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Perception of Anticipatory Time in Temporal Discounting

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The current article focuses on the role of anticipatory time perception in temporal discounting. We propose a perceived-time–based model and demonstrate that 2 aspects of time perception are relevant to hyperbolic discounting. Specifically, our model states that *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 the degree of hyperbolic discounting. We estimate individual differences in the degree of diminishing sensitivity to time and the degree of time contraction, and demonstrate that each significantly predicts the degree of hyperbolic discounting. These results empirically confirm two unique aspects of anticipatory time perception in determining individuals' temporal discounting.

Keywords: hyperbolic discounting, impatience, time perception

Perhaps the most documented finding in the intertemporal choice literature is 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). Such time-dependent discounting (as opposed to constant rate 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 get closer to the present (Kirby & Herrnstein, 1995; Strotz, 1955). Another important manifestation of time-dependent 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).

There is now a substantial body of empirical evidence demonstrating time-inconsistent discounting (often referred to as *hyperbolic discounting*[1]) 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),

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[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 article, we use the term *hyperbolic discounting* to denote not the specific functional form of discounting but this broad tendency.

and a quasi-hyperbolic discount function (e.g., Laibson, 1997).

Thus, 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?

Our main objective in this article is to present a model of intertemporal preferences which centers on how people perceive future time. Our goals are to present theoretical arguments and a formal model, and to provide empirical support that extends existing findings. We first review current explanations of hyperbolic discounting, contrasting various behavioral theories with our perceived-time–based model. We then present an experiment designed to empirically test this model, with a specific emphasis on how individuals' idiosyncratic time perception contributes to individual differences in temporal discounting, an aspect that has so far been relatively neglected.

Psychological Determinants of Hyperbolic Discounting

In recent years, 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, we denote these explanations as *perceived-value–based accounts.* We contrast these explanations with our *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.

More recent attempts to explain hyperbolic discounting have focused on the role of the cognitive representation of outcomes. For instance, individuals who represented outcomes abstractly (vs. concretely) showed a lower degree of present bias (Malkoc & Zauberman, 2006; Trope & Liberman, 2003), as did those who were primed to adopt a high-level construal (Fujita, Trope, Liberman, & Levin-Sagi, 2006; Malkoc, Zauberman, & Bettman, 2009) or those who expected to have greater change in available resources (slack) from the present to the future (Zauberman & Lynch, 2005).

Perceived-Time–Based Account

While 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; Read, 2001; Takahashi, 2005; Zauberman, Kim, Malkoc, & Bettman, 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—1 year is not subjectively perceived to be four times longer than 3 months. Because of such biased time perception, individuals can have a constant discount rate over subjective time while still appearing to discount 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 (e.g., the Weber-Fechner Law or Stevens' Power Law), it is not clear whether the same phenomenon will be observed in perceptions of *anticipatory time* (i.e., future time that decision makers have not experienced but have to incorporate into intertemporal decisions). In the first empirical test of this hypothesis, Zauberman and colleagues (2009) measured participants' perception of various anticipatory time horizons and found that nonlinear functions (both log and power functions) fit the subjective time estimates better than a linear function, confirming diminishing sensitivity to anticipatory time. Zauberman et al. (2009) further tested whether the nonlinear scaling of anticipatory time could account for decreasing discount rates. They found that annual compound discount rates calculated without considering participants' subjective time estimates were decreasing as a function of time (i.e., hyperbolic discounting). However, when the subjective time estimates were accounted for, discount rates were no longer decreasing for most time horizons (i.e., exponential discounting). These results imply that consumers who scale time nonlinearly may behave *as if* they have decreasing discount rates when they in fact have constant (i.e., exponential) discount rates.

Building on these findings, the current article aims to achieve the following objectives: First, we present a formal model of our perceived-time–based account of temporal discounting in which 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 a greater degree of hyperbolic discounting. Second, although Zauberman et al. (2009) empirically demonstrated the role of nonlinear time perception in hyperbolic discounting, they did not focus on individual variations. In this article, we estimate each participant's degree of diminishing sensitivity in time perception and their individual level of time contraction; we then test whether the two measures predict hyperbolic discounting at the individual level. In addition, in terms of methodology, Zauberman et al. (2009) measured anticipatory time perception using a continuous time scale, which might have restricted participants' response range and thus exaggerated the degree of nonlinearity. To test for this possibility, we measured participants' time perception using a physically unbounded scale.

A Perceived-Time–Based Model of Temporal Discounting

This model separates temporal discounting into an internal discounting process and a time perception process, which provides us the ability to test the extent to which hyperbolic discounting can be attributed to a time perception process versus an internal discounting process.

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

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

We assume that the "true" internal discounting process is exponential, but we 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.

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

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 perceived time rather than calendar time).[2] Next, to incorporate the nonlinear scaling nature of time perception, we define T as a function of objective time. Either a log function or a power function can be used (e.g., the Weber-Fechner Law or Stevens' power Law); in the current demonstration, we used the power function as shown below (see Takahashi, 2005, for a similar demonstration using a log function).

$$\mathrm{T} = \alpha \cdot \mathrm{t}^{\beta} \qquad (3)$$

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[2] In equation 2, R reflects the rate of discounting with respect to perceived delays. We used R instead of r because by convention r often refers to an annual compound discount rate measured over calendar time, as defined in equation 1. Although we see R as a measurable construct separate 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.

In Equation 3, T is the subjective perception of objective time t, α captures the *overall* level of time contraction, and β captures the degree of nonlinearity (diminishing sensitivity to time). In most analyses of hyperbolic discounting, individuals 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 a positive number less than 1 to incorporate diminishing sensitivity to anticipatory time horizons.

When nonlinear 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.

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

Equation 4 represents hyperbolic discounting when $0 < \beta < 1$.[3] 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 different from previous models in the use of two parameters to capture the time perception process. That is, while previous models consider only the diminishing sensitivity to time as being responsible for the degree of hyperbolic discounting, we 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 of perception or an arbitrary scaling parameter. Similar issues have been heavily debated in the psychophysical scaling literature (for more details, see the debate between Mellers [1983] and Zwislocki [1983]). Despite this disagreement, we 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).[4] 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) depict 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; 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 our 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.

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 photographs of attractive females revealed a greater degree of hyperbolic discounting in a delay discounting task of monetary outcomes compared to those who rated nonattractive fe-

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[3] Instantaneous discount rate over calendar time can be defined as $-\frac{D(t)'}{D(t)}$ (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.

[4] The difference in instantaneous discount rates measured at different points 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 $R > 0$.

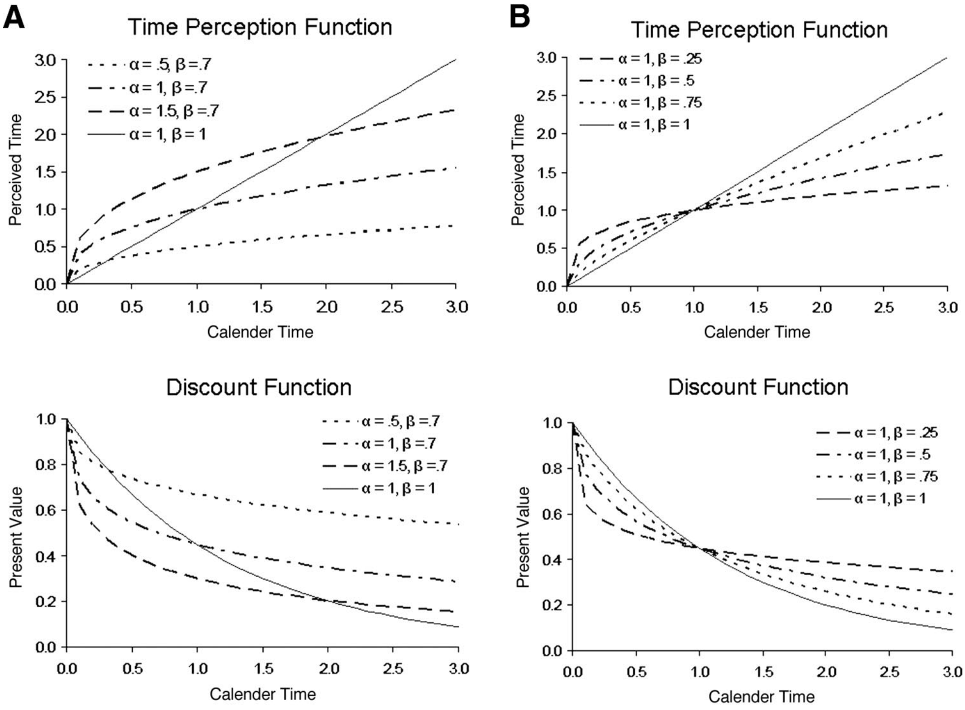

Figure 1. (A) Time perception functions and corresponding discounting functions at different values of the α parameter. (B) Time perception functions and corresponding discounting functions at different values of the β parameter.

males (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 (2009a) 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 nonlinear scaling parameter to reflect time perception would not allow researchers to uniquely capture this time perception process.

In the following study, we empirically test whether our perceived-time–based model with two time-perception parameters can explain hyperbolic discounting. Our analysis focuses on linking time perception to individual-level variation in temporal discounting. Specifically, we aim to show that time perception explains not only hyperbolic discounting at the aggregate level analysis (e.g., Zauberman et al., 2009), but also individual level preferences. In addition, based on the proposed perceived-time–based model, we aim to demonstrate that both aspects of time perception, diminishing sensitivity to time (β) as well as time contraction (α), are related to the degree of hyperbolic discounting.

Experiment

The current study empirically tests our perceived-time–based model of temporal discounting. Specifically, by applying our perceived-time–based model, we aim to show that hyperbolic discounting depends not just on diminishing sensitivity to time (β) but also on the level of time contraction (α).

Beyond replicating the basic effect in the context of the current model, this study was designed to achieve two important goals. The first goal was to address a potential methodological limitation of Zauberman et al. (2009). They measured participants' nonlinear time perception with a continuous line scale, in which the left and right anchors of the scale were labeled as very short and very long. While the authors varied the anchor labels and found no effect on responses (see the web appendix of Zauberman et al., 2009), their scale was always physically bounded in its range. This may have caused more contraction of time horizons by restricting participants' response range, resulting in an exaggerated degree of nonlinearity (i.e., smaller β parameter values). To test for this possibility, in this experiment we used a physically unbounded line scale, applying cross-modality matching methods (e.g., participants directly match the perceived magnitude of the unbounded line to the perceived magnitude of time horizons; Epstein & Florentine, 2006).[5] The second goal of this study was to extend Zauberman et al.'s (2009) analyses to test how individual differences in time perception account for individual variations in discount rates. In this study, we estimated each participant's degree of nonlinear time perception (β) and level of time contraction (α), and tested whether these two variables predicted the degree of hyperbolic discounting at the individual level.

Method

Sixty-six undergraduate students (37 women; $M_{\text{age}} = 20.17$, $SD = 1.58$) at the University of Pennsylvania participated in this study as part of a 1-hr-long session and received $10. Participants were informed at the beginning of the study that they would be estimating 12 time horizons ranging from 3 months to 36 months. For each of the 12 time horizons, presented in random order, participants indicated the magnitude of the perceived duration by adjusting the length of an unbounded line. For instance, participants were asked to consider the duration of the time period starting today and ending 3 months from today. They then reported the perceived duration of this time period by adjusting the line length using the left or right arrow keys on the computer keyboard. At the beginning of each trial, a black, square shaped bar (40 by 40 pixels) was shown on the left side of the computer screen. When the arrow key was pressed, the bar became longer or shorter. The theoretical upper boundary of the scale was infinite: when the length of the bar exceeded the physical boundary of the screen, a scroll bar appeared at the bottom of the screen to allow participants to look over the entire length of their response. After completing the time perception tasks, participants responded to a standard intertemporal preference task for the same durations (from 3 month to 36 months in a random order): participants considered an immediately available $75 gift certificate and then indicated how much they would have to be paid to delay receipt of this certificate by each of the durations.

Results and Discussion

To construct the subjective time perception measure, the physical length of the unbounded bar was transformed into a monthly unit. Specifically, the mean distance for the 3-month time horizon was set equal to 3 months (e.g., $M_{3\text{ months}} = 13.62$ mm, so 13.62 mm of physical length represents 3 months of subjective time). Next, to assess the extent of nonlinearity, these monthly estimates were fitted with both a nonlinear function $T = \alpha t^{\beta}$ and a linear function $T = \gamma + \delta t$, using maximum likelihood estimation. Replicating Zauberman et al.'s (2009) results and confirming our model assumption that β is less than 1 (i.e., time perception is nonlinear), fit statistics indicated that a nonlinear function $T = 1.05t^{.72}$ fit the data better than a linear function $T = 2.43 + .37t$ ($BIC = 3{,}062.8$ vs. 3,128.8).

We next examined the model assumption that the internal discounting process is exponential, after controlling for subjective time perception. In our experiment, we treated the perceived-time–based discount rate, R, as the remaining variance in discounting after subjective time perception is fully accounted for. Therefore, we calculated each participant's idiosyncratic perceived-time–based discount rate, R, from the data using equation 4 in

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[5] The perception of line length has been shown to be directly proportional to its actual length (Gescheider, 1985), and thus responses on this scale can capture the nonlinearity of time scaling. Therefore, there is no need for further functional transformation of the responses.

our model ($D(t) = e^{-R \cdot \alpha \cdot t^{\beta}}$) 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 *ith* participant. We estimated the α and β parameters of each participant using the following equation, ($\ln T_i = \ln \alpha_i + \beta_i \ln t$). If the calculated perceived-time–based discount rate, *R*, is decreasing as a function of time horizon, it indicates that the internal discounting process is hyperbolic rather than exponential. We 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 time perception. A 12 (time horizon) × 2 (discount rate: perceived-time–based vs. calendar-time–based) repeated measures analysis of variance (ANOVA), with both time horizon and discount rate measure as within-subjects factors, revealed a significant time horizon by discount rate interaction, $F(11, 715) = 9.60$, $p < .001$, indicating that the pattern of discount rates differed as a function of whether discount rates were computed with respect to calendar or perceived time (see Table 1 and Figure 2).

In perceived-time–based discounting, planned contrasts looking at changes in discounting between pairs of adjacent time horizons revealed that decreasing discount rates were observed only 2 out of 11 pairs of comparisons (e.g., t_6 vs. t_9, $F(65) = 5.39$, $p < .05$; t_5 vs. t_6, $F(65) = 10.51$, $p < .01$). 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 vs. t_6; t_6 vs. t_9; t_{15} vs. t_{18}; t_{21} vs. t_{24}; t_{30} vs. t_{33}; t_{33} vs. t_{36}; $F(65) = 5.16$ to 28.19, all *p*s $< .05$). These results indicate that, across participants, nonconstant discounting (i.e., hyperbolic discounting) was more pronounced in observed behavior (i.e., calendar-time–based discount rate) than in their internal discounting process (i.e., perceived-time–based discount rate).

Next, we examined the predictions of the perceived-time–based model that either an increase in α or a decrease in β would lead to a greater degree of hyperbolic discounting at the

Table 1
Mean Annual Compound Discount Rates Calculated Separately for Objective and Subjective Time

Variable	Time horizons in months											
	3	6	9	12	15	18	21	24	27	30	33	36
R	.75 (.68)	.66 (.59)	.59 (.51)	.59 (.45)	.62 (.45)	.56 (.42)	.57 (.40)	.54 (.39)	.56 (.37)	.56 (.38)	.55 (.37)	.53 (.36)
r	1.19 (.95)	.89 (.73)	.68 (.46)	.63 (.40)	.63 (.39)	.52 (.31)	.52 (.31)	.49 (.26)	.48 (.25)	.47 (.24)	.45 (.24)	.41 (.22)

Note. *R* (perceived-time–based discount rate) is calculated using the perceived-time–based model, $D(t) = e^{-R \cdot \alpha \cdot t^{\beta}}$, and *r* (calendar-time–based discount rate) is calculated using the exponential discount function, $D(t) = e^{-r \cdot t}$. Numbers in parentheses show *SD*.

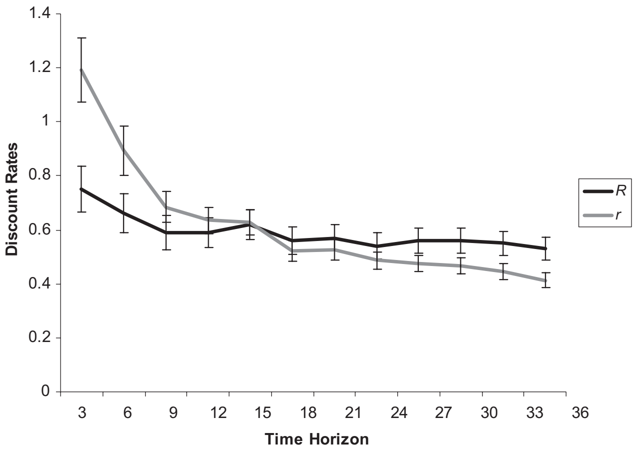

Figure 2. Mean annual compound discount rates calculated separately for objective and subjective time. *R* is a perceived-time–based discount rate, and *r* is a calendar-time–based discount rate. Error bars indicate *SEM*.

individual level. That is, we tested whether a participant's individual level α and β parameters can significantly predict the participant's degree of hyperbolic discounting. We estimated the degree of hyperbolic discounting by estimating the degree of hyperbola in a discount function (Mazur, 1984), $D_i(t) = 1/(1 + k_i t)$.[6] The estimated parameter values revealed a significant positive correlation between the degree of time contraction (α_i) and the degree of hyperbola (k_i) [$r = .27$, $p < .05$] and a negative correlation between the degree of diminishing sensitivity (β_i) and the degree of hyperbola (k_i) [$r = -.28$, $p < .05$], supporting our predictions that both an increase in the α parameter value or a decrease in the β parameter value across individuals is associated with a greater degree of hyperbolic discounting. That is, as individuals perceive time horizons to be longer overall or perceive time more nonlinearly, they deviate more from exponential discounting, as predicted by our perceived-time–based model of temporal discounting.

Taken together, our results confirm two major ways in which anticipatory time perception determines temporal discounting: diminishing sensitivity to longer time horizons (i.e., how sensitive are individuals' time perceptions to changes in anticipated duration), and the overall level of time contraction (i.e., how long or short individuals perceive a given time horizon to be). We find the two effects at both the aggregate (e.g., Zauberman et al., 2009) and on the individual level.

General Discussion

The main goal of this article was to present an argument for the importance of considering the role of time perception in temporal discounting, a perspective that only recently has started to receive attention and empirical investigation (e.g., Zauberman et al., 2009). We present a perceived-time–based model of temporal discounting and provide empirical evidence supporting this model. The current model is important in that it formalizes how specific patterns in time perception can correspond to changes in the pattern of temporal discounting. Specifically, the two parameters distinguish the effect of overall contraction of time (α) and the effect of diminishing sensitivity (β). Empirically, we found that participants' degree of hyperbolic discounting is positively associated with level of contraction and negatively associated with diminishing sensitivity. These results provide support for our approach.

Methodologically, because we applied a physically unbounded scale in the current study (adapted from psychophysics), we can compare

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[6] The estimated aggregate level hyperbolic discount function was $D(t) = 1/(1 + .72t)$.

our results to results in the time perception literature. Many previous studies in psychophysics examined the nonlinear scaling of time, focusing mainly on perception of the actual passage of time for intervals lasting a few milliseconds to a few seconds. The current study demonstrated that human perception of anticipatory time (i.e., prospective duration of future time intervals that individuals have not experienced) is also nonlinearly scaled. It is interesting to note that the estimated mean β parameter value in the current study was .72, which is smaller than the reported power of .90 to .99 in studies examining the perception of the actual passage of time (Bobko, Thompson, & Schiffman, 1977). While very speculative, this may indicate that perceived duration is more contracted in anticipation than in experience. Future research controlling the length of the duration should further investigate this question.

Although the study we presented was designed to examine specific predictions, we believe anticipatory time plays a more general role in human time-related judgment and behavior. Various empirical studies in the literature have reported a wide individual and group differences in measured discount rates among participants. For instance, in the experiment of the current paper, two participants indicated the present value of a $75 gift certificate delayed by 3 months to be $75, revealing zero discounting, while two other participants indicated it to be $200, revealing an annual compound discount rate of 392.33%. In prior research, substance abusers of alcohol or heroin were shown to discount delayed monetary rewards more steeply compared to normal controls (Bickel et al., 1999; Charbris, Laibson, Morris, Schuldt, & Taubinsky, 2008; Dixon, Marley, & Jacobs, 2003; Kirby & Petry, 2004; Mitchell, 1999; Reynolds, 2006; Vuchinich & Simpson, 1998). In addition, many individual difference variables (e.g., age, income, intelligence) have been found to covary with measured discount rates (Frederick, 2005; Green, Fry, & Myerson, 1994; Kirby et al., 2002; Shamosh et al., 2008). While these individual and group differences in temporal discounting have often been attributed to individual's impulsive reactions to immediate (vs. delayed) outcomes, we suspect that many of these findings can be explained, at least in part, by the differences in time perception.

To provide preliminary support for this argument, in a separate study, we measured participants' time estimates (e.g., perceived anticipatory duration of 1 and 3 months) and their self-report trait impulsivity, and compared these measures in terms of their ability to predict temporal discounting (Kim & Zauberman, 2009b). For the time perception and temporal discounting measures, we used tasks similar to the one used in the main experiment of the current paper. For trait impulsivity, we used the 30-item Barratt Impulsiveness Scale with three subfactors of Attentional Impulsiveness, Motor Impulsiveness, and Nonplanning Impulsiveness (BIS-11; Patton, Stanford, & Barratt, 1995) and the 36-item Self-Control Scale (SCS; Tangney, Baumeister, & Boone, 2004). This experiment revealed no support for an association between trait impulsivity and temporal discounting. Temporal discounting was not predicted by the total BIS score, the BIS subdimensions, or SCS scores. Only the measured time estimates predicted temporal discounting. Specifically, participants' individual-level degrees of temporal discounting, measured as the hyperbolic discounting parameter (k; Min $= 0$, Max $= 17.33$, $M = 2.23$, $SD = 2.74$), were significantly correlated with their time estimates ($r = .31$, $p < .001$). While very preliminary, these results imply that various psychological variables that have been shown to be associated with differences in discount rates, such as age, income, or intelligence, may be due to the individuals' perception of time delays rather than differences in impulsive reactions. For example, those who are substance abusers, younger, have low income, or are less intelligent may perceive the same delays to be longer than those who are nonsubstance abusers, older, have high income, or are more intelligent. Future research should study these and other questions about the link between delay discounting and factors that have been assumed to change discounting by changing the (de)valuations of outcomes by addressing the role of time perception.

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