = e^{-R \cdot \alpha \cdot t^{\beta}}$) in the following way:

$$R_i(t) = \ln\left(\frac{FV_i}{\$75}\right) \Big/ \alpha_i \cdot t^{\beta_i}$$

In the above equation, FV_i is the response in the intertemporal preference task for the i^{th} participant, and each participant' α and β parameters are estimated from their subjective time estimates. If the resulting perceived-time-based discount rate, R, is decreasing as function of time horizon, it indicates that internal discounting process is hyperbolic rather than exponential. They compared these internal discount rates with the calendar-time based discount rate (e.g., annual compound discount rate), $r_i(t) = ln(FV_i/\$75)/t$, ignoring the role of subjective time perception. From this comparison, they found that the pattern of discount rates differed as a function of whether discount rates were computed with respect to calendar or perceived time (see Figure 3). Specifically, in perceived-time-based discounting, decreasing discount rates were observed only 2 out of 11 pairs of comparisons (e.g., t_6 versus t_9; t_5 versus t_6). For the calendar-time based discount rates, however, the decrease in discount rates was significant for 6 out of 11 pairs of time horizons (e.g., t_3 versus t_6; t_6 versus t_9; t_{15} versus t_{18}; t_{21} versus t_{24}; t_{30} versus t_{33}; t_{33} versus t_{36}). These results indicate that, across participants, non-constant discounting (i.e., hyperbolic discounting) was more pronounced in observed behavior (i.e., calendar-time based discount rate) compared to their internal discounting process (i.e., perceived-time based discount rate), confirming the role of subjective time perception in hyperbolic discounting.

FIGURE 3. MEAN ANNUAL COMPOUND DISCOUNT RATES CALCULATED SEPARATELY FOR OBJECTIVE AND SUBJECTIVE TIME



R is a perceived-time based discount rate and *r* is a calendar-time based discount rate. Error bars indicate standard error of the mean (Kim & Zauberman, 2009).

OVERVIEW OF ESSAYS

In the following four essays, I provide empirical evidence examining the second prediction drawn from the perceived-time-based model of temporal discounting: the role of subjective time perception in various intertemporal choice phenomena. In the first essay *("Can Victoria's Secret Change the Future? Sexually Arousing Images, Anticipatory Time Perception, and Impatience")*, I demonstrate that sexually arousing images induce a greater degree of temporal discounting by shifting the psychophysical function of anticipatory time perception upward (i.e., prospective durations are perceived to be longer). Previous research showed that exposure to sexually arousing images leads male heterosexual participants to steeply discount delayed monetary rewards (Van den Bergh, Dewitte, & Warlop., 2008; Wilson & Daly, 2003), and this effect has been commonly attributed to the activation of a general reward circuitry. That is, sexually arousing images induce stronger appetitive responses towards all immediately available rewards, thus enhancing the perceived "value" of immediate versus future monetary rewards. In contrast, based on the perceived-time-based account of temporal discounting, I propose that sexually arousing images induce impatience by influencing the perceived temporal "*distance*" to the delayed rewards. That is, such images make people perceive prospective durations as longer, resulting in a greater degree of impatience due to a perceived longer waiting time for the delayed reward.

In the second essay (*"Feel More Distant to Your Retirement When You Retire to a Distant City? Space-time Interdependence, Time Perception, and Impatience"*), I examine the implications of the perceived-time-based account of temporal discounting for the retirement savings decision. While research on retirement savings views duration to retirement as objective information, I consider the possibility that individuals perceive the same duration subjectively differently and explore a factor influencing individuals' subjective perception of duration to their retirement: that is, spatial distance to a retirement city. Specifically, I demonstrate that the distance to the city where participants will retire or the distance on a hypothetical map influences their subjective estimates of prospective durations, which in turn influence the degree of impatience in intertemporal decisions by implicating different waiting times until the receipt of delayed rewards.

The third essay (*"Spend 2-Da-Beat: The Impact of Auditory Tempo on Impatient Decisions"*) examines whether auditory tempo such as pulse sounds or beats in music influence anticipatory time perception (e.g., estimates of prospective duration in the future), and subsequent time-related judgments. By manipulating the tempo of a pulse or the tempo of a given piece of music, I demonstrate that auditory tempo affects anticipatory time perception and impatience in intertemporal decisions.

Finally, in the fourth essay *(“When Brain Science Makes People Impatient: Perceived Life Span, Time Perception, and Intertemporal Preference”*), I demonstrate that manipulating participants’ perceived life span by showing them brain research findings leads them to be more impatient in intertemporal decisions, and I show that this heightened impatience occurs due to changes in participants’ perceptions of time. This result not only provides addition support for the perceived-time-based account of temporal discounting, it extends the inverse relationship between scarcity of objects and the valuation of those objects to the domain of time perception.

II. ESSAY I

CAN VICTORIA'S SECRET CHANGE THE FUTURE?

SEXUALLY AROUSING IMAGES, ANTICIPATORY TIME PERCEPTION, AND IMPATIENCE

ABSTRACT

Sexually arousing images have been shown to induce steep discounting of future monetary rewards (i.e., impatience). Previous research has commonly attributed this effect to the activation of a general reward circuitry. That is, sexually arousing images induce stronger appetitive responses generally towards all immediately available rewards, thus enhancing the perceived "value" of immediate versus future monetary rewards. In contrast, I propose an alternative underlying psychological mechanism to explain the effect: sexually arousing images induce impatience by influencing the perceived temporal "*distance*" to the delayed rewards. That is, such images shift the psychophysical function of anticipatory time perception upward (i.e., prospective durations are perceived to be longer), resulting in a greater degree of impatience due to perceived prolonged waiting time for the delayed reward.

CAN VICTORIA'S SECRET CHANGE THE FUTURE?
SEXUALLY AROUSING IMAGES, ANTICIPATORY TIME PERCEPTION, AND IMPATIENCE

Sexually arousing stimuli have been shown to impact not only sex-related behavior (Ariely & Loewenstein, 2006; Blanton & Gerrard, 1997; Nordgren, van der Pligt, & van Harreveld, 2007), but also seemingly irrelevant behaviors, such as impatience for monetary rewards (Van den Bergh, Dewitte, & Warlop., 2008; Wilson & Daly, 2003). Researchers have commonly attributed such effects to the presence of a general neural reward system (Aharon et al., 2001) that is activated by a diverse set of rewarding stimuli, including both sexually arousing images and money. The general reward circuitry view explains impatience for delayed monetary rewards (or steep discounting) in the presence of sexually arousing images by positing that these images enhance the perceived "value" of immediate rewards (i.e., arousal induces stronger appetitive responses toward immediately available rewards). In this research, I propose an alternative, but not incompatible, view of the underlying psychological mechanism, which is centered on shifts in the perception of anticipated time. Specifically, I argue that sexually arousing images induce steeper discounting of monetary rewards by influencing the perceived *distance* to the delayed rewards. That is, sexually arousing images lead prospective durations to be perceived as longer, resulting in a greater degree of impatience by implicating a prolonged waiting time until their receipt.

Research on time perception of elapsed time has shown that durations over which affective images are presented are experienced as longer than equivalent durations over which neutral images are displayed (Droit-Volet, Brunot, & Niedenthal, 2004; Thayer & Schiff, 1975; Watts & Sharrock, 1984). When participants were visually presented with human faces for different durations (from 400ms to 1600ms), the proportion of participants categorizing these durations as long (vs. short) was higher for emotional faces than for neutral ones (Droit-Volet, Brunot, & Niedenthal, 2004). Demonstrating the impact of arousal on time perception more directly, administering dopaminergic agents was shown to influence time perception in both humans and non-humans (Chiang et al., 2000; Maricq, Roberts, & Church, 1981; Matell, King, & Meck, 2004). These results, however, may not be directly applicable to our hypothesis because they involve the perception of *experienced time* (i.e., time that has actually passed), whereas our interest is in *anticipated time* (i.e., future time that has not yet passed). That is, while the impact of physiological arousal and dopamine on time perception has been demonstrated for the perception of elapsed duration, intertemporal choice decisions concern prospective future durations. Therefore, in Experiment 1, I examined whether sexually arousing images would induce a shift in the psychophysical function of anticipatory time perception (i.e., future durations are perceived to be longer).

If sexually arousing images do indeed influence anticipatory time perception, it then follows that their affect on impatience can be directly predicted. As long as people incorporate perceived durations into their intertemporal decisions, as has been recently documented (Ebert & Prelec, 2007; Zauberman, Kim, Malkoc, & Bettman, 2009; Wittmann & Paulus, 2007), then subjectively expanded durations (due to the effect of sexually arousing images) will result in a greater degree of impatience for delayed rewards (i.e., greater temporal discounting), since prolonged durations imply greater delays until the receipt of rewards. Thus, in Experiment 2, I tested whether changes in anticipatory time perception can account for the effects of sexually arousing images on impatience for monetary rewards.

Experiment 1

Experiment 1 tested whether sexually arousing images would induce a shift in the psychophysical function of anticipatory duration perception. Specifically, I tested our prediction that perceived prospective durations would expand (i.e., be perceived longer) when participants are exposed to sexually arousing images.

Method

Fifty-nine self-reported heterosexual male undergraduate students at the University of Pennsylvania participated in this computerized experiment as part of a one-hour long laboratory session in exchange for $10. Participants were randomly assigned to either the hot or the neutral condition.

The experimental procedure consisted of what was presented as two separate studies: "Photo Evaluation Study" and "Time Estimation Study". In the photo evaluation study, participants in the hot condition were sequentially presented with 15 photographs of female models wearing lingerie, taken from the Victoria's Secret online catalogue (http://www.victoriassecret.com). For each photograph, participants were asked to imagine that they were on a date with the woman shown in the picture and indicate how attractive she was on an 11-point scale (1: Not attractive at all, 11: Very attractive). Participants in the neutral image condition were presented with 15 photographs of landscapes and asked to evaluate the attractiveness of each landscape photo on the same 11-point scale.

Next, in the time estimation study all participants were informed that they would be estimating 12 anticipatory durations, ranging from 1 month to 23 months and increasing in 2-month increments. For each of the 12 time horizons, which were presented in random order for each participant, participants indicated the magnitude of the perceived duration by adjusting the length of a physically-unbounded vertical line using the left or right arrow keys on the computer keyboard. At the beginning of each trial, a black squared bar (measuring 40 by 40 pixels) was shown on the left side of the computer screen. When the arrow keys were pressed, the bar extended or shortened its length accordingly. When the length of the bar exceeded the physical boundary of the screen, the screen generated a scroll bar at the bottom of the screen to allow participants to look over the entire length of their response; thus, the theoretical boundary of the scale was infinite.[6]

Results

The physical length of the line scale was normalized into month units by setting the overall mean distance for the 1-month duration as the baseline unit for the subjective estimates made by each participant (1-month M = 32.71mm). In other words, participants' responses in millimeters for the remaining 11 time durations were divided by 32.71mm (see Table 1 for raw data).[7]

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[6] This scale is a modification of Epstein & Florentine (2006) use of real embroidery floss.
[7] This linear transformation did not influence any of the statistical analyses or results.

TABLE 1. PARTICIPANTS' TIME ESTIMATES IN MONTHS (AND IN MILLIMETERS) AS A FUNCTION OF THE HOT AND NEUTRAL CONDITIONS

Duration	Hot condition	Neutral condition
	Time estimate in months (in millimeters)	
1 month	1.13 months ± .76 (37.04mm ± 24.75)	.88 months ± .43 (28.80mm ± 14.08)
3 months	2.39 months ± 1.67 (78.09mm ± 54.66)	1.89 months ± 1.44 (61.93mm ± 47.25)
5 months	3.35 months ± 1.76 (109.68mm ± 57.42)	2.30 months ± 1.25 (75.16mm ± 40.96)
7 months	3.91 months ± 2.05 (127.80mm ± 66.98)	2.89 months ± 1.70 (94.51mm ± 55.56)
9 months	4.61 months ± 2.65 (150.64mm ± 86.62)	3.49 months ± 1.97 (114.30mm ± 64.44)
11 months	5.77 months ± 3.09 (188.80mm ± 101.00)	4.05 months ± 2.31 (132.51mm ± 75.72)
13 months	6.06 months ± 3.66 (198.34mm ± 119.63)	4.51 months ± 2.59 (147.62mm ± 84.80)
15 months	6.46 months ± 3.12 (211.31mm ± 103.27)	4.99 months ± 2.59 (163.27mm ± 84.75)
17 months	7.32 months ± 4.19 (239.74mm ± 136.95)	5.35 months ± 2.87 (175.02mm ± 94.01)
19 months	7.92 months ± 4.19 (259.09mm ± 137.12)	5.85 months ± 2.91 (191.22mm ± 95.28)
21 months	8.85 months ± 5.40 (289.32mm ± 176.69)	6.43 months ± 3.46 (210.35mm ± 113.11)
23 months	8.90 months ± 4.17 (291.08mm ± 136.37)	7.32 months ± 3.67 (239.37mm ± 119.62)

Next, these time estimates in months were fitted with linear and non-linear (Stevens' Power Law) time functions, using a maximum likelihood estimation procedure:

$$T_{ik} = \gamma_i + \delta_i \cdot t_{ik} + \varepsilon_{ik}$$

$$T_{ik} = e^{\ln(\alpha_i) + \beta_i \cdot \ln(t_{ik})} + \varepsilon_{ik}$$

In the above equations, T_{ik} represents the subjective duration estimate for the corresponding physical duration, t_{ik}, made by the i^{th} participant for the k^{th} duration. Both the α and β parameters were allowed to randomly vary among participants in the estimation process. The non-linear function fits the data better than a linear function for both hot (non-linear vs. linear; *BIC* = 1014.7 vs. 1055.6) and neutral conditions (*BIC* = 1049.6 vs. 1096.5).[8]

The resulting estimated non-linear functions are displayed below (see Figure 4):

Hot condition: $T = 1.0 \cdot t^{.68}$

Neutral condition: $T = .61 \cdot t^{.73}$

Demonstrating diminishing sensitivity in time perception (e.g., Stevens' Power Law), I observe that $\beta < 1$ for both conditions. As the critical test of our predictions, the differences in the values of the α and β parameters between the two conditions were tested. Consistent with our predictions, the α-parameter values were significantly greater in the hot condition than in the neutral condition, $t(57) = 2.18$, $p = .03$, $p_{rep} = .90$, $d = .58$, while the β-parameters were not different between conditions, $t(57) = -.87$, *ns*. These results indicate that participants who were exposed to the sexually arousing images perceived the same anticipatory durations to be longer compared to those in the neutral condition. However, participants in the two conditions did not differ in their degree of diminishing sensitivity to anticipatory durations.

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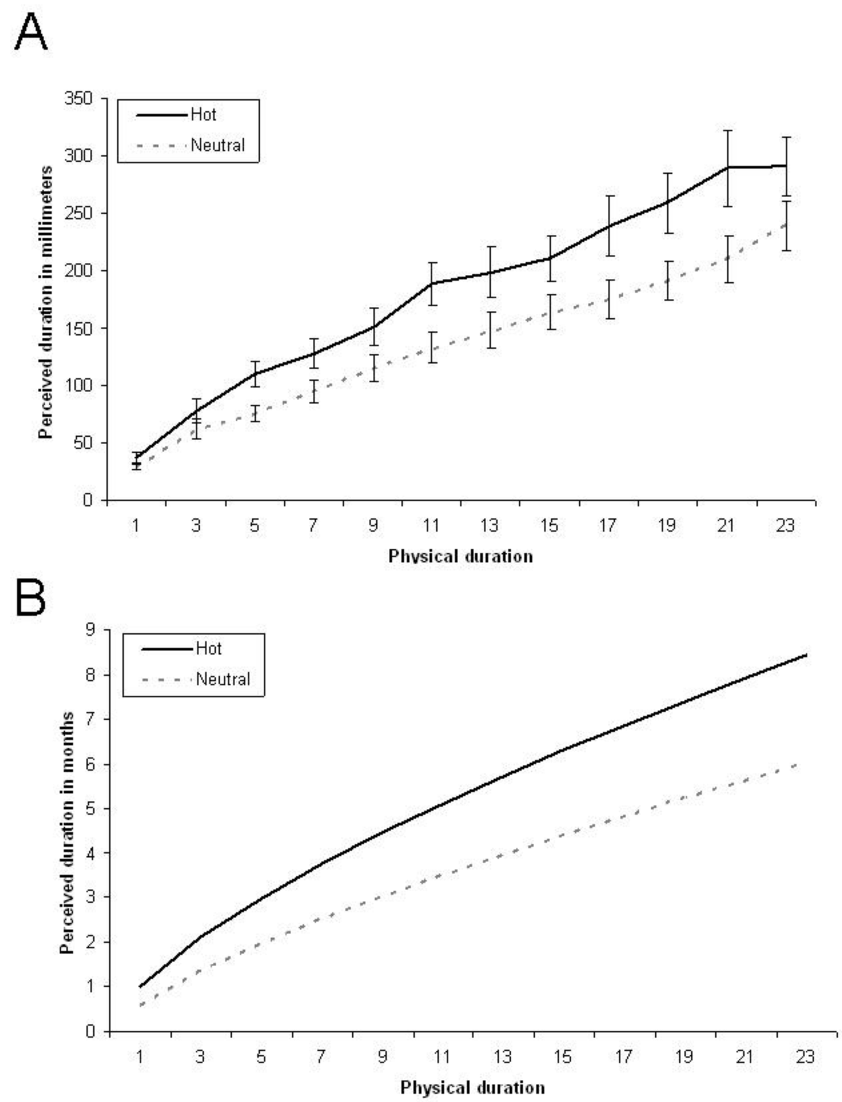
[8] For the Bayesian information criterion (BIC), a difference greater than 10 indicates *very strong* evidence that one model fits better than the other (Raftery, 1995).

FIGURE 4. TIME PERCEPTION AND DISCOUNT FUNCTION AS A FUNCTION OF THE HOT AND NEUTRAL CONDITIONS



(A) Raw time estimates in millimeters for 12 physical durations (error bars represent standard error of means) and (B) estimated psychophysical functions as a function of experimental conditions (hot vs. neutral) in Experiment 1.

Experiment 2

In Experiment 2, I extended our results by examining the implications of the impact of sexually arousing images on expanded time perception for impatience for monetary outcomes. I do this by extending the paradigm I used in Experiment 1 to include, in addition to the photo evaluation task (to manipulate sexual arousal) and the time perception task, a third task designed to capture impatience for monetary outcomes.

Method

One hundred and sixteen self-reported heterosexual male undergraduates at University of Pennsylvania participated in this experiment as part of a one-hour long laboratory session in exchange for $10.

The experiment consisted of three parts, presented as separate studies: "Photo Evaluation Study", "Time Estimation Study", and "Gift Certificate Study". The procedure and materials utilized in the photo evaluation study were similar to those used in Experiment 1. In the time estimation study, all participants were informed that they would be estimating two anticipatory durations (3 months and 12 months)[9]. Similar to Experiment 1, participants indicated the magnitude of the perceived duration by adjusting the length of an unbounded line. Finally, in the gift certificate study, participants' impatience levels were elicited, using a standard time discounting elicitation method (e.g., Thaler, 1981) and computation procedure (Mazur, 1994; see details below). Participants were asked to imagine receiving a $65 gift certificate valid today and redeemable at any

[9] Unlike in Experiment 1, we use only two time horizons in this study, because two time horizons allow us to examine relative time perception and relative impatience (e.g., Zauberman et al., 2009), while keeping the experiment short enough for the effect of the photo evaluation tasks to still carry over to the third part of the study.

department at Amazon (www.amazon.com) and to indicate the dollar gift certificate amount they would require instead if they had to wait for 3 months to receive it. This task was repeated for the 12-month duration.

Results

Anticipatory Time Perception. As in Experiment 1, the physical length of the line scale was normalized into month units by setting the mean distance for the 3-month duration as the basic unit for the subjective estimates made by each participant (3-Month M = 117.44mm). Replicating the prolonged time perception demonstrated in Experiment 1, a repeated measures ANOVA with anticipatory duration (3 vs. 12 months) as a within-subjects factor and the experimental manipulation (sexually arousing vs. neutral images) as a between-subjects factor revealed a significant main effect of the manipulation on subjective time estimates, $F(1,114) = 7.14$, $p < .01$, $p_{\text{rep}} = .96$, $\eta_p^2 = .06$, indicating that those participants in the hot condition perceived the anticipatory durations to be longer than those in the neutral conditions (see table 2). The manipulation by anticipatory duration interaction, which tests the difference in the diminishing sensitivity to future time, was again not significant ($F(1,114) = 1.77$, *ns*).

Impatience for Monetary Rewards. Next, participants' degree of impatience was calculated based on the following hyperbolic function (Mazur, 1994):

$$PV = FV \cdot \frac{1}{(1 + kt)}$$

In this equation, PV is the present value of the gift certificate, which was fixed at \$65 in our task. FV is the participants' response for the future value of the gift certificate when it is delayed by t (3 and 12 months). For each participant, the *impatience* *parameter*, *k*, was calculated for 3 month and 12 months delay separately, and these values were then averaged to reflect participants' idiosyncratic degree of impatience. That is, higher values of *k* indicate that an individual is more impatient, since they prefer to receive a smaller reward immediately rather than wait for a greater but delayed reward. Because *k* values are not normally distributed (Kolmogorov-Smirnov $Z = 1.79$, $p < .01$ in the hot condition; $Z = 1.49$, $p < .03$ in the neutral condition), a natural-logarithm transformation was applied.[10] Replicating previous research demonstrating the influence of sexual-arousal on impatience (e.g., Van den Bergh et al., 2008; Wilson & Daly, 2003), participants in the hot condition discounted delayed rewards more steeply ($k = 1.63$) than those in the neutral condition ($k = 1.04$), $t(114) = 2.02$, $p < .05$, $p_{rep} = .88$, $d = .38$.

The Mediating Role of Anticipatory Time Perception on Impatience. Finally, I directly tested whether participants' subjective time estimates mediated the impact of sexually arousing images on the degree of impatience. For this analysis, participants' time estimates for 3 and 12 months time horizons were weighted averaged to indicate their idiosyncratic time perception. Using the bootstrapping method (Preacher & Hayes 2004; Zhao, Lynch, & Chen 2010), I identified the indirect path from the arousal manipulation to the subjective time estimates (a = -9.10, $t = -2.83$, $p < .01$), the indirect path from the time estimates to impatience holding the manipulation constant (b = .01, $t = 1.98$, $p = .05$), and the direct effect from the manipulation to intertemporal preference after controlling the mediator (c = -.27, $t = -1.44$, $p > .15$). In addition, the 95% confidence interval from the sampling distribution of the indirect effect (a × b) did not include zero (-.21 to -.01), statistically confirming the mediating role of subjective time perception.

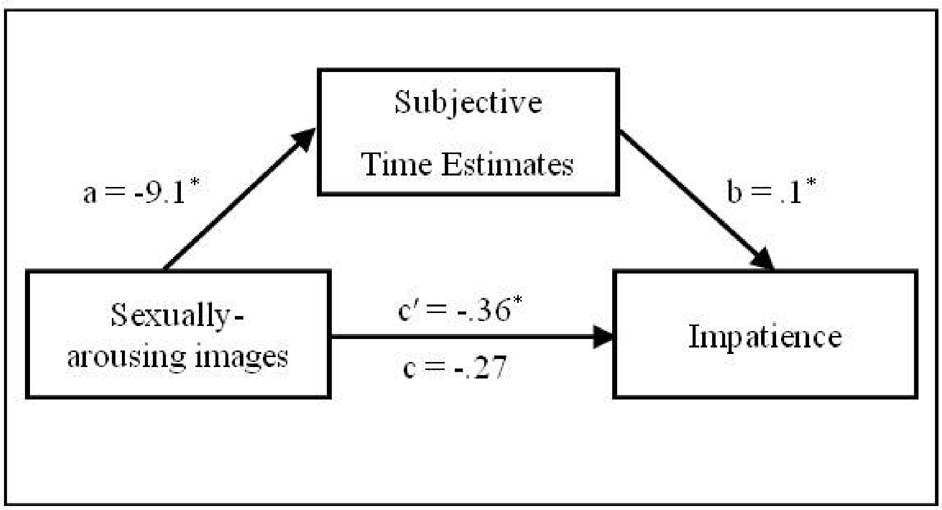
[10] Although *k* is commonly log transformed in the literature (e.g., Kirby, Petry, & Bickel, 1999), our results also hold without log transformation, $t(114) = 2.26$, $p = .026$, p_{rep} =. 92, $d = .42$.

TABLE 2. PARTICIPANTS' TIME ESTIMATES IN MONTHS (AND IN MILLIMETERS) AND IMPATIENCE PARAMETER, *K*, AS A FUNCTION OF THE HOT AND NEUTRAL CONDITIONS

Duration	Hot condition	Neutral condition	Hot condition	Neutral condition
	Time estimate in months (in millimeters)		Impatience parameter, *k* (raw responses in dollars)	
3 months	3.46 months ± 2.24 (135.27mm ± 87.60)	2.44 months ± 1.32 (95.49mm ± 51.68)	1.91 ± 2.37 ($96.05 ± 38.52)	1.08 ± .90 ($82.54 ± 14.60)
12 months	6.44 months ± 3.70 (252.04mm ± 144.65)	4.92 months ± 2.92 (192.67mm ± 114.43)	1.35 ± 1.48 ($152.88 ± 96.23)	1.00 ± 1.14 ($129.85 ± 74.02)

The data are means ± SD. Higher numbers of *k* indicate a greater degree of impatience based on a hyperbolic discount function.

FIGURE 5. MEDIATION OF SEXUALLY AROUSING IMAGE EFFECTS ON IMPATIENCE BY ANTICIPATORY TIME ESTIMATES



The unstandardized regression coefficient is shown above the arrow for the direct pathway. The coefficient below the arrow is for the direct pathway after statistically controlling for anticipatory time estimates. Statistical significance of the coefficients is indicated by * ($p \leq .05$).

General Discussion

In this paper, I propose and demonstrate that the effect of sexually arousing images on impatience for monetary outcomes can be explained in part by changes in time perception, rather than by changes in appetitive responses towards money alone. That is, sexually arousing (vs. neutral) images induce impatience not merely by changing the perceived "value" of immediate rewards, but also by influencing the perceived "distance" to the delayed rewards. Specifically, I show that sexually arousing images expand perceived anticipatory durations, which in turn results in a greater degree of impatience for delayed monetary rewards by implicating prolonged waiting time until the receipt of delayed rewards.

Our current research complements and extends the prevailing theoretical paradigm of general reward circuitry by further incorporating time perception processes into the study of intertemporal preferences. I used sexually arousing images to highlight that even a highly visceral stimulus, so far assumed to operate through changes in value, also has an independent effect on future preferences by changing the perception of anticipated time. Other effects that have been assumed to operate through changes in value, such as the concreteness effect of mental representations on intertemporal preference (Malkoc & Zauberman, 2006), might also operate by changing how people perceive time.

Our results also offer further intriguing implications for future behavioral and neuroimaging research. The proposed process (i.e., changes in time perception) is not restricted to specific types of rewards. Therefore, while the current report focuses on the influence of sexually arousing images on impatience for money, I predict similar effects of a variety of arousing stimuli (e.g., tempting foods) on a diverse set of time-related decisions (e.g., savings for retirement), as long as the stimuli induce enough arousal to alter the perception of anticipatory time. In addition, our results may stimulate new investigations among brain scientists who seek to identify brain regions commonly associated with both the processing of rewarding stimuli and time perception, which so far have been studied in separate research streams. I leave these questions for future research.

III. ESSAY II

FEEL MORE DISTANT TO YOUR RETIREMENT WHEN YOU RETIRE TO A DISTANT CITY? SPACE-TIME INTERDEPENDENCE, TIME PERCEPTION, AND IMPATIENCE

ABSTRACT

While research on under-saving for retirement views duration to retirement as objective information, I suggest that individuals perceive the same duration subjectively differently and explore a factor influencing individuals' subjective perception of duration to their retirement: that is, spatial distance to a retirement city. I present four studies showing the influence of spatial distance information on subjective duration estimates. The first two studies demonstrate the distance to the city where participants will retire or the distance on a hypothetical map influences their subjective estimates of prospective durations, which in turn results in changes in the degree of impatience in intertemporal decisions by implicating different waiting time until the receipt of delayed rewards. The next studies demonstrate that the observed spatial distance effect on time perception is not driven by a response bias, and explore the boundary condition of the effect.

FEEL MORE DISTANT TO YOUR RETIREMENT WHEN YOU RETIRE TO A DISTANT CITY? SPACE-TIME INTERDEPENDENCE, TIME PERCEPTION, AND IMPATIENCE

According to a survey to workers in United States, 68% of respondents reported they are saving too little compared to what they ideally should save. These self-reported responses are also confirmed to be accurate: among these people, 36% had only saving rates of 0 to 4% rates and another 36% had 5 to 8% for 401(k) plan while the average ideal saving rates was 14%. In addition, among those who think saving too little but intend to increase their saving in the next few months, only 14% did actually so (Choi et al. 2006).

Such under-saving problem for retirement has recently attracted many psychologists and behavioral economists to find its explanations and remedies (Ameriks, Caplin, & Leahy 2003; Duflo & Saez 2003; Iyengar, Huberman, & Jiang 2003; Laibson, Repetto, & Tobacman 2002; Madrian & Shea 2001; Thaler & Benartzi 2004). While these lines of research all view duration to retirement as objective information (i.e., for any 30-year-old workers who will retire at age 65, the duration to their retirement is 35 years), in this article, I consider the simple possibility that individuals may perceive the same duration subjectively differently (i.e., some 30-year-old workers may perceive their retirement is farther away than others), and propose a factor that influences individuals' subjective perception of duration and, subsequently, their preferences in intertemporal trade-off decisions (e.g., tendency to opt for smaller outcomes immediately vs. wait for larger but delayed outcomes). Specifically, by demonstrating the interdependence between spatial distance perception and time perception, I aim to show that individuals who plan to move to a city located far away for their retirement perceive the duration to their retirement to be subjectively longer, and reveal a greater degree of impatience in making intertemporal decisions because subjectively prolonged duration implicates extended waiting time until the receipt of delayed outcomes.

UNDER-SAVING AND TEMPORAL DISCOUNTING

In studies of intertemporal decisions - decisions requiring a tradeoff between smaller sooner and larger ‘delayed’ outcomes – individuals’ discount rates or a degree of *impatience* for delayed outcomes are often measured to describe one’s intertemporal preference. When one’s impatience is measured (especially for monetary outcomes) in a delay-discount task (e.g., preference between $100 today and $110 tomorrow), it is directly applicable to depict and explain retirement saving decisions, which is also intertemporal decisions requiring a trade-off between immediate spending and delayed but increased spending from saving (Laibson et al. 2002; Loewenstein & Prelec 1992; Thaler & Shefrin 1981). For instance, hyperbolic discounting, which is a tendency to heavily discount the value of delayed consumptions when delaying immediate consumptions compared to any other consumptions in the future, explains why people plan to increase saving rates but are not able to act on it (Laibson et al. 2002). When people plan ahead to contribute their income in the future for retirement, the benefits from saving looks desirable because delayed benefits are only little discounted, but when time passes and they have to contribute their income, the pain from giving up immediate consumptions looms much larger than it is used to look in a distance.

While intertemporal choice literature has been characterized by extensive efforts to measure individuals' discount rates and its functional forms (for a review, see Frederick et al. 2002), it has not focused as much on psychological underpinnings. In particular, this literature has largely neglected the role of anticipatory time perception (Ebert & Prelec 2007; Kim & Zauberman 2009; Zauberman et al. 2009). When individuals' subjective time perception is considered, one's impatience can be explained not by how much they internally discount the value of delayed outcomes, but more simply by how long or short they perceive the delay to be. For instance, if one perceives the same prospective duration to be longer than others, he or she would reveal more impatience for delayed consumptions because prolonged waiting time means extended waiting time until the receipt of delayed consumptions.

In this article, building on this approach to consider subjective time perception into the understanding of intertemporal preferences, I explore a factor that may influence individuals' impatience in intertemporal decisions by changing their subjective estimates of prospective durations. Especially when making intertemporal decisions for retirement, spatial information often accompanies (i.e., when thinking about retirement, people often envision moving to a different place for retirement). Thus, I investigate whether spatial distance information embedded in intertemporal decisions will influence individuals' subjective time perception.

SPACE-TIME INTERDEPENDENCE AND TIME PERCEPTION

Space-time interdependence has been studied theoretically and empirically across diverse research fields from Physics to Psychology (Boroditsky & Ramscar 2002;

Casasanto & Boroditsky 2008; Collyer 1977; Elman 1990; Helson 1930; Jones & Huang 1982; Saniga 2003). For instance, perception of time passage is influenced by spatial distance between visual marks indicating onset and offset of duration in experiments, and priming different spatial relations (e.g., I move toward it vs. it moves toward me) changes individuals' interpretation of ambiguous temporal-relation words (e.g., the meeting has been moved *forward* two days; Boroditsky & Ramscar, 2002).

These findings, however, looked at whether spatial distance information influences human judgment of *experienced* time (e.g., duration of time that actually has passed) or judgment of temporal order of events. Our interest in time perception refers to subjective estimates of *prospective* duration, especially for prolonged periods lasting days to years. Unlike experienced time perception, which has been studied rigorously in the past a few decades (e.g., Block & Zakay 1996; Church 1984; Treisman 1963), it is not clear what inputs are mentally represented and processed when people judge prospective duration, in which time is not directly experienced, not to mention whether spatial information would influence individuals' perception of prospective duration. Thus, I examine, when the duration to be anticipated is embedded in space (e.g., today in location A and 3 months later in location B), spatial distance information will influence subjective estimates of prospective duration (e.g., how long or short people subjectively perceive the three-month duration to be). In addition, as long as individuals incorporate subjective time perception in intertemporal trade-off decisions, their impatience will be influenced along. That is, if the spatial distance between two places is far away, individuals perceive the same duration to be long, which in turn, results in a greater degree of impatience for immediate consumption by implicating longer waiting time until the receipt of delayed outcomes. Therefore, I hypothesize that when temporal distance is embedded in a longer spatial distance, people estimate the same prospective duration to be subjectively longer. But when temporal distance is embedded in a longer spatial distance, people reveal a greater degree of impatience.

One possible alternative explanation for the proposed spatial distance effect on time perception is a response bias in estimating subjective time perception. Spatial distance information, regardless of whether it is visually presented or mentally imaged, share the same physical nature (e.g., linear distance) with psychophysical measures of time perception I implement in studies (e.g., a linear line measuring the magnitude of perceived duration). For this reason, spatial distance information may influence how participants perceive the length of the scale units (e.g., perceptual contrast effect from manipulation to scale) rather than how they actually perceive time. Thus, I further test whether spatial distance information influences in other tasks that reflects the actual changes in time perception but not the changes in response generation. Specifically, I examine whether spatial distance information influences how long participants to take to mentally simulate time passage (i.e., simulate in mind time passage from today to a day in 2 months). I predict that if what is changed by the spatial distance manipulation is indeed time perception, participants will also reveal differences in time to mentally simulate time passage. If what is changed is a mere scale usage, however, I do not expect any difference in the mental simulation time. Based on this, I hypothesize, when temporal distance is embedded in a longer spatial distance, people take longer time to mentally simulate the passage of the same prospective duration.

Finally, a boundary condition of the spatial distance effect on time perception is examined. Recent research in psychology shows that simple visual distance primes (e.g., drawing a line on Cartesian coordinates) influence participants' judgments of various emotional responses (e.g., enjoyment from an embarrassing movie or bonds to one's hometown; Williams & Bargh 2008). Given that people are continuously exposed to various visual distance cues in everyday lives, it is critical to test how susceptible subjective time perception would be to visual distance primes and how much elaboration is needed for the spatial distance effect to show. For this question, I take an exploratory approach rather than setting a specific direction of predictions, and test the impact of various distance primes and the level of elaboration in processing spatial distance information on participants' subjective time estimates.

Overview of Experiments

I find support for our hypotheses on the spatial distance effect on time perception and impatience in four experiments. Across experiments, I provide respondents either long or short spatial distance information and measure their subjective time estimates for prospective duration and impatience in intertemporal preferences. In experiment 1, spatial distance is manipulated using a retirement cities shown on the map of United States and, in experiment 2, it is manipulated using a hypothetical map. Experiment 3 demonstrates the proposed effect is not driven by a response bias (i.e., changes in a way using a scale rather than changes in time perception by demonstrating the spatial distance effect on time perception by measuring differences in participants' duration to mentally simulate time passage. In experiment 4, I test various simple visual distance primes, and manipulate the level of elaboration for the spatial distance information and examine a boundary condition of the spatial distance effect.

Experiment 1

I tested whether those who think they will retire to a city farther away from their current location subjectively perceive duration to their retirement to be longer than those who think they will retire to a more closely located city. In addition, I examined whether distance to the retirement cities influences impatience in making intertemporal trade-off decisions.

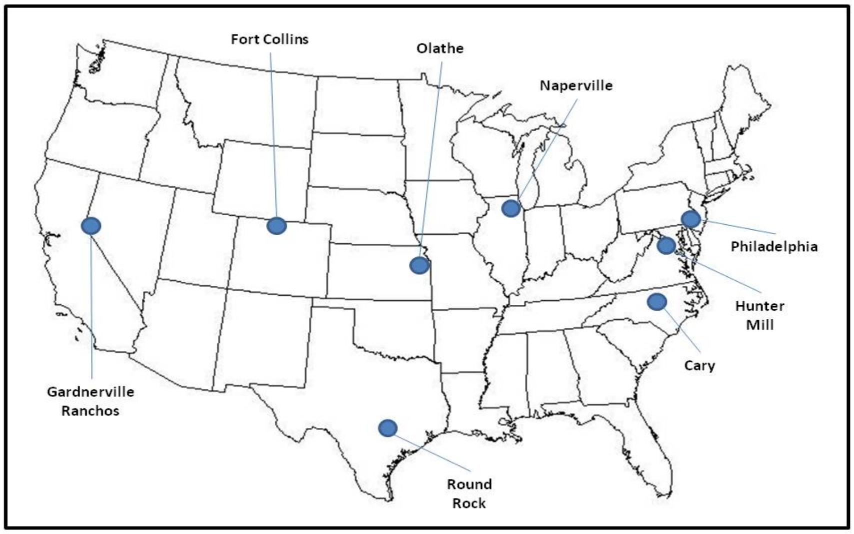
Method

Two hundred and three undergraduates participated in a computerized study as part of an hour-ling session in exchange for $10. Using a randomization function in a java-script[11], each participant was randomly assigned to one of two spatial distance conditions (long vs. short). Participants were presented with a map of United States, where seven retirement cities were shown (see Figure 6) and were asked to memorize the locations of each city. Specifically, they were told that "A retirement magazine announced a list of the best small cities to retire to. Seven of these cities are shown on the map below along with your current location, Philadelphia. Please memorize the location of each city shown on the map." Once they memorized the map, the map disappeared from the screen, and they were asked to imagine that they were going to live in Philadelphia until they retire but plan to move to Gardnerville Ranchos (the long-distance condition) or Cary (the short-distance condition) after they retire. They were

[11] This procedure ensures a random assignment but results in unequal cell sizes because experimental condition is decided independently for each participant.

asked to take a moment to imagine moving from Philadelphia to Gardnerville Ranchos (vs. Cary) when they retire.

FIGURE 6. A MAP OF UNITED STATES WITH SEVEN RETIREMENT CITIES AND THE CURRENT LOCATION OF PARTICIPANTS, PHILADELPHIA



Participants' subjective perception of duration to their retirement was measured using a computerized line scale. They were asked how long they consider the duration to be between today and their retirement, and indicated their response by lengthening or shortening the length of the line scale. At the beginning, a small black square-shaped bar (e.g., 40 by 40 pixels) was shown on the left side of the computer screen, and participants were asked to adjust the length of the line using the left and right arrow keys on the keyboard to indicate the duration such that if they consider the duration to be short, they adjust the length of the bar to be as short as they feel would be equivalent to the duration and if they consider it to be long, vice versa. Next, participants' level of impatience was measured using a standard delay-discounting task (e.g., Thaler, 1981). Participants imagined they won a lottery and would receive $500 today. They could either receive the cash prize of $500 today, or save it for their retirement and receive a greater amount of cash. They were asked to indicate the amount of cash that would lead them to be willing to wait until their retirement to receive the cash.

Although I are mainly interested in whether spatial distance influences subjective perception of duration (e.g., whether they subjectively perceive the same duration to be longer or shorter), it is possible that spatial distance influences participants' actual estimation for the duration to retirement. To test this, I asked participants to indicate in how many years they think they would retire. And, finally, for a manipulation check, they were asked to indicate how many miles they thought were between Philadelphia and Gardnerville Ranchos or Cary.

Results

Manipulation Check. Participants in the long-distance condition estimated the spatial distance to Gardnerville Rancho to be longer than those in the short-distance condition did to Cary (M = 5192.55 miles vs. 1413.29 miles; $t(201) = 2.67$, $p < .01$).

Subjective Duration Estimation. I tested whether such difference in the spatial distance impacts participants' subjective estimation of duration to their retirement. Responses using the computerized line scale bar was coded in millimeters (overall M = 323.79*mm*, SD = 193.77*mm*). Confirming our prediction, a *t*-test revealed that participants who imagined moving to Gardnerville Ranchos estimated the duration to retirement to be longer than those who imagined moving to Cary (M = 353.41*mm* vs. 299.24*mm*; $t(201) = 2.00$, $p < .05$). I further examined whether different distance to the retirement cities influences not just subjective estimates of duration but the actual estimation of duration to retirement, and found participants in the long-distance condition estimated they would retire later than those who in the short-distance condition (M = 44.93 years vs. 42.75 years; $t(201) = 2.06$, $p < .05$), indicating that the spatial distance manipulation influenced both their subjective estimates of the duration and their actual estimation of duration to retirement. The difference in the latter makes it difficult to discern whether the observed difference in subjective duration estimates was purely due to the differences in subjective time perception or influenced by the differences in their objective estimation for duration to retirement. To examine this, I tested whether the distance effect on subjective duration estimates still held after controlling their estimation for actual duration to retirement. An ANCOVA analysis with the estimated duration to retirement in years as a covariate confirmed that participants in the long-distance condition (i.e., Gardnerville Ranchos) subjectively perceive the duration to retirement to be longer than those in the short-distance condition (i.e., Cary) even after controlling the actual time to retirement, but the effect became weaker ($F(1, 200) = 3.56$, $p = .06$).

Impatience. Participants' degree of impatience was examined by comparing their responses in dollars in the delay-discounting task. Results showed, although participants in the long-distance condition requested a greater amount of cash to postpone $500 available today than those who in the short-distance condition (M = \$58815.76 vs. \$23706.31), the difference was only directionally shown ($t(201) = 1.34$, $p < .18$). Non-parametric test requiring no assumptions on the distribution of data revealed the difference was marginally significant (Mann-Whitney U test, $p = .09$).

TABLE 3. MEAN SUBJECTIVE AND ACTUAL ESTIMATES OF DURATION TO RETIREMENT, AND IMPATIENCE AS A FUNCTION OF LONG AND. SHORT SPATIAL DISTANCE

Spatial Distance	Long		Short	
	M	*SE*	*M*	*SE*
Subjective estimates	353.41*mm*	22.28*mm*	299.24*mm*	16.39*mm*
Actual estimates	44.93 years	.78 years	42.75 years	.72 years
$500 delayed until retirement	$58815.76	$25228.92	$23706.31	$7285.06

Discussion

As hypothesized, participants estimated the duration to their retirement to be longer when they imagined retiring to a city farther away. This spatial distance effect in duration estimation showed both in the subjective estimation using the computerized line scale and in the objective estimation in years. For the difference in the degree of impatience, however, no strong evidence was observed. I find the reason from the possible compounds in using real cities as a spatial distance manipulation. That is, Gardnerville Ranchos and Cary differ not only in the distance from Philadelphia, they may also differ on various other factors such as cost of living and weather, which may influence participants' preference for monetary outcomes. For this reason, in the subsequent studies, I examine the spatial distance effect using distances on a hypothetical map. In addition, to directly test whether spatial distance influences subjective perception of duration, I ask participants to indicate their subjective time perception for the same fixed duration (e.g., duration of 1 month).

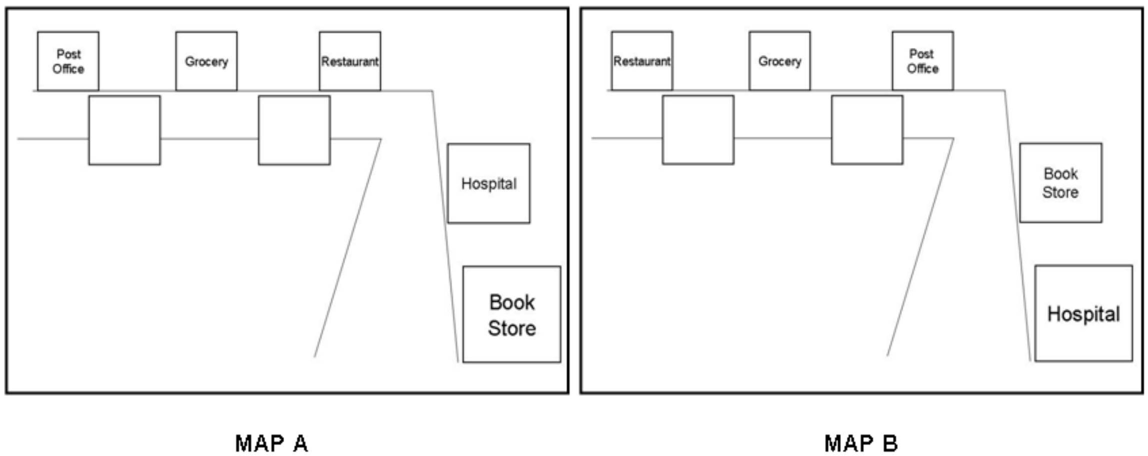
Experiment 2

In Experiment 2, I manipulated spatial distance between two places by asking participants to memorize a hypothetical map with different spatial distances. I then asked participants to estimate a fixed duration (e.g., 1 month) embedded in space (e.g., tomorrow in place A and 1 month later in place B), and examined changes in time perception (H1) and whether these changes in time perception subsequently affect impatience in a delay-discounting task (H2). I predicted that those who estimated the prospective duration for places a greater distance apart in the map would estimate longer durations and request a great amount of monetary rewards when delaying immediate rewards, because longer perceived duration corresponds to longer perceived delay.

Method

One hundred and eighty-seven undergraduates were randomly assigned to one of two spatial distance conditions (long vs. short). Participants were presented with a hypothetical map, where spatial distance between the post office and the book store was varied (see figure 7), and asked to memorize the locations of each building. Once they memorized the map, the map was taken away, and they were asked to mentally visualize the map. Next, participants' anticipatory time estimates were measured using a 155*mm* continuous line scale worded as very short on the left end-point and very long on the right. Specifically, they were told "suppose that you have to visit a post office tomorrow and a book store in 1 month. How long do you consider the duration between tomorrow and a day in 1 month? Place a mark to indicate the duration". On the next page, participants' degree of impatience in was measured. They imagined receiving a $75 gift certificate valid today and indicated the dollar gift certificate they would require instead if they had to wait for 1 month to receive it.

FIGURE 7. MAPS OF HYPOTHETICAL TOWN



Results and Discussion

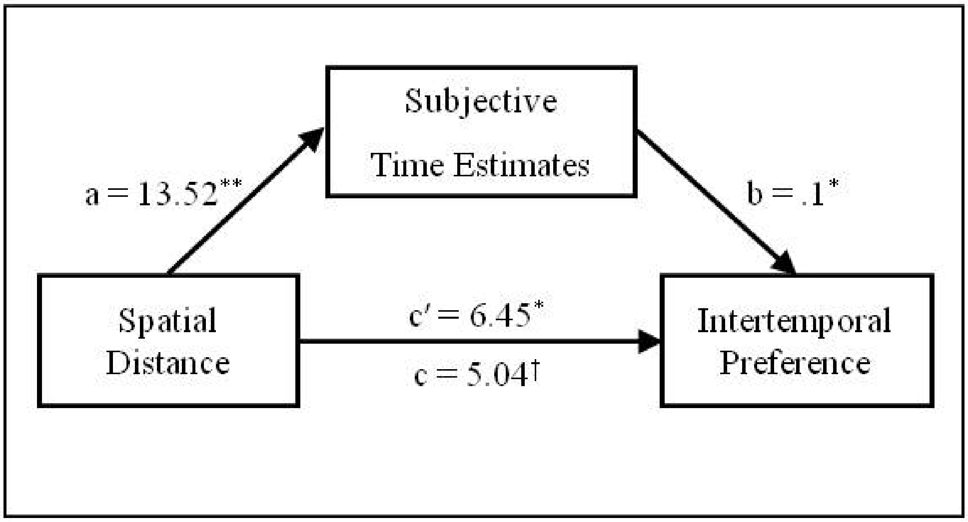
The spatial distance from the left end of the scale was measured in millimeters (overall $M = 63.46mm$, $SD = 35.04mm$). A t-test revealed a significant difference between conditions such that participants who memorized the long-distance map estimated the one-month duration to be longer than those who memorized the short-distance map ($M = 70.26mm$ vs. $56.73mm$; $t(185) = 2.68$, $p < .01$). Next, participants' degree of impatience was compared and revealed that those who in the long-distance map condition required a greater amount of gift certificate to delay the \$75 one available today than those in the short-distance map condition (M = \$94.53 vs. \$88.08; $t(185) = 2.22$, $p < .03$).

TABLE 4. MEAN SUBJECTIVE TIME ESTIMATES AND IMPATIENCE AS A FUNCTION OF LONG AND. SHORT SPATIAL DISTANCE

Spatial Distance	Long		Short	
	M	*SE*	*M*	*SE*
Subjective time estimates	70.26*mm*	2.36*mm*	56.73*mm*	1.69*mm*
$75 delayed by 1 month	$94.53	$2.36	$88.08	$1.69

I further tested whether subjective time estimates mediated the impact of the spatial distance manipulation on temporal discounting (see Figure 8). Using the bootstrapping procedure detailed in the literature (Preacher & Hayes 2004; Zhao, Lynch, & Chen 2010), I identified the indirect path from the spatial distance manipulation to the subjective time perception (a = -13.52, $t = -2.68$, $p < .01$), the indirect path from the subjective time perception to intertemporal preference holding the manipulation constant (b = .10, $t = 2.49$, $p = .01$), and the direct effect from the manipulation to intertemporal preference after controlling the mediator (c = -5.04, $t = -1.73$, $p < .09$). Confirming the mediating role of subjective time perception, the sampling distribution of the indirect effect (a × b) revealed that its 95% confidence interval did not include zero (-3.13 to -.13).

FIGURE 8. MEDIATION OF TIME PERCEPTION FOR SPATIAL DISTANCE EFFECTS ON INTERTEMPORAL PREFERENCE



The unstandardized regression coefficient is shown above the arrow for the direct pathway. The coefficient below the arrow is for the indirect pathway after statistically controlling for anticipatory time estimates. Statistical significance of the coefficients is indicated by †p < .1, *p < .05, **p < .01.

Experiment 3

In experiments 1 and 2, I demonstrated that spatial distance influences how long or short people subjectively perceive anticipatory duration to be. Although our main prediction was confirmed, I did not completely rule out the possibility that our effect is not driven by the actual changes in how people perceive future time but by how people perceive the physical length of scale units. To address this question, I asked participants to mentally simulate time passage (i.e., simulate in mind time passage from today to a day in 2 months) rather than to indicate their time perception using a linear line scale and compared how long it took them to mentally simulate time passage across conditions.

Method

One hundred and sixty-eight undergraduates were randomly assigned to one of two spatial distance conditions (long vs. short). Two trial sessions were preceded to make participants comfortable in using the computerized reaction time measure. Specifically, participants were asked to imagine tomorrow and a day in 3 months, and mentally simulated time passage from tomorrow to a day in 3 months. They pressed a "tomorrow" button when they began the simulation and then pressed a "three months" button when they completed their mental simulation. In the main task, similar to Experiment 2, participants memorized either long-distanced or short-distanced maps (see Figure 7) and imagined visiting a post office tomorrow and a book store in 2 months. Next, they were asked to mentally simulate time passage from tomorrow to a day in 2 months by pressing a "tomorrow" button when they began the simulation and then pressed a "two months" button when completed, and the elapsed time between the two button presses was recorded.

Results and Discussion

The duration between two buttons were pushed was recorded in milliseconds ($M = 9601.62ms$, $SD = 9766.07ms$). This dependent measure revealed that participants who memorized the long-distance map took longer to mentally simulate the anticipatory time passage of two months than those who memorized the short-distance map (M = 11003.74*ms* vs. 8001.76*ms*; $t(165) = 2.06$, $p = .04$) [12]. These results lend additional support to our account by discounting a simple response scale artifact.

[12] One extreme outlier in the short distance condition was dropped from the analysis. This respondent's matching response of 58783*ms* was more than 7 standard deviations from the mean of his or her cell without that response.

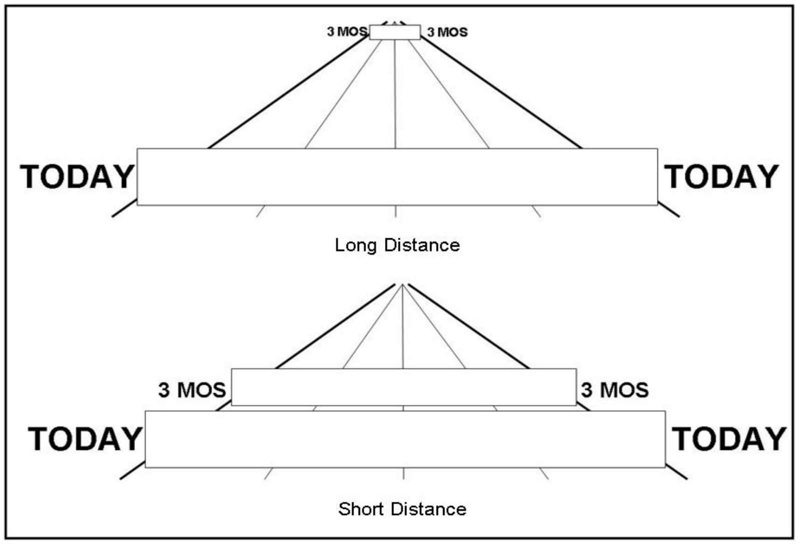
Experiment 4

In Experiment 4, I examined a boundary condition of the spatial distance effect. Especially, I tested whether exposure to simple visual distance primes alone is enough or a certain degree of elaboration is required for the spatial distance effect to reveal. I presented participants visual distance primes (long vs. short) and examined whether exposure to simple visual primes show similar spatial distance effects on time perception (Experiment 4a and 4b). I also manipulated the level of elaboration in processing spatial distance information and tested whether a certain degree of elaboration is required for the spatial distance effect (Experiment 4c).

Method

Experiment 4a. Seventy undergraduate participants were randomly assigned to either long or short visual distance primes. Participants were asked to fill out each of two blank blocks with foods they wanted to eat today and 3 months later. To manipulate visual distance, two blocks were shown on a perspective view of a road so that the perceived distance between the block for today and the block for 3 months is visually greater in the long-distance condition than in the short-distance condition (see Figure 9).

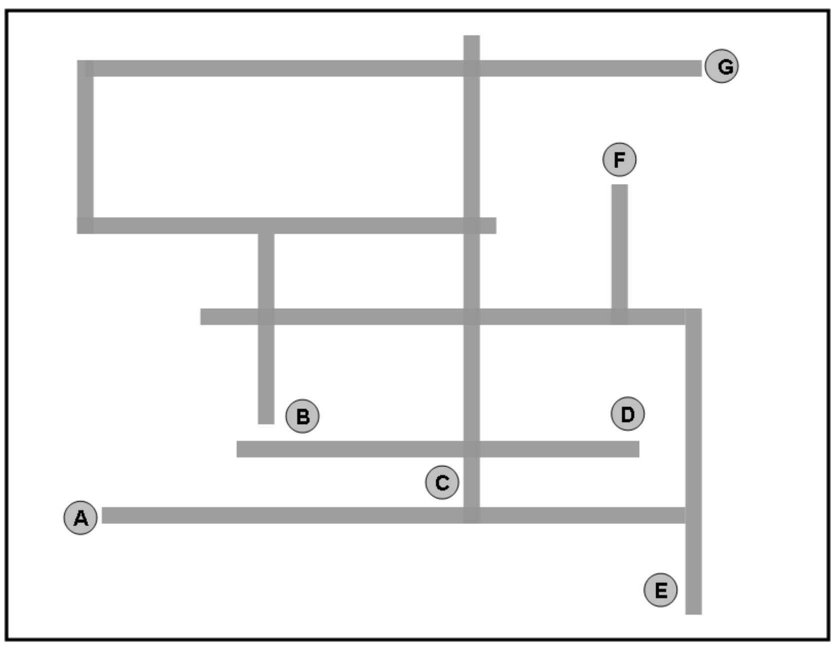
FIGURE 9. VISUAL DISTANCE PRIME USED



Experiment 4b. One hundred and six undergraduate participants were randomly assigned and presented with long or short visual distance primes. Participants were given a standard intertemporal task which is similar to the tasks used in experiments 1 and 2 in this article. They were asked to price the future value of a $75 reward today delayed by 3 months by filling the blank in the sentence, "$75 today = $____ in 3 months". In the long-distance condition, the words on the left (i.e., $75) and right side ($____) of the equal sign were spaced longer apart (120*mm*), while they were closed located in the short-distance condition (23*mm*) on the print. Right below this question, participants' perception of three-month duration was measured.

Experiment 4c. One hundred and ninety-six undergraduates were randomly assigned to one of the four conditions: 2 (spatial distance: long vs. short) × 2 (elaboration: yes vs. no). The procedure in the elaboration condition were similar to the previous experiments except for the specific map used (see Figure 10): participants memorized the map, mentally imaged it without the presence of the map, and imagined visiting store A tomorrow and store G (vs. store C) in 1 month. In the no-elaboration condition, participant neither memorized map nor mentally imaged it without looking the map. Instead, the map was presented right above the subjective time measure on the same page, and participants were asked to look at the map and imagine visiting store A tomorrow and store G (vs. store C) in 1 month. All participants indicated their subjective estimates for the one-month duration using the continuous line scale.

FIGURE 10. A MAP OF HYPOTHETICAL TOWN USED

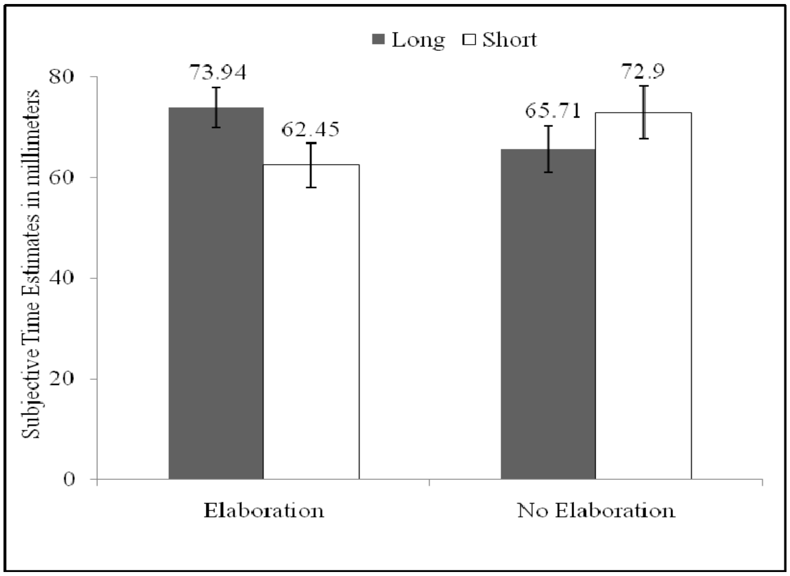


Results and Discussion

Experiment 4a and4b. In neither experiment 4a nor 4b, participants' subjective time estimates were not different across long vs. short visual distance conditions (Experiment 4a: $M = 77.21mm$ vs. $71.58mm$, $t(68) = .66$, $p > .51$; Experiment 4b: $M = 46.65mm$ vs. = $51.24mm$, $t(104) = .89$, $p > .37$). These results show that mere exposure to long vs. short visual distance primes did not bring changes in participants' subjective time perception.

Experiment 4c. A 2-way ANOVA with the spatial distance and elaboration manipulation as between-subjects factors revealed a significant interaction on estimated duration ($F(1,192) = 4.18$, $p = .04$). Specifically, in the elaboration condition, participants whose time was embedded in a longer spatial distance (Store A and Store G) estimated the one-month duration to be longer ($M = 73.94mm$) than those whose time was embedded in a shorter distance ($M = 62.45mm$; $F(1,192) = 3.22$, $p = .07$). In the no-elaboration condition, however, no difference emerged between the long and the short distance conditions ($M = 65.71mm$ vs. $72.90mm$; $F(1,192) = 1.21$, $p > .27$). These results indicate that people need to elaborate on the spatial distance information for the spatial distance to influence temporal distance perception.

FIGURE 11. MEAN SUBJECTIVE TIME ESTIMATES AND IMPATIENCE AS A FUNCTION OF SPATIAL DISTANCE AND ELABORATION



Error bars represent standard errors of the mean.

General Discussion

When thinking about time, it is hard not to consider its relation to space. Indeed, diverse theoretical and empirical work demonstrates various aspects of space-time interdependence (Boroditsky & Ramscar 2002; Casasanto & Boroditsky 2008; Collyer 1977; Elman 1990; Helson 1930; Jones & Huang 1982; Saniga 2003). Our paper examined another novel aspect of space-time interdependence relating to the perception of future time that has a direct implication for financial decision making: the influence of spatial distance influences anticipatory time perception and subsequent intertemporal preferences for monetary outcomes.

I presented results from four experiments confirming our hypotheses. I demonstrated the distance to the city where individuals will retire (Experiment 1) or the distance on a hypothetical map (Experiment 2) influences their subjective estimates of prospective durations, which in turn, changes their impatience in making intertemporal trade-off decisions by implicating different waiting time until the realization of delayed outcomes. Specifically, participants who imagined moving to a retirement city farther away from their current location estimated the duration to their retirement to be (both subjectively and objectively longer). Participants who mentally imaged moving to a longer spatial distance also perceived the one-month duration subjectively longer and required a greater amount of money when they have to delay the immediately available rewards. Further, in Experiment 3, I showed that the observed distance effect on time perception is not driven by a response bias (e.g., changes in using a vertical line scale) by demonstrating that the spatial distance effect was shown even when participants mentally simulate the time passage. Experiment 4 examined a boundary condition for this spatial distance effect. While spatial distance information elaborated enough revealed the distance effect on time perception, visual primes without elaboration did not show this effect.

Implications and Future Directions

Under-saving for retirement. As I stated at the beginning of the paper, many psychologists and behavioral economists have suggested ways to increase contribution to retirement saving (Choi et al. 2006; Iyengar, Huberman, & Jiang 2003; Thaler & Benartzi 2004). For instance, Thaler and Benartzi (2004) proposed a precommitment device, "Save More Tomorrow", in which employees can commit in advance their future incremental income to savings for retirement. But no retirement programs I know of have considered the role of subjective time perception in retirement saving rate decisions.

Our findings suggest that changing individuals' perception of duration to their retirement can be a subtle but effective way to increase their contribution to saving rates. Especially when people plan to move far away after they retire or when retirement program booklets make such moving salient (e.g., a picture of a distant city), our results can be used to increase saving rates. I believe that investigation of the presence of spatial distance cues information in a retirement saving information booklet and whether changing these cues actually increase contribution to saving for retirement will be fruitful to further increase our understanding of the spatial distance effects on saving behavior.

Other influence of spatial distance. In this paper, I looked that whether spatial distance people imagine moving influences time perception. But, in addition to the distance, the direction of moving may influence time perception as well. In a recent Experiment, people estimated to take longer to travel north than south (Nelson & Simmons 2009). Such effect may reveal in time perception as well such that people may perceive the duration to retirement to be longer when they move to northern area after they retire than when they move to southern area. How long or short people subjectively perceive the physical spatial distance itself to be may also influence subjective time perception. For instance, retirement cities around beach may look far away or close depending on the area and weather of the current location. I leave these and other related questions for future investigations.

Conclusions

Our investigation aims to demonstrate the interdependence between spatial distance information and subjective time perception that has implications for retirement saving decisions. There is a growing body of behavioral research to understand under-saving rate, but little investigation has been done to understand the impact of subjective time perception on impatient for delayed monetary rewards. I believe that findings in this paper shed a new light into the understanding of impatience and saving decisions as well as space-time interdependence.

IV. ESSAY III

SPEND 2-DA-BEAT:

THE IMPACT OF AUDITORY TEMPO ON IMPATIENCE

ABSTRACT

In time perception literature (i.e., research on judgment of elapsed time), auditory tempo has been shown to influence time perception by changing the speed of an internal clock. I examined whether auditory tempo such as pulse sounds or beats in music also influence anticipatory time perception (e.g., estimates of prospective duration in the future), and subsequent time-related judgment. First, I found that participants' judgment of elapsed time was significantly correlated with their anticipatory time perception (Experiment 1), implying that the same psychological process may be involved in both experienced and anticipatory time perceptions. More importantly, using different speed of pulse sounds (Experiment 2) or beats in music (Experiement 3), I found that auditory tempo affects anticipatory time perception and impatience in intertemporal decisions. Taken together, I provide a novel way to influence consumers' time-related decisions by changing their anticipatory time perception.

SPEND 2-DA-BEAT:

THE IMPACT OF AUDITORY TEMPO ON IMPATIENCE

Suppose that you were offered a free therapeutic massage session available today at a massage center nearby your house. When you arrived, you were told that because massage sessions were overbooked, but if you were willing to wait for 10 days, you will be offered an upgraded massage session with spa and complementary drinks. Now, suppose that when you make these decisions, you are listening to your life-favorite music of all time "Beat it" by Michael Jackson or the very same song remade in rock music by Fall Out Boy. Would the music you are listening to influence your intertemporal preference to opt for the inferior but immediately available outcome? Probably, but why?

In this article, I propose and demonstrate that auditory tempo (e.g., pulse sound or beat of music) influences perception of *anticipatory time* (i.e., prospective duration in the future) and subsequent time-related decisions. Auditory tempos such as pulse sounds or metronome beats has been shown to affect individuals' judgment of *experienced time* (i.e., elapsed duration) by presumably changing the speed of a biological pacemaker, an internal clock. Although experienced and anticipatory time perceptions are not the same in nature (i.e., only the former involves actual passage of physical time), they are relatively similar to each other compared to other sensory perceptions like vision and audition as there is no identified sensory receptors dedicated for its perception and have less explicit informational and perceptual entity compared to visual, auditory, and somatosensory stimuli. Therefore, the psychological process (i.e., internal clock) known to govern judgment of experienced time may also influence anticipatory time perception at least to a certain degree, and, therefore, external tempo shown to influence individuals' judgment of elapsed time may influence anticipatory time perception as well. I further predict that external tempo influences time-related decisions, in which anticipatory duration is one of the key attributes to be processed in judgment and decision making. In the introductory scenarios, the tempo of the original 'Beat it' is 138.2bpm (Beat Per Minute; analyzed by a software, DJ Twist and Burn 1.03) while the rock version of the same music runs faster at 149.7bpm. If fast tempo induces overestimation in judgment of anticipatory duration presumably by increasing the speed of an internal clock, it will result in a greater degree of impatience in intertemporal decisions (e.g., choosing inferior outcomes at the expense of superior but delayed ones) because the perceived delay until the receipt of the rewards is extended as well.

TEMPO AND TIME PERCEPTION

Internal Clock. Human and even lower animals can easily discriminate two temporal events (e.g., duration of a tone) separated by very short intervals like 400ms (Ivry, 1996). In order to explain such ability to precisely discern intervals, many theories of time perception have assumed the working of a biological pacemaker of one sort or another (Block & Zakay, 1996; Gibbon & Church, 1984; Gibbon, Church, & Meck, 1984; Hoagland 1966; Killeen & Fetterman, 1988; Killeen & Weiss, 1987; Treisman, 1963; Wearden & Doherty, 1995). For instance, the information-processing model of interval timing (judgment of elapsed time in second-to-minute range) theorizes that physical time is processed into psychological time by an internal clock consisted with three components: a pacemaker, switch, and integrator (Gibbon, Church, & Meck, 1984). A pacemaker continuously generates a raw material for temporal judgment, a pulse, in a Poisson process (i.e., the probability that a pulse generates at a given time is constant) to integrator, which accumulates the total number of emitted pulses in a given time interval. A switch is located between the pacemaker and the integrator, and it opens to send pulses to the integrator when attention is allocated to time judgment while it close when attention is shifted away from time. Pulses accumulated in the integrator then compared with the values stored in memory for similar duration and a response is made if it is close enough to prior values (Meck and Benson, 2002). Several neuroimaging studies reported that neural activities in a specific brain region (e.g., striatum) is associated with judgment of second-to-minute time and proposed this as a biological clock (e.g., Hinton, Matell, & Meck, 1996; Matell & Meck, 2000; Meck & Benson, 2002). But the investigation for brain regions dedicated to the internal clock or pacemaker is still in progress (Ivry, 1996), and the mechanism how attention and memory involve in processing pulse generated by the pacemaker is not yet in agreement (Block & Zakay, 1996; Gibbon, Church, & Meck, 1984; Zakay, 1999).

Whether it is a biological entity or a hypothetical construct, the proposed existence of a pacemaker provides explanations for many intriguing phenomena in time perception. For instance, administration of dopamine-releasing agents like methamphetamine (Chiang et al., 2000; Maricq, Roberts, & Church, 1981; Matell, King, & Meck, 2004) and judgment of affective stimuli (Droit-Volet, Brunot, & Niedenthal, 2004; Thayer & Shiff, 1975; Watts & Sharrock, 1984) were shown to induce overestimation in duration judgment, while decreased body temperature induced underestimation. The reported changes in duration judgment were often proportional to the length of duration (e.g., all duration is perceived to be 20% longer) rather than additive (e.g., all duration is perceived 200ms longer) and such proportional changes has been suggested as evidence for changes in the speed of an internal clock. That is, if dopamine agonist or arousal speeds up an internal clock by 20%, it emits 20% more pulses for a given time interval, resulting in 20% increase in the estimated duration.

Internal Clock Speed Change. Researchers have attempted to directly change the speed of internal clock. In the early stage of this research, many studies involved changing body or room temperature by theorizing that if an internal clock is a biological entity, then 'heating' the clock would make the clock run faster by increasing chemical activity of the pacemaker (see Werden & Pento-Voak, 1995). Later on, researchers began to use external tempo (i.e., repetitive stimulation by auditory or visual stimuli) to influence the speed of an internal clock. For instance, listening to fast pulses (e.g., 10ms-long tones repeated every 190ms) or repeatedly being presented with fast visual flickers before estimating elapsed time was shown to induce overestimation in judgment of time passage (Droit-Volet & Wearden, 2002; Treisman & Brogan, 1992; Treisman, Faulkner, Naish, & Brogan, 1990; Penton-Voak, Edwards, Percival, & Wearden, 1996; Wearden & Win, 1999; Wearden, Philportt, & Win, 1999; Zakay, Nitzan, & Glicksohn, 1983). Other external tempos such as a tapping task (Michon, 1996), a beat of a metronome (Frankenhaeuser, 1959; Ornstein, 1969), or rhythmic bodily activity (Denner, Wapner, McFarland, & Werner, 1963) were also shown to influence temporal judgment. These manipulations were shown to induce proportional changes in time estimation and theorized to affect the speed of an internal clock, but the proposed mechanism of why external tempos influence temporal judgment varies. Many researchers attributed it to arousal or activation such that arousal speeds up an internal clock, which in turn emits pulses at a faster rate for the same time interval (Penton-Voak, Edwards, Percival, & Wearden, 1996), or more directly to the interference effect (a certain frequency of external pulses interrupts the function of internal clock if the frequency is multiples of the fundamental biological frequency; Treisman, Faulkner, Naish, & Brogan, 1990). Some others attributed it to the attention allocation: that is, external tempos attract decision makers' attention to time, inducing more pulses accumulated in the integration stage of an internal clock (Zakay, 1990).

Investigating whether a biological entity of an internal clock exists and how exactly external tempo influences time judgment are beyond the scope of the current article. Instead, the current article aims to address the following two questions: 1) Would external tempo influencing judgment of elapsed time (or experienced time) affect judgment of anticipatory duration? 2) Would changes in anticipatory time perception due to external tempo influence time-related decisions such as intertemporal choice or preference for goods and services with time component? In the following section, I discuss the relationship between anticipatory time perception and time-related decisions.

ANTICIPATORY TIME PERCEPTION AND TIME-RELATED DECISIONS

Intertemporal choice is characterized as a choice between inferior but immediately available outcomes and superior but delayed ones. Individuals' intertemporal preferences are often measured and explained by discount rates, which measures the extent to which the value of delayed rewards is discounted in relative to that of immediate ones. While measured discount rates *describe* individuals' intertemporal preferences, it is not clear why individuals discount the value of delayed outcomes more heavily when the delay happens earlier than later (i.e., hyperbolic discounting) and why some individuals reveal greater temporal discounting than others. Recently, to explain hyperbolic discounting and the individual and group differences in temporal discounting, many researchers began to emphasize the role of time perception (e.g., Zauberman, Kim, Malkoc, & Bettman, 2009; Wittmann & Paulus, 2007). For example, individuals discount the value of delayed outcomes more steeply when delay happens earlier that later not because they are discounting the value of delayed outcomes hyperbolically but because early delays may seem longer than later ones (Kim & Zauberman, 2009; Zauberman et al., 2009). Similarly, some individuals reveal greater temporal discounting not because they actually devalue delayed consequences more than others but simply because they perceive delays (i.e., waiting time until delayed outcomes will be delivered) longer than others (Kim & Zauberman, 2009). That is, for two individuals with the same internal discount rate (e.g., the value of delayed outcomes is discounted by the same rate), a person who perceives waiting time longer would discount the value of delayed outcomes more heavily than another person who perceives the same delays to be shorter. In line with these time-based accounts of temporal discounting, I hypothesized that if tempo or beat of music induces overestimation in anticipatory time perception, the overestimation would induce greater impatience for immediately available outcomes because waiting time would seem longer. The impact of external temps on anticipatory time perception has also important implications on various non-intertemporal choice decisions as well. For many goods and services, duration is an important attribute in determining its perceived value (e.g., continuous-talk-time of cell phone, recording time of a digital camcorder after a full charge, duration of a massage session, delivery time to receive an order, waiting time for a ride in a theme park, etc). As long as there is a linear relationship between duration and perceived value, fast external tempo inducing overestimation in anticipatory time perception would make the same goods and services look more attractive, while slow tempo would decrease the perceived value.

PROCEDURE AND SCALE

All participants in the experiments were undergraduate student at the University of Pennsylvania. They participated in this study as part of a one-hour long session and received $10 for their participation. For all the experiments, materials were fully computerized and one common psychophysical scale was used to measure anticipatory time perception. Participants first sat in front of a computer screen, and in the instruction page, they were informed ahead the entire range of duration they would be estimating (e.g., duration from 10 to 60 days in 10 days interval). On the next screen, anticipatory duration was verbally presented. Specifically, participants were asked imagine a day after the presented duration (e.g., imagine a day in 60 days). Presentation order of duration was randomized for each participant using a randomization function in a java-script language. For a given duration randomly presented, participants were asked to consider the duration and indicate it by adjusting the length of a line scale using the left or right button on the computer keyboard. That is, participants matched the length of line to the magnitude of perceived anticipatory duration (Epstein & Florentine, 2006; Gescheider, 1985). At the beginning of each trial, a black squared bar (e.g., 40 by 40 pixels) was shown on the left side of the computer screen and when the arrow key was pressed, the bar extended or shortened its length. The theoretical boundary of the scale was infinite: when the length of the bar exceeded the physical boundary of the screen, the screen generated a scroll bar at the bottom of the screen to allow participants to look over the entire length of their response. Participants' raw responses were the physical length of the line of the unbounded line scale coded in a millimeter unit.

Experiment 1

Before I tested whether external tempo affects anticipatory time perception, I examined whether individuals' estimates of experienced time is significantly associated with their anticipatory time estimates. If the former predicts latter, then the common psychological process, the internal clock, may also influence anticipatory time perception directly or indirectly (i.e., individuals' experienced time perception serve as inputs for the judgment of anticipatory time perception).

Method

One hundred and seventy-five students participated in this study. The experiment included two tasks: experienced time estimation and anticipatory time estimation. In the experience time estimation task, participants listened to a tone (pitch of 157.49*Hz*; sampling frequency of 44100*Hz*) through a headphone and estimated its duration using the unbounded line scale. Two sets of six tones lasting 2, 7, 11, 18, 23, and 30 seconds (12 durations in total) were randomly presented to each participant. Each tone was played just once when participants pushed a button on a computer screen. They were instructed not to count numbers when they listened to a tone, but estimate its length just by listening to it. In the subsequent anticipatory time estimation task, participants estimated anticipatory duration using the line scale. Two sets of six anticipatory durations (10, 17, 25, 33, 49, and 60 days; 12 durations in total) were randomly presented for each trial.

Results and Discussion

To examine whether participants' experienced time estimates and anticipatory time estimates were significantly correlated, I calculated an index for unit duration in the following way. All participants estimated the same duration twice, so the two estimates for the same duration was averaged and then divided by its duration. This procedure generated their estimates for unit duration (1 second for experienced time or 1 day for anticipatory time). Next, these unit-duration estimates for each of six durations were averaged and used as participants' idiosyncratic time estimate indexes (see Table 5 for mean and *SD* of raw data). As predicted, correlation analysis revealed a reliable internal consistency between the indexes (Pearson $r = .31$, $p < .00003$). That is, participants' experienced time perception explained 10% of the variance in their anticipatory time estimation ($R^2 = .10$). This observed association between experienced and anticipatory time suggests that a common psychological process may govern both types of time perception, or at least individuals' reliance on judgment of experienced time to estimate anticipatory duration. Regardless of whether this association was driven by a third-level process or one was an input for the other, both mechanisms predict that external tempo which influences experienced time perception would influence anticipatory time perception as well.

TABLE 5. PARTICIPANTS' RAW TIME ESTIMATES IN MILLIMETER AND CALCULATED INDEX FOR A UNIT DURATION

		Experienced time						
Duration		2	7	11	18	23	30	unit duration (1 sec)
Time Estimates	Mean	52.25	146.95	201.28	271.38	315.50	369.13	17.69
	SD	41.91	100.94	131.38	191.63	222.32	252.52	11.17
		Anticipatory time						
Duration		10	17	25	33	49	60	unit duration (1 day)
Time Estimates	Mean	44.48	66.48	86.37	105.87	137.93	168.93	3.33
	SD	39.71	52.11	63.84	78.43	93.49	113.65	2.48

Experiment 2

The goal of Experiment 2 was to directly examine whether auditory tempo would influence the judgment of anticipatory time perception. Adapting the click-train procedure in interval timing literature (e.g., judgment of elapsed time in second-to-minute range), I exposed participants to different speeds of sine pulses when they were estimating anticipatory durations (Penton-Voak et al., 1996; Treisman & Brogan, 1992; Wearden & Win, 1999).

Method

Participants ($N = 195$) were randomly assigned to either fast pulse or slow pulse conditions using a randomization command in a java-script language. Participants in the fast pulse condition estimated anticipatory durations using an unbounded scale while listening to sign pulses repeated every 190*ms* (pulse width = 1.179*ms*), while those in the slow pulse condition did the task while listening to pulses repeated every 1500*ms*. For anticipatory time perception measure, participants estimated 12 randomly presented anticipatory durations (two sets of 10, 17, 25, 33, 49, and 60 days) using the line scale.

Results and Discussion

Similar to Experiment 1, participants' unit time index (i.e., 1 day unit) was calculated and used as their idiosyncratic anticipatory time estimates. A *t*-test confirmed the predicted difference in time estimates between the fast and slow pulse conditions ($t(193) = 2.23$, $p = .027$). Specifically, participants listening to the fast pulses estimated anticipatory durations longer ($M = 3.40mm$) than those who were listening to the slow pulses ($M = 2.71mm$). This result is the first empirical report in the literature showing that auditory tempo influences judgment of anticipatory duration. Although experienced and anticipatory time perceptions differ in many aspects, the same manipulations that were shown (evidenced by the proportional changes in elapsed time estimates) to influence the speed of an internal clock also affected anticipatory time perception.

Experiment 3

The goal of Experiment 3 was two folds. First, I implemented more natural way of manipulating auditory tempo. That is, rather than using sine pulses, I changed tempo of the same music piece. While there has been research involved manipulations of the speed of music to investigate its impact on motor behavior (e.g., rate of consumption or driving; Bordsky, 2002; Stroebele & de Castro, 2006), all studies, I know of, used different music for different tempo manipulation rather than directly changing the tempo of same music. To control for other factors that may influence participants' responses such as pitch, lyrics, or musical instrument, I used the same music (e.g., 'Across the universe' by Beatles) across the conditions, but only changing its tempo.

Method

Participants (*N* = 218) were randomly assigned to either fast music or slow music conditions. The original BPM (beat per minute) of the music was 76.5*bpm*. Participants in the fast music condition listened to the music with 98*bpm* and those in the slow music condition listened to a 55*bpm* version of the same music. While listening to the music, they participated first in the duration estimation task and then the temporal discounting task. In the duration estimation task, participants estimated 12 randomly presented anticipatory durations (three sets of 24, 49, and 62 days) using the line scale. In the temporal discounting task, participants' discount rates were elicited for the randomly presented 12 durations of delays (three sets of 24, 49, and 62 days). Specifically, when the presented delay was 24 days for instance, they were asked first to imagine to be chosen to receive a $50 gift certificate that is valid today and redeemable at any departments at Amazon (www.amazon.com), but the receipt of the gift certificate being delayed by 24 days. Then, they indicated the amount of a gift certificate they would want to receive to on order to wait for 24 days later to use the gift certificate instead of using it today by filling the blank in the following sentence. The same procedure was repeated 12 times for randomly presented 12 durations.

> "I feel indifferent between receiving a $65 gift certificate today and receiving a $____ gift certificate in 24 days."

Manipulation check. A separate group of participants (*N* = 144 undergraduates) who did not participate in the main study listened to either the fast or slow tempo versions of the same music and answered the following questions: 1) how much they liked the music (11-point scale; 1: Not like it at all, 5: About the same, and 11: Very like it), 2) how they felt about the tempo of the music (11-point scale; 1: Too slow, 5: Moderate, and 11: Too fast), and 3) whether they felt the tempo of the music was different from the tempo of the original music (Yes, No, I do not know). This pretest revealed that participants' liking for the music did not vary depending on whether it was fast or slow (Fast vs. Slow; *M*= 7.76 vs. 7.73; $t(142) = .32$, $p = .75$), although they were aware whether the tempo of the music they listened was fast or slow (*M*= 6.84 vs. 4.70; $t(142) = 7.20$, $p = .001$). Finally and most importantly, although one third of participants felt the tempo of music was different from that of the original piece (27 out of 74 for the fast music; 22 out of 70 for the slow music), this proportion was not driven by either one of the tempos ($\chi^2(2) = .42$, $p = .81$). That is, regardless of the tempo of music (fast vs. slow), about the same proportion of participants chose "yes", "no", and "I do not know" responses for the question asking whether the tempo of the music was different from the original one.

Results and Discussion

Participants' anticipatory time estimates for each 24, 49, and 62 days were averaged[13]. For participants' degree of temporal discounting, I calculated annual compound discount rate, *r*, based on the exponential discount function for each 24, 49, and 62 days.

$$PV = FV \cdot e^{-r \cdot t}$$

PV was the value of immediately available gift certificate, which was fixed as $50, *FV* was participants' raw responses in dollars, and *t* was delays in a year unit (24/365, 49/364, and 62/365 years). A *t*-test revealed that participants' time estimates were

[13] Because measured discount rates depends on the length of delays (Thaler, 1981), we first analyzed data separately for each of the three durations. But results using unit-time estimates and averaged discount rates were also reported in the paper.

significantly different between the fast and slow music conditions for 24 days (Fast vs. Slow; *M* = 67.63*mm* vs. 86.29*mm*; $t(216) = 2.22$, $p = .028$), 49 days (M_t = 134.78*mm* vs. 109.51*mm*; $t(216) = 2.06$, $p = .041$), and 62 days (*M* = 173.47*mm* vs. 141.28*mm*; $t(216) = 2.00$, $p = .048$), indicating that participants who listened to the fast music estimated anticipatory durations longer that those who listened to the slow music.

Participants' degree of temporal discounting (measured as discount rates) was also significantly different between conditions for 24 days (*M* = 4.82 vs. 3.59; $t(216) = 2.05$, $p < .05$), 49 days (*M* = 3.93 vs. 2.93; $t(216) = 2.14$, $p < .05$), and 62 days (*M* = 4.27 vs. 3.17; $t(216) = 2.35$, $p < .05$), revealing that participants in the fast music condition discounted values of delayed outcomes more than those who in the slow music condition. I also analyzed data using the unit-duration index (see Experiments 1 and 2 for details) and averaged discount rates. Similar to analyses of each duration, participants were significantly different across conditions in this index (Fast vs. Slow; *M* = 2.44*mm* vs. 3.05*mm*; $t(216) = 2.14$, $p = .034$) and discount rates (26.25 vs. 25.14; $t(216) = 2.17$, $p = .032$). To further examine whether the differences in temporal discounting was driven by the changes in anticipatory time perception due to the fast or slow music, I conducted mediation analysis. Mediation analysis confirmed the direct impact of the tempo of music on hyperbolic discounting was significantly reduced when anticipatory time estimates were introduced as a mediator (Sobel $z = 2.14$, $p = .03$ for 24 days; Sobel $z = 2.01$, $p = .044$ for 49 days; Sobel $z = 1.98$, $p = .048$ for 62 days). In sum, these results confirmed our prediction that external tempo influences individuals' impatience in intertemporal choice decisions. Specifically, participants who listened to fast pulses estimated the same duration longer and displayed greater temporal discounting for the same delayed outcomes.

General Discussion

In this article, I examined whether auditory tempo such as sine pulses or beat of music influences anticipatory time perception and subsequent time-related decisions. Participants' judgment of experienced time was significantly correlated with their anticipatory time perception, suggesting the possibility that external tempo influencing experienced time perception would influence anticipatory time perception. Confirming this possibility, different speed of sine pulses (Experiment 2) and different tempo of music beat (Experiment 3) influenced perception of anticipatory durations. Furthermore, external tempo changed participants' intertemporal preferences (Experiment 3).

Although changes in experienced time perception has been often theorized as a result of changes in internal clock speed, it is not yet clear why external tempo influences internal tempo. In a similar vein, I do not know how exactly external tempo manipulations implemented in our experiments influenced anticipatory time perception and impatience. I leave this question for future research. This article, however, shed a new light on the nature of anticipatory time perception. Because most research on time perception has been focused on humans and animal's perception of elapsed time, almost nothing has been known regarding the nature of anticipatory time perception. My results of the significant association between experienced time perception and anticipatory time perception, and the influence of external tempo on judgment of anticipatory duration suggest that these two types of time perception are highly related in one of two ways.

Firstly, the same brain region that is dedicated to processing temporal information may govern both experienced and anticipatory time perception processes. Second, even if two types of time might be processed by distinctive brain regions, one would serve as a perceptual input for the other. That is, when individuals estimate anticipatory time, they may rely on perception of current time passage and project it for estimating future duration, or, on the contrary, their perception of experienced time might be influenced by how they perceive anticipatory duration. Future research is expected to address these intriguing questions further.

V. ESSAY IV

WHEN BRAIN SCIENCE MAKES PEOPLE TO BE IMPATIENT: PERCEIVED LIFE SPAN, TIME PERCEPTION, AND INTERTEMPORAL PREFERENCES

ABSTRACT

A recent brain study showed a high correlation between the speed of tapping and myelin integrity in the brain, both of which peak at age 39 and sharply decline thereafter. While such academic findings intend to increase audiences' understanding of relevant phenomena, wide media coverage may result in a non-intended effect: when young people are informed when their mental ability starts declining, it may make their perceived life span subjectively short. In this article, I demonstrate thata shortened life span may influence how people scale time (e.g., perceive 1-month duration to be longer), and lead them to be more impatient in making intertemporal trade-off decisions by influencing perceived waiting time until the receipt of delayed rewards.

WHEN BRAIN SCIENCE MAKES PEOPLE TO BE IMPATIENT: PERCEIVED LIFE SPAN, TIME PERCEPTION, AND INTERTEMPORAL PREFERENCES

A recent brain study, where male adults participated in a finger-tapping task and had their brain scanned, reports a high correlation between the speed of tapping and myelin integrity in the brain, both of which peak at age 39 and decline at an accelerating rate thereafter (Bartzokis et al., 2009). This finding has been widely covered in media including *Spirit* (Southwest in-flight magazine), *CBS News*, and *Telegraph* to name a few.

While such academic findings intend to increase audiences' understanding of relevant phenomena, wide media coverage on brain aging may result in a non-intended effect as well. That is, such information makes young individuals' perceived life span (i.e., perception of time to live) to be short that it would have been without it (Lang & Carstensen, 2002), which, in turn, influences various judgment and decision making in everyday life. Especially, in this report, we examine whether shortened life span due to the presence of information on brain aging makes people to be more impatient in intertemporal preferences (i.e., opt for smaller sooner outcome at the expense of larger delayed one) by influencing how they scale time.

Scarce objects are shown to be perceived as more valuable (Dai, Wertenbroch, & Brendl, 2008; Hirshleifer, Glazer, & Hirshleifer, 2006; King, Hicks, & Albdelkhalik, 2009). While the scarcity effect has been limited to the valuation of objects, we hypothesize that similar effect would reveal for time perception. That is, when people perceive short time to live, they perceive a given duration to be relatively long. People with short life span, then, would be more impatient in intertemporal decisions because they perceive the waiting time until the receipt of delayed rewards subjectively longer. In the following study, we manipulate participants' perceived life span by utilizing the brain aging research, and examined whether shortened life span increases impatience in intertemporal choice by changing their time perception. We further demonstrate that the perceived life span effect on impatience is not driven by changes in affective reaction to the manipulation.

Method

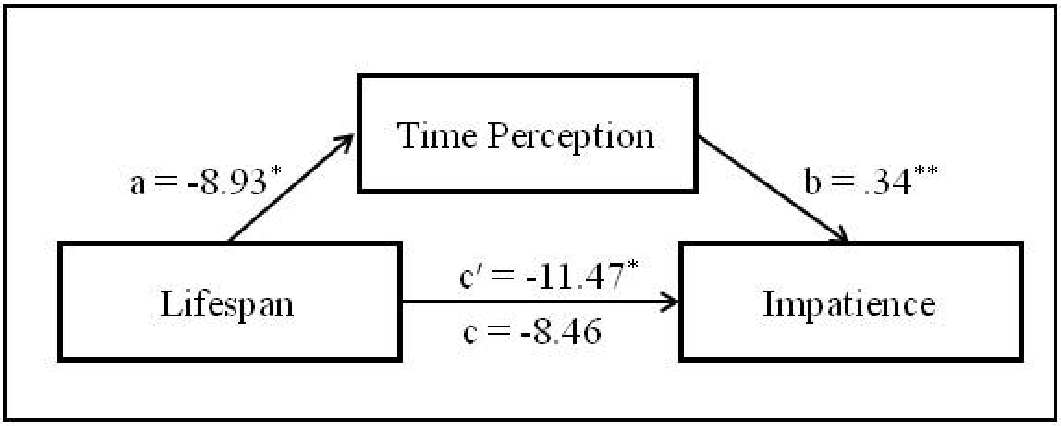
One hundred and sixty-four undergraduates (95 females; $M_{age} = 20.8$) were randomly assigned to two life span conditions (long vs. short). Participants in the long life span condition were informed that the life expectancy (i.e., the average length of survival) of people living in North America has reached 80 years while those in the short-lifespan condition were told that the optimal life expectancy (i.e., the average age before human brain function starts declining) has reached age 39. Below this information, they were provided with a pie chart (95*mm* in diameter) and asked to fill out the chart to indicate their current age. In the long life span condition, the chart was designed to be filled only one fourth by denoting each quartile as 20-year and the end point as age 80. In the short life span condition, the chart was designed to be filled half (e.g., each quartile denotes 10-year and the end point is age 40).

After the life span manipulation, participants' impatience using a standard delay-discounting task (Thaler, 1981): participants imagined receiving a $55 gift certificate valid today and redeemable at Amazon.com and indicated the dollar amount they would require instead if they had to wait for 3 months to receive it. Next, participants' subjective perception of 3-month duration was measured. They were provided with a 155*mm* continuous line scale worded as very short and very long to each endpoint, and then marked how long they consider the duration of 3-month to be on the scale. Finally, participants' affective states were measured using 20-item state anxiety inventory (Spielberger, Gorsuch, & Lushene, 1970) and 10-item Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). The order of these tasks was cross-balanced.

Results

Participants in the short life span condition requested more money to delay the receipt of $55than those in the long life span condition (M = $89.05 vs. $77.57), $t(163)=2.00$, $p=.047$, $p_{rep}=.88$, $d=.31$, indicating that participants became more impatient after the short life span manipulation. Participants in the short life span condition also perceived the same 3-month duration to be longer than those in the long life span condition (M = 56.26*mm* vs. 47.34*mm*), $t(163)=2.13$, $p=.034$, $p_{rep}=.90$, $d=.33$. I tested whether participants' subjective time estimates mediated the impact of life span manipulation on the degree of impatience (see Figure 12). A bootstrapping of the sampling distribution of indirect effect (Preacher & Hayes, 2004; Zhao, Lynch, & Chen, 2010) did not include zero in its 95% confidence interval (-7.32 to -.19), statistically confirming the mediating role of subjective time perception (see Figure1 for details). I further tested whether our manipulation changed participants' affective states which might influence their impatience for money. However, the state-anxiety measure did not reveal differences between life span conditions (M = 1.88 vs. 1.93), $t(163)=.58$, *ns*, so as the positive affect items (*M* = 25.11 vs. 25.53), *t*(163)=.36, *ns*, and the negative affect items in PANAS (*M* = 13.95 vs. 14.93), *t*(163)=1.08, *ns*.

FIGURE 12. MEDIATION OF LIFESPAN MANIPULATION ON IMPATIENCE BY SUBJECTIVE TIME PERCEPTION



The indirect path from the lifespan manipulation to the subjective time estimates, a = -8.93, *t* = -2.13, $p < .05$, the indirect path from the time estimates to impatience holding the manipulation constant, b = .34, *t* = 3.25, *p* =.001, were significant. The direct effect from the manipulation to impatience, c′ = -11.47, *t* = -2.00, $p < .05$, became reduced and insignificant after controlling the mediator, c = -8.46, *t* = -1.50, *ns*. Statistical significance of the coefficients is indicated by * ($p < .05$) and ** ($p < .01$).

General Discussion

In this report, I demonstrated that perceived life span manipulation using brain aging research led participants to be more impatient in intertemporal decisions by changing their perception of time, suggesting that there may be an unintended effect of brain aging research on everyday decision-making. Our results have intended effects as well. First, our results extend the inverse relationship between scarcity of objects and its valuation to the domain of time perception. A recent study showed that participants who were exposed to death-related words valued their life more positively (King, Hicks, &

Albdelkhalik, 2009). Our findings suggest that the similar relationship exists not just for the valuation of life but for the perception of time. Second, our results provide an empirical support for the role of time perception in impatience. There is a growing interest to investigate the role of time perception in intertemporal decisions (e.g., Killeen, 2009; Zauberman et al., 2009), and our results empirically demonstrate that individuals' impatience can be influenced by the changes in subjective time perception. In sum, we propose that brain aging findings may lead people to be more impatient by influencing how people scale time.

VI. GENERAL DISCUSSION

In four essays, I demonstrated the role of subjective time perception in intertemporal decisions. Specifically, I demonstrated that 1) sexually arousing images induce a greater degree of temporal discounting by shifting the psychophysical function of anticipatory time perception upward, 2) the spatial distance to the city where participants plan to retire or the distance on a hypothetical map influences their subjective estimates of prospective durations, which in turn results in changes in the degree of impatience in intertemporal decisions by implicating different waiting times until the receipt of delayed rewards, 3) auditory tempo, such as pulse sounds or beats in music, influence anticipatory time perception and subsequent time-related judgments, and 4) a perceived life span manipulation using brain research findings also led participants to be more impatient in intertemporal decisions by changing their perception of time. While I showed the impact of various factors on anticipatory time perception and subsequent intertemporal preferences, a remaining question is what can be learned more generally about the nature of anticipatory time.

Based on my findings in four essays, I conclude that anticipatory time perception shares both properties of *perceptual inputs* (e.g., people process anticipatory time *as if* they were "perceiving" elapsed time) and *embodied cognitions* (e.g., people mentally construe anticipatory time as they do other abstract concepts). That is, although anticipatory duration and experienced duration are different, both of them are governed by similar mechanisms determining the perception of time. Arousal and auditory tempo has been shown to influence human judgment of experienced duration by changing the speed of people's internal clock. The impact of sexually arousing images and auditory tempo on anticipatory time perception demonstrated in my essays implies the possibility that people process anticipatory durations as if they were perceptual inputs, being influenced by the working of an internal clock. On the other side, because anticipatory time is not explicit information that is directly perceived, anticipatory time perception is *construed* rather than *perceived*, and thus influenced by other cognitive information in the environment, revealing the nature of embodied cognitions. In the following sections, I detail these two aspects of anticipatory time perception.

Anticipatory time is processed as if it were an explicit perceptual input. Multiple theories of time perception have assumed the working of a biological pacemaker of one sort or another as a basic processor of experienced duration, and the pacemaker is known to be influenced by physiological arousal. Administration of dopamine-releasing agents like methamphetamine and judgment of affective stimuli were shown to induce overestimation in duration judgments, while decreased body temperature induced underestimation. The impact of tempo manipulation on experienced time perception is also often attributed to arousal; that is, the internal clock is a chemical entity, thus, arousal increases chemical activity of the pacemaker which in turn, emits pulses at a faster rate for the same time interval.

The demonstration in my essays that arousing stimuli (e.g., sexually arousing images or auditory tempo) influence anticipatory time perception replicates basic findings in the experienced time perception literature. But this similarity itself cannot be interpreted as evidence that anticipatory time is directly processed as a perceptual input and governed directly by the working of the internal clock. Rather, I propose that when people judge anticipatory time, there are no direct perceptual inputs, therefore they have to rely on the information they draw from their perception of time currently passing. Due to the reliance on experienced time perception in anticipatory time perception, anticipatory time may revealaspects similar to those of experienced time perception. Results from experiment 1 of my third essay support this view. In this study, participants estimated both experienced and anticipatory durations, and these estimations were found to be significantly associated, implying the possibility that the perception of experienced time is used as a perceptual input and guidespeople's judgment of anticipatory time perception.

Anticipatory time is construed. Because there are no direct perceptual inputs for anticipatory time perception, it is more plausible that anticipatory time is cognitively processed, being influenced by other information available in the environment during the judgment process. I propose there are at least two possible ways that anticipatory time is cognitively construed rather than directly perceived.

My second essay suggests one way that people rely on mental imagery of time. When communicating anticipatory duration, people often rely on the visual image of a horizontal line and depict the temporal relation of events along the line or use spatial metaphors to describe the length of the duration (e.g., a long vacation; Casasanto & Boroditsky, 2008). Thus, it is possible that when processing anticipatory duration, people may construe it as mental imagery (e.g., mentally visualize a line), and when time is mentally imaged as a spatial dimension, the spatial nature of mental imagery (Kosslyn, 1994) may affect the length of the imaged line and hence judgments of anticipatory duration and subsequent decisions. That is, if one imagines a long line in representing anticipatory duration, she may perceive the anticipatory duration to be long and subsequently discount the value of delayed outcomes in intertemporal decisions to a greater extent than someone who imagines the same duration as a shorter line. Furthermore, due to the multimodal and 'grounded' nature of mental imagery (Barsalou, 2008; Gibbs 2006; Wilson, 2002), how long people imagine the anticipatory duration to be is likely influenced by spatial information accessible when people formtheir mental imagery of time.

My fourth essay suggests a second way that people may construe anticipatory time as a valuable resource. That is, even when they estimate the duration of anticipatory time and not when they judge the value of it, they may still treat time as a resource rather than as perceptual information. Viewing time as a resource is frequently observed in everyday life and diverse literature. The adage, first used by Benjamin Franklin and by many others later, "Remember time is money", well demonstrates this view of time as a resource. In the marketing literature, many researchers have compared whether and how people value time and money differently (Okada & Hoch, 2004; Zauberman & Lynch, 2005). These lines of research assumed time was a resource like money and measured participants' valuation of time or emotional reactions to time usage. Although valuation of time and estimation of duration are not the same processes, anticipatory time perception is often made in the context of value judgment. That is, people judge the anticipatory duration of a given amount of time not simply to assess duration, but to make decisions about whether spending that time in a particular way would maximize their utility or whether that time is worth trading off for other resources (e.g., money). For example, people estimate the anticipatory time of waiting in a line at a cafeteria not merely because they want to know about the duration, but to make a decision about whether it is worth the wait. Therefore, anticipatory time may be processed as a valuable resource that is limited and thus should be used well.

To summarize, because there are no explicit perceptual inputs to be *perceived* in anticipatory time perception, people need to rely on other information relevant to their time perception, such as their perception of experienced time and other cognitive information available at the time when they judge anticipatory duration.

Conclusion

In my dissertation, I first established the relationship between anticipatory time perception and impatience. Specifically, I proposed and showed that both *diminishing sensitivity* to longer time horizons (i.e., how long individuals perceive short time horizons to be relative to long time horizons) and the level of *time contraction* overall (i.e., how long or short individuals perceive time horizons to be overall) contribute to how much individuals discount the value of delayed outcomes. Second, I demonstrated two different aspects of anticipatory time perception: 1) anticipatory time is processed *as if* it were an explicit perceptual input, and 2) anticipatory time is cognitively construed. Taken together, my dissertation essays incorporate both anticipatory time perception research and consumer research on time-related judgment and decision making and shed light on both domains.

VII. BIBLIOGRAPHY

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