How did it get so late so soon? The effects of time distortion on discounting

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Abstract: *(The paper is preliminary, please do not quote)*

In this paper, we study the role of subjective time perception in influencing intertemporal choice. When choosing between a smaller sooner and a larger later reward, an individual considers both the magnitude of the rewards and their distance in time. Here, we test the idea that when subjective time does not match the clock time, prospective time delays diverge from the observed calendar delays, generating more or less patient choices. We designed a laboratory experiment to test this idea. In our experiment, we exogenously induced time distortions through an external stimulus. We found that time distortion does indeed affect elicited discount rates. The results of our study present new theoretical and methodological challenges to behavioral economists.

Keywords: Time perception, discounting, laboratory experiments
JEL: C91, C92, D03, D99

"How did it get so late so soon? It is night before afternoon. December is here before June. My goodness how the time has flewn. How did it get so late so soon?" ~Dr. Seuss

1. Introduction

Prevalent theories of inter-temporal choice assume that decision-makers share identical time duration, which is exogenously determined by the external clock or calendar time. This assumption is also predominant in behavioral models that aim at explaining observed biases in inter-temporal decisions through the fitting of non-conventional discount functions (e.g., hyperbolic and quasi-hyperbolic discounting). Indeed, neither approach allows for the possibility that individuals distort time and that the perceived or subjective time may not be the same to everyone all the time and identical to the observed clock time. Yet, why should a given time duration feel to be the same to you as to me? And, why should our perception of time duration be exactly the same as the clock time under all circumstances?

The idea that people may be prone to distorting time is not new. Indeed, since the pioneering work of (Hoagland, 1933, 1935), time distortions have attracted much attention in both psychology and neuroscience. Psychologists and neuroscientists contend that our internal clocks and the external clock typically do not match and that time is both expandable and contractible; that is, an individual can both overestimate (expand) and underestimate (contract) the actual duration of time (Eagleman, 2008; van Wassenhove, Wittmann, Craig, & Paulus, 2011; Wittmann, 2009; Wittmann & van Wassenhove, 2009). In addition, experimental evidence suggests that individual characteristics, such as gender and age and external factors, such as sound and illumination can influence our perception of time (Block, Hancock, & Zakay, 2000; Brañas-Garza, Espinosa-Fernández, & Serrano-del-Rosal, 2007; Eisler, 1976; Goldstone, Lhamon, & Sechzer, 1978; Hancock & Hancock, 2013; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007; Rammsayer, 1997; Van Hagen, Galetzka, Pruyn, & Peters, 2009; Wearden & Penton-Voak, 1995). Although the exact brain processes underlying the experience of time are not well understood, it is believed that our sense of time is primarily (but not uniquely) mediated by the activation in dopamine receptors located in the basal ganglia (Allman & Meck, 2012; Droit-Volet & Gil, 2009; Geoffard & Luchini, 2010; Pine, Shiner, Seymour, & Dolan, 2010; van Wassenhove et al., 2011; Wiener, Lee, Lohoff, & Coslett, 2014; Wittmann & van Wassenhove, 2009). These and related pharmacological studies reveal that when dopamine levels increase, the internal clock speeds up, resulting in subjective time expansion. When dopamine levels are reduced, the internal clock slows down, resulting in time contraction.[1]

To establish a theoretical link between the external clock time and subjective time, researchers have used psychophysiological relationships that connect the magnitude of a stimulus to its perceived intensity. One of these relationships is the Steven's Power Law (SPL) (Stevens, 1957). The SPL is a two-parameter power function.[2] In the time domain, the SPL shows how perceived or subjective time, $s(t)$, and the external clock time, *t*, relate. More specifically, $s(t) = \tau t^{\eta}$. Psychologists have used the SPL to empirically estimate the kind and degree of prospective time distortion (Eisler, 1976; Laming, 1997). The parameter η is a measure

[1] Scientists have shown that when affected by Parkinson's disease or AHAD, humans show impaired duration discriminations (Allman & Meck, 2012); time distortions are also observed after administering dopamine receptor agonists or antagonists. Antagonists, such as haloperidol and raclopride produce a decrease in clock-speed or time contraction, making perceived time feel going fast. In contrast, dopamine agonists such as levodopa, cocaine and methamphetamine appear to make time speed up or time expansion, making the perceived duration of the external clock stop to a crawl (Drew, Fairhurst, Malapani, Horvitz, & Balsam, 2003; Maricq & Church, 1983; Pine et al., 2010). For a complete review of the literature on internal and external influences on time perception, please see Park (2016).

[2] The mathematical foundations or primitives of psychophysical laws were developed by Duncan Luce and co-authors in a series of studies published in the 2000s. These studies provided foundational support for the power function as a testable prediction of a sensation measurement theory about how physical stimuli and behavioral responses relate. For a review of these contributions, please see Steingrimsson (2016).

of distance scaling that expresses our sensitivity to the experience of time duration, whereas τ is a proportionality constant that can capture time-invariant individual differences in time perception (Glicksohn, 1996; Glicksohn & Hadad, 2012; Ivry & Hazeltine, 1995). For example, when η and τ equal 1, there is no time distortion. In contrast, an individual who ever compresses time would have values of $\tau, \eta < 1$, reflecting a concave relationship between clock and perceived time for all *t*. Similarly, an individual who ever expands time would have a value of $\tau, \eta > 1$, reflecting a convex relationship between *t* and $s(t)$ for all *t*.

In recent years, a few economists have considered how time distortions may influence time preferences. These studies have generally implied that reductions in the anticipatory duration of temporal length (i.e., time contraction) can account for hyperbolic discounting (Bradford, Dolan, & Galizzi, 2013; Brocas, Carrillo, & Tarraso, 2016; Kim & Zauberman, 2009; Ray & Bossaerts, 2011; Read, 2001; Zauberman, Kim, Malkoc, & Bettman, 2009).[3] In these studies, it is argued that when temporal distance is longer, humans perceive time as ever compressing, resulting in decreasing discount rates over time or myopic (short-sighted) behavior. These studies, however, do not consider the possibility of time expansion; a phenomenon which has been extensively documented by psychologists and neuroscientists, and may be linked to hyperopic discounting or discount rates that increase over time (see Frederick, Loewenstein, and O'Donoghue (2002); Kivetz and Simonson (2002); Loewenstein and Prelec (1991); Loewenstein and Prelec (1993); Sayman and Öncüler (2009); Takeuchi (2011)).

In this paper, we are interested in whether induced time distortions can influence elicited discount rates. Indeed, traditional discount rate elicitation mechanisms that rely on subjects choosing between a smaller sooner and larger later reward assume that the delay or "waiting time" is the same to all subjects and is identical to the clock or calendar time. Yet, whenever t is not equal to $s(t)$, the elicited discount rate is an estimate of the individual discount rate in distorted time, $s(t)$, not in clock time t, and $s(t)$ is generally not observed. Thus, we designed a laboratory experiment where we measured individual prospective subjective time, $s(t)$, and exogenously induced time distortion through a subtle external stimulus: tempo. There are several

[3] Researchers including (Ebert & Prelec, 2007; Kim & Zauberman, 2009; Zauberman et al., 2009) and more recently Brocas et al. (2016), have used the SPL to correlate time distortion with hyperbolic discounting. Takahashi (2005); (2006) used the Webber-Fletcher Law, which assumes a logarithmic (concave) relationship between subjective and clock time.

reasons for why we used tempo. First, it is believed that simple structural properties of music affect central neurotransmission in the automatic nervous system and dopaminergic networks (see Chanda and Levitin for a review of the literature). Moreover, previous experimental studies on the effects of music on time perception have identified tempo as a major factor in generating time distortion (Droit-Volet & Zélanti, 2013). Finally, we believe tempo is a relatively simple stimulus to implement in the lab and can be replicated experimentally by anyone who has access to headphones. In our experiment, we assigned subjects to one of three different tempo conditions that varied only slightly with respect to the number of beats-per-minute or BPM. To test the effects of time expansion and contraction, we measured time preferences using a multiple-time-list (MPL) as in Coller and Williams (1999) and Harrison, Lau, and Williams (2002), before and after the three tempo conditions.

We measured time distortions following the psychophysiological laws relating external stimuli and response as described by the Steven's Power Law. By estimating the time distortion parameters, η and τ, we found that people both contracted and expanded time. We also estimated individuals' discount rates before and after the tempo intervention to see whether induced time distortion affected inter-temporal choices. Our analyses reveal that higher tempo conditions yielded estimated discount rates that were 8.3% higher, on average. In addition, longer anticipatory duration of time predicted higher discount rates. More specifically, a one day overestimate of subjective horizon added about 0.34 extra points to the elicited discount rates.

Unlike previous works, here, we also explore the possibility that both time contraction and time expansion can affect the choice between smaller sooner and larger later rewards. In addition, the temporal length of the delay reward itself can induce contraction and expansion. That is, a duration of three weeks, for example, may seem 'too short' whereas five weeks may seem 'too long', resulting in both increasing and decreasing discount rates over time. Consequently, our approach is more comprehensive and allows for the coexistence of both myopic decision-making, such as procrastination and failure to diet, and far-sighted decision-making, such excessive saving (Keinan & Kivetz, 2008; Kivetz & Simonson, 2002). In addition, this approach may help us elucidate puzzling behaviors, including the interval effect (Scholten & Read, 2006, 2010) and context-dependent discounting (Urminsky & Zauberman, 2016). Finally, we are the first to show that externally induced time distortions affect our measures of time preferences. This, we believe, has important theoretical and methodological implications for our

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discipline. Indeed, so far, economists interested in modeling non-standard time preference have concentrated their efforts in finding the curve that best fits the data. Instead, through this work, we hope to encourage behavioral economists to take a more serious look at the psychology of time. It may be possible to build models of choice that are both parsimonious and true to the empirical evidence regarding human decision processes. Methodologically, our results present a challenge to those who are interested in eliciting individual time preferences, as it may be difficult if not impossible to observe them with the current approaches.

The rest of the paper is organized as follows: we first briefly review the Steven's Power Law and show how time contraction and expansion can vary based on the time duration and the two parameters in the SPL. In section 3 we describe how time distortion relates to discounting. Sections 4 and 5 include the experimental design and the results, respectively. We end the paper with a discussion.

1. Psychophysical Laws in the Time Domain

Since the pioneering work of Hoagland (1935), psychologists have believed that humans have different time senses and have postulated two laws in psychophysics—the Weber-Fechner law and the Stevens power law —to formulate a structural relationship between the external clock time and subjective time perception. Let p be a perception, s a stimulus, and K ia a constant. The Weber-Fechner law says that differential perception, dp, is proportional to the relative change in stimulus, $\frac{ds}{s}$; that is, $dp = K\,\frac{ds}{s}$ and $p = K \log s$. In time domain, the Weber-Fechner law suggests a logarithmic relationship between time duration, t, and its subjective perception, $s(t)$. This relationship implies that longer temporal distance becomes increasingly compressed. Namely, individuals perceive temporal length as shorter when it is more distant in time. Thus, subjective time perception can account for why discount rates decrease over time, rendering hyperbolic discounting (Takahashi, 2005, 2006).

Another approach of the psychophysics of time perception is the Stevens' Power Law (SPL). The SPL establishes a relationship between perceived duration of time, $s(t)$ and the physical time, t, such that $s(t) = \tau t^{\eta}$. The parameter η is a measure of distance scaling that expresses the sensitivity of time duration. When its value is equal to 1, there is no time distortion.

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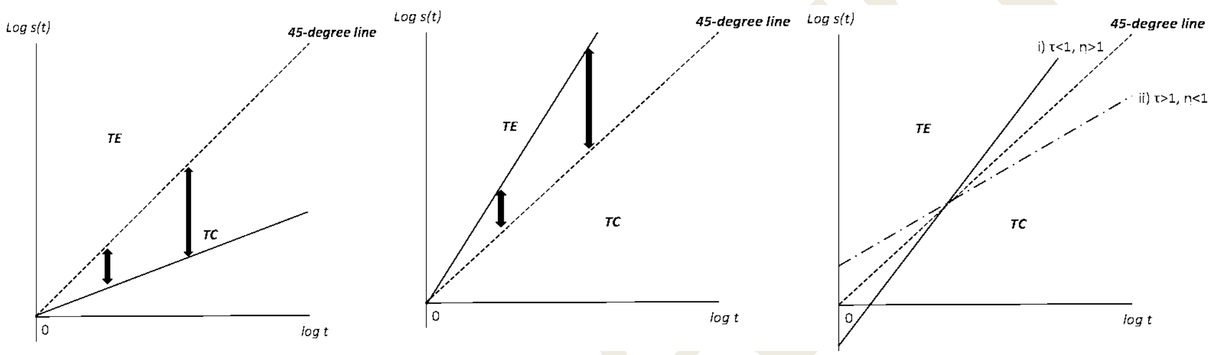
The parameter τ is a proportionality constant that can capture time-invariant individual differences in time perception. Figure 1 shows this relationship between t and $s(t)$ in log-log coordinates. The graphs help one visualize the effects of changes in τ, η and t on the perception of time. In the absence of time distortion, each value of τ and η would equal 1 and $s(t) = t$ as $\log s(t) = \log(t) \Leftrightarrow s(t) = t$. This is represented by the 45° line that also separates time expansion (TE), shown above the 45° line, from time contraction (TC), shown below this line.

Figure 1. Time Distortion in Log-log Coordinates

Pane (A): Time contraction Pane (B): Time expansion Pane (C): Time cont. & exp.



Previous literature has all but ignored the effects of τ and restricted the value of the power exponent to be $0 < \eta < 1$ (Ebert & Prelec, 2007; Kim & Zauberman, 2009, 2013; Radu, Yi, Bickel, Gross, & McClure, 2011; Read, 2001; Takahashi, 2005; Zauberman et al., 2009). This means that researchers have assumed a "natural" form of distortion whereby 1) subjective duration of time is always shorter than the real duration, generating contraction for all *t,* as shown in Pane (A), and 2) subjects increasingly contract the future as represented by the increasing vertical distance from the 45° line on the shadowed TC area also in Pane (A) of Figure 1. However, this approach has limitation in capturing other kinds of time distortion. Indeed, even assuming a constant $\tau = 1$, the relationship between actual time and perceived time can be concave when $0 < \eta < 1$, as shown in Pane (A) of Figure 1, and convex when $\eta > 1$, as shown in Pane (B). A second consideration is the role of τ. For values of $\tau \neq 1$, Rule (1993) asserted that changes in τ were due to the negative correlation with η. However, several other studies insisted that the value of τ is likely to reveal individual differences (Borg & Marks, 1983; Glicksohn, 1996 1998; Ivry & Hazeltine, 1995; Rachlin 2006) and can be independently influenced. Overall, different combinations of τ and η can create time distortion patterns that

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span the TC and TE areas. Pane (C) shows such two cases for: i) $\tau < 1, \eta > 1$, and ii) $\tau > 1, \eta < 1$. In the latter case (dash-dot line), expansion and contraction co-exist. For example, people may perceive that time goes slowly when assessing the near future, but feel that it flies by thereafter. In sum, the values of τ and η and temporal distance t together can determine whether time is expanded (TE), contracted (TC), or both depending on the duration of the external clock time. Table 1 classifies the time distortions based on feasible values of τ and η.

Table 1. Time distortion and the SPL parameters

	$\tau < 1$	$\tau = 1$	$\tau > 1$
$\eta < 1$	TC	TC	TE/TC
$\eta = 1$	TC	No distortion	TE
$\eta > 1$	TC/TE	TE	TE

2. *Time Perception and Discounting*

In general, it is believed that time distortions can influence anticipatory temporal distances, thus affecting inter-temporal choice. To intuitively see how this works, consider an individual who does not distort time and is indifferent between \$10 at t=1 and \$11 at t=2. Let's assume that an exogenous change in context generated time expansion, so that a given time duration is now perceived longer than the clock time; that is, $\Delta s(t) > \Delta t$, where $s(t)$ is subjective time. If this happened, waiting an additional period to get one more dollar would now feel like a drag, and the individual would need more than \$1 to compensate for the "wait". From the point of view of the observer, who only considers the external clock time, this individual would now behave more impatiently. Conversely, suppose an exogenous change in environment generated time contraction; under time contraction $\Delta s(t) < \Delta t$ and the individual would feel the clock time moves fast, so waiting an additional period would not seem long at all. From the perspective of the observer, who only observes clock time, this would render more patient choices. Accordingly, the overestimation of temporal distances may result in higher discount rates (more impatience) and the underestimation of temporal distances may result in lower discount rates (more patience).

In the measurement of time preference, researchers usually "uncover" a discount rate $\rho(t)$, a discount factor $\delta(t)$, or a discount function $D(t)$ from sequences of two-choice options

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so that $(0: P) \sim (t: F)$, where $(t: F)$ denotes receiving \$ F at time t $(t > 0)$, and P is a present value. However, anticipatory distance between 0 and t may differ. Some individuals may have $s(t) > t$ while other may have $s(t) < t$. In addition, for the same individual, it is possible that $s(t) > t$ and $s(T) < T$ where $(T > t)$, and $s(t)$ may also vary across situations. Whenever t is not equal to $s(t)$, the estimated value of $\rho(t)$ is not a "true" estimate of the individual discount rate for delay time t, but it is for $s(t)$, which is not observed.

Let $\rho(s(t))$ represent the observed "explicit" discount rate or discount rate over subjective time $s(t)$, that is customarily measured experimentally; $D(t)$ is the discount function, and $D\big(s(t)\big) = \delta^{s(t)}$ represents the "explicit" discount function. Subjective time is assumed to follow Steven's Power Law, such that, $s(t) = \tau t^{\eta}$.

Proposition 1. *The explicit discount rate can be represented in objective time and depends on the two parameters of time perception,* τ *and* η*, and on the horizon t.*

$\rho\big(s(t)\big) = -\frac{\frac{dD(s(t))}{dt}}{D\big(s(t)\big)} = -\frac{\frac{d\delta^{s(t)}}{dt}}{\delta^{s(t)}}$; using the chain-rule and $s(t) = \tau t^{\eta}$, we can show that $\rho\big(s(t)\big) = -ln\delta(t).\tau\eta t^{\eta-1}$. When there is no time distortion, the discount rate in objective time is $\rho(t) =- \ln \delta(t)$, or $\delta(t) = e^{-\rho(t)}$. Thus, we can express explicit discount rate as:

$$\rho\big(s(t)\big) = \rho(t).\tau\eta t^{\eta-1} \qquad \textbf{(1)}$$

Form equation (1), we can see that $\rho(s(t))$ can vary both across the levels of τ and across those of η, and $\rho(s(t))$ is equivalent to $\rho(t)$, the exponential discount rate, for individuals who do not distort time (i.e., when $\eta = \tau = 1$). Additionally, if we can experimentally estimate $\rho(s(t))$ and the values of τ and η for an observed external duration of time (t), it is possible to uncover the constant discount rate in objective time.

Given that $\rho(s(t)) = \rho(t) \cdot \tau\eta t^{\eta-1}$, the observed or explicit discount rate is determined by the constant implicit discount rate, $\rho(t)$, the values of τ and η, and the horizon, t. If the value of $\tau\eta t^{\eta-1}$ is equal to 1, then $\rho(s(t)) = \rho(t)$. If the value of $\tau\eta t^{\eta-1}$ is less than 1, then $\rho(s(t)) < \rho(t)$. Conversely, if the value of $\tau\eta t^{\eta-1}$ is greater than 1, then $\rho(s(t)) > \rho(t)$. In other words, subjective time perception generates observed discounting, which may be equal, less, or greater than the exponential discounting for a given external horizon, *t*.

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Figure 2. Examples of Discount Rates

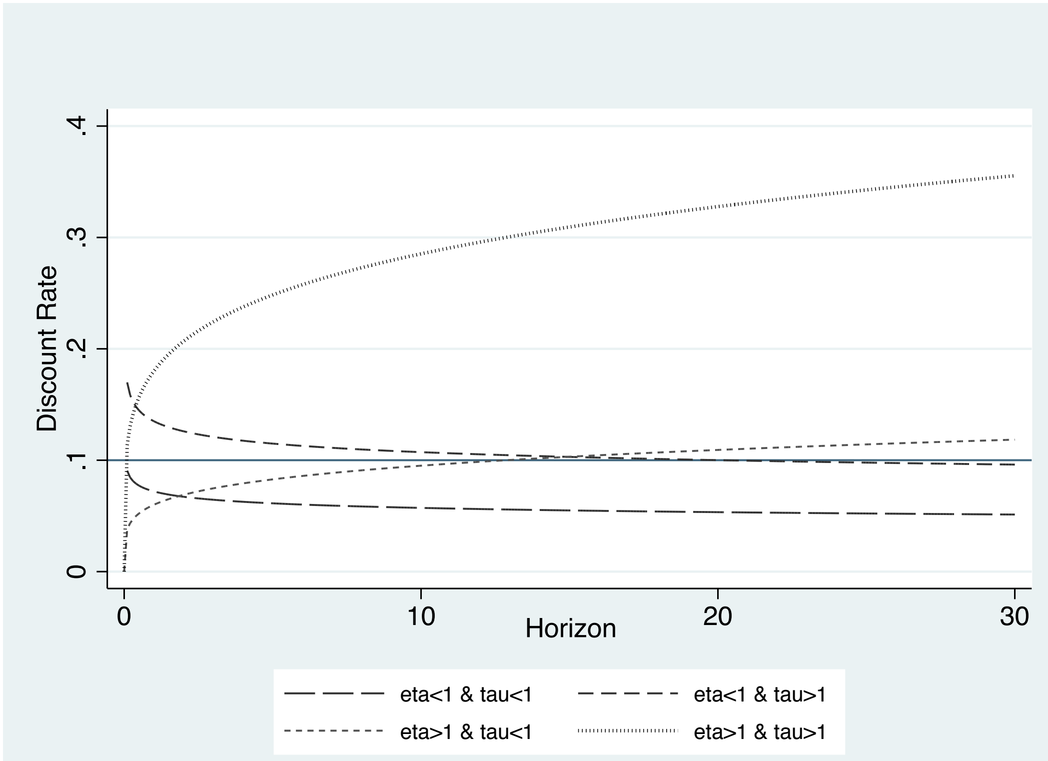

Figure 2 shows examples of how different values of τ and η can affect the explicit or observed discount rate of equation (1). Exponential discounting (constant discount rate) is shown by the solid line at y=0.10, which corresponds to equal values of the implicit and explicit discount rates; that is, when values of $\tau = \eta = 1$. Assuming the implicit discount rate equals 0.10, time distortions can cause the observed or explicit rate to decrease (dashed lines) or increase (dotted lines) over time at non-constant rates. Previous studies have only considered distortions that would render discount rates like the ones represented by the dashed lines. Notice that these describe hyperbolic discounting. Yet, rates can also increase over time, which would yield hyperopic behavior.[4]

3. *Experiment*

In the experiment, we have three objectives. The first objective is to determine whether

[4] To depict these examples in Figure 2, we chose values of the parameters that were observed in our experiment.

participants do indeed have different sense of external time. Second, we want to see if time perception itself can be manipulated in the lab using a subtle stimulus. Finally, we postulate that the misjudgment of time duration can affect tradeoffs between smaller sooner and larger later rewards. To see this, we test whether induced time distortions influence elicited discount rates.

All experimental sessions took place during the month of August 2015 at the Experimental Social Sciences Laboratory (ESSL) at the University of California, Irvine. We conducted eight sessions with 15-25 participants, each lasting about one hour and 15 minutes. We analyzed choices from a total of 138 subjects in the experiment[5] (69 females; mean age 20.28). Participants were compensated based on their decisions and chance. At the beginning of each session, the experimenter gave a presentation describing the entire experiment to the participants. During this presentation, participants were asked to remove their wristwatches and to put mobile phones and notebooks away. After this, they were instructed to wear headphones, which they could not remove until the end of the experiment. In all sessions, the headphones emitted white noise followed by a metronome beat with a specified tempo, as described below.

In each session, subjects were randomly grouped into three different treatments that varied with respect to the tempo of the metronome: 55BPM, 60BPM, or 65BPM.[6] A total of 48, 43, and 47 subjects participated in each of these conditions, respectively. Each session consisted of seven parts, six of which provided participants with an opportunity to make money in US and experimental currency that we latter converted into US dollars. The first three parts of the experiment were identical for all participants across all treatments. In part 1, immediately after consenting to participate in the experiment, subjects started hearing white noise from their headphones and made decisions from an incentivized multiple price list (MPL) with 15 choices in simple lotteries. This task was similar to Holt and Laury (2002) and its purpose was to get subjects accustomed to hearing white noise and to making decisions while hearing white noise. In the second part, we measured subjects' baseline of time perception prospectively. Subjects were asked to guess 4 different durations of time of 12, 17, 24, and 34 seconds, three times. These durations were randomly presented to each subject. Subjects made more money the closer

[5] We recruited 166 participants, but only 157 participants completed the experiment. We had to exclude data from 19 participants who "misbehaved" by clicking the time button (parts 2 and 5) constantly or switching back and forth in the MPL tasks (part 3). Exclusion of a many subjects in MPL tasks is not uncommon.

[6] In principle, although subtly different, our tempos (not too fast or slow) should allow for the synchronization of participants' internal clocks with the metronome sound (Wittmann, 2009; Wittmann & van Wassenhove, 2009).

their estimates were to the external time duration. In the third part, we measured subjects' time preferences using an incentivized multiple price list similar to Coller and Williams (1999) and Harrison et al. (2002), but with 5 different time horizons. Each time horizon had 14 questions and each question had two different options. The first option (Plan A) always offered a smaller reward (Ex$ 3000) in a week; whereas the second option (Plan B) offered an increasingly larger amount into the future. Thus, there was a front-end delay in every option and the five horizons for Plan B that we included in this part of the experiment were 2, 4, 6, 8, and 10 weeks into the future. Finally, the annual effective rates for the longer rewards were common knowledge. Please refer to Table A1 in the Appendix.

The different tempo treatments were started in part 4. To get accustomed to the tempo and to making decisions while hearing the tempo, we asked subjects to respond to a 7-items Cognitive Reflect Test (CRT) questionnaire (Toplak, West, & Stanovich, 2014) and were compensated based on how many answers they got right. In parts 5 and 6 we replicated parts 2 (time estimation) and 3 (time preference elicitation), respectively under the three different tempo conditions (55, 60, and 65 BPM). Plan B's five horizons were 2, 4, 6, 8, and 10 weeks longer than Part A's. This allowed us to compare the discount factors under white noise and tempo conditions. In part 7, we also included a set of piped questions to test for decision consistency. More specifically, based on the decision option at which the subject switched from Plan A to Plan B in part 3, we asked two additional questions with: 1) higher discount rates and 2) lower discount rates to test for consistencies. In this way, we could check for the effect of changes in subjective time on the likelihood of observing reversals. Finally, in part 8, we used a questionnaire to gather demographic and behavioral data. After this part, one randomly selected a question from each part 1, 2, 4 and 5, and 3 or 6 was chosen count towards each subject's earnings.

Table 2 shows the timeline of the different parts and the decision tasks. In addition, please see the Appendix where we have attached the instruction presentation that we used during the experiment.

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Table 2. Experimental Conditions and Decision Tasks

Part	Task	Description	Headphones
1	MPL/Risk	Adjust to White Noise	White Noise
2	Time Estimation	Random 12 durations	White Noise
3	MPL/Time	Horizons: 1, 3, 5, 7 & 9	White Noise
4	CRT-7	Adjust to Tempo	Tempo 55 / 60 / 65
5	Time Estimation	Horizons: 2, 4, 6, 8, & 10	Tempo 55 / 60 / 65
6	MPL/Time	Random 12 durations	Tempo 55 / 60 / 65
7	Time Inconsistency	Piped Question from Part 3	Tempo 55 / 60 / 65
8	Survey	Demographic Questions	No Sound

Payments

All experimental earnings were paid in US dollars. Choices from the MPL were converted into US dollars at the rate 30Ex$ = $1, which was publicly announced earlier while reading the instructions. On average, each subject earned $12.23 from parts 1, 2, 4, and 5 immediately after completing the experiment, and an additional $10.30 from parts 3 or 6 to be paid in the future; that is, 1 week to 11 weeks from the date of the experiment. As subjects arrived to be paid privately and in cash, all their future payments were placed in cash inside a dated envelope and with the participants' ID number written on it. Participants were contacted one week before the designated future payment date to pick up their envelopes from ESSL. Overall, 79.62% of the participants collected their future earnings, which they did one to eleven weeks after their participation in the experiment.[7]

4. Results

Do participants' perceptions of time differ from the external clock time? We used the results of the time estimation task (part 2 of our experiment) to see if prospective time estimates varied from the external clock time. Figure 3 shows the box plot of subjects perceived time deviations from the clock time, $t - s(t)$, while participants heard white noise (Before) and while listening to the tempo conditions (After). Positive values imply subjects shrank the duration of time (i.e., time contraction or the estimated duration of time is shorter than the real duration of

[7] Our experiments started on August 7th. Future payments were available for pickup on the pre-determined date that was written on the envelope. Future payments were distributed starting on August 14th until November 2nd, 2015. Out of a total of 157 future payments, averaging $10, 125 were picked up from the ESSL on the announced date.

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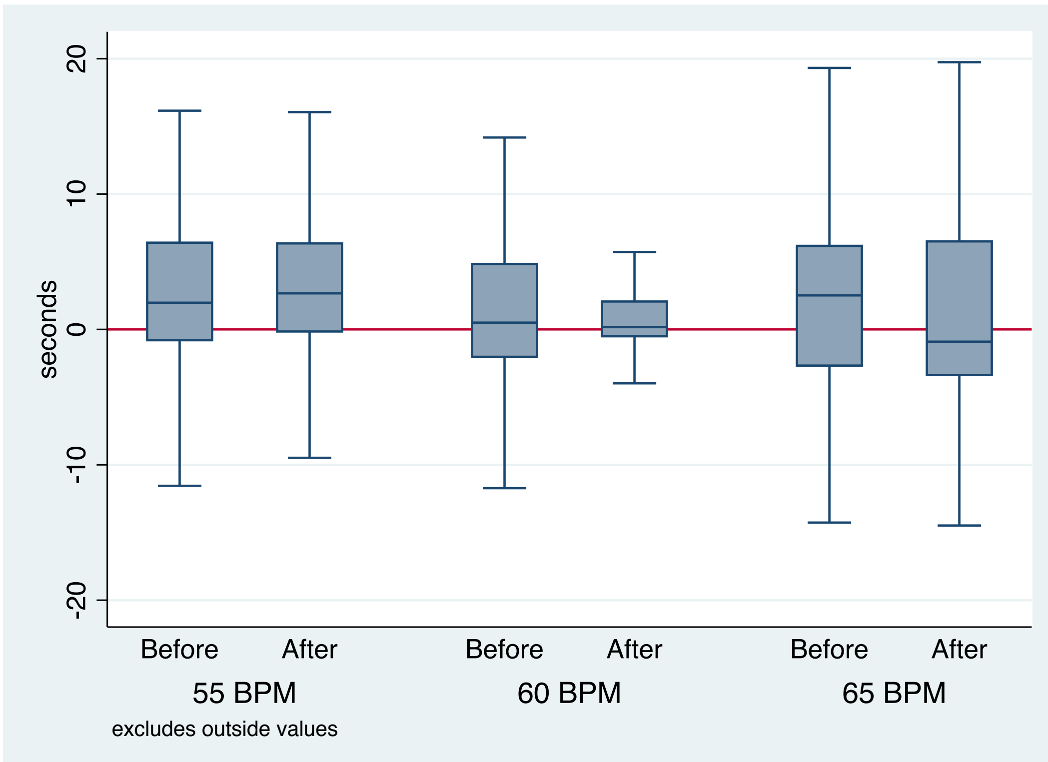
time, $s(t) < t$). In general, before the metronome, all groups' median deviations depict under-estimates of time or time contraction. In contrast, when listening to tempo, higher tempo seems to result in higher median estimate of the passage of time or a tendency towards expansion.

Figure 3. Box Plot of Deviations from the External Clock Time



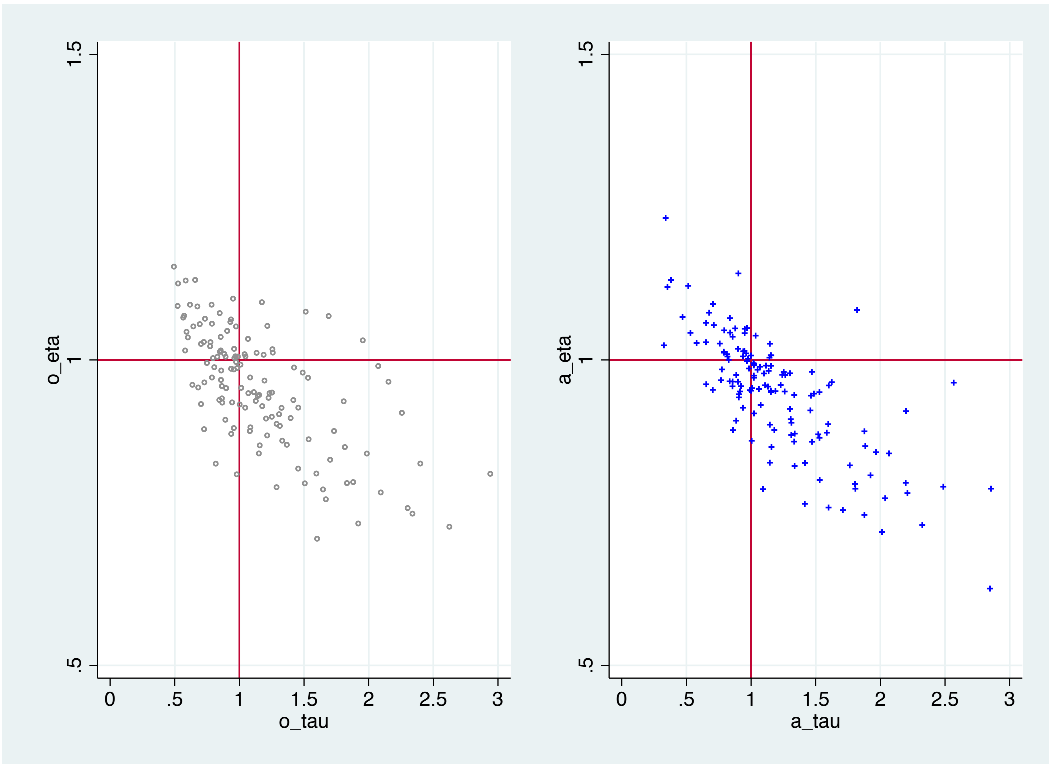
Is it possible to systematically influence time perception through an external stimulus? The effect of tempo on time perception can be seen through its effects on the two parameters τ and η in Stevens' power law. We estimated each subject's two parameters using the following expression:

$$\log p(t)_i = \beta_0 + \beta_1 \log t_i + \varepsilon_i$$

Where *i* represents a subject and *t* is the duration of time (12, 17, 24 and 34 seconds); β_0 corresponds to $\log \tau$ (in the individual's subjective time function, $s_i(t) = \tau_i t^{\eta_i}$) while β_1 corresponds to η. The estimated values of the parameters "before" (dot) and "after" (plus) are shown in Figure 4. The left pane of the figure represents values of η and τ while subjects listened to white noise; whereas, the right pane represents estimated values while subjects listened to the

3 different tempos. As shown in the figure and consistent with others' findings, there is an inverse relationship between η and τ (Brocas et al., 2016).

Figure 4. Estimated Time Distortion Parameters



To estimate the effect of tempo on time distortion across the three different groups, we regressed the changes in values of the parameter eta on $\Delta\tau$ and the tempo treatments as categorical variables. We also added variables representing the interaction between the tempo conditions and the initial positions in the eta/tau plane. Indeed, because each individual has different initial parameter values, the expected effect of our three tempo conditions would depend not only on the tempo itself, but also on the initial position of the parameters.[8] Without interactions, the effects of the tempo treatments are not statistically significant. However, with interactions, there are weakly significant treatment effects when comparing 55BPM (baseline) with 60BPM (*coef. =0.046, t=1.74, p=0.084*) and when comparing 55BPM with 65BPM (*coef.*

[8] There are four quadrants in the eta/tau plane that represent the initial individual time distortions (see also Table 1). Consider an individual whose initial time distortion parameter values fall on the lower-left quadrant of Figure 4 (i.e., $\eta < 1$ and $\tau < 1$); a high tempo of 65BPM would most likely result in higher values of η, but a low tempo of 50BPM may have no effect.

*=0.047, t=1.71, p=0.*090).[9] Because the tempo could influence both parameters, however, we also tested for differences in the changes in the slope or $\Delta\eta/\Delta\tau$ across all tempo conditions and found that they were statistically different ($\chi^2(2) = 11.01, p = 0.004$). In addition, we conducted a Multivariate ANOVA with $\Delta\tau$ and $\Delta\eta$ as dependent variables and the twelve categorical variables that represented the interactions between the 3 treatments and the 4 initial positions to see the joint effect of treatments on the two variables. The results reveal that there are statistical differences among the twelve conditions (*Roy's=0.46, F (11, 126) =5.23, p<0.001*). Thus, the interaction between the tempo conditions and the initial degree of time distortion have differential effects on the final values of τ and η.

Finally, to see the effects of tempo on $\Delta\eta$ and $\Delta\tau$ for each treatment group separately, we estimated changes in the slope of Figure 4 for each treatment condition before and after the tempo. The results show that the changes in slope for each of the treatments were statistically different from zero ($\Delta slope$ *= -0.216 (s.e.=0.022), -0.115 (s.e.=0.021), and -0.184 (s.e=0.030) for 55BPM, 60BPM, and 65 BPM, respectively*). These changes are principally driven by eta. Indeed, we observed a statistically significant increase in the overall average values of η in the 65BPM condition (*coef. = 0.051, t=2.04, p=0.044*). We think this is because most people tended to contract time and the higher tempo had a more impactful effect than the slower tempos. Yet, in the 50BPM treatment, the value of η decreased for those whose initial position was on the upper-left and upper-right quadrants in Figure 4 compared to those with values on the lower-left (*coef. = -0.050, t=0.028, p=0.011 and coef. =-0.0951, t=-2.64, p=0.090*), generating a downward movement towards the horizontal line at η=1. We did not see a statistically significant effect of the tempo conditions on the estimated values of τ. All in all, we found that the different treatments together with the initial tendency to distort time affected final time estimations.

Discount Rates

Were participants randomly assigned to the higher tempo conditions more impatient? Did changes in time perception affect measured time preferences? To answer these questions, we

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[9] All regression results presented are with clustered and robust standard errors. Clustering at the individual level.

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used interval regressions to estimate discount rates from the MPL. Table 5 shows the result of our interval regression as a function of the treatment (*Metronome*) and controlling for age category (*Older*), gender (*Female*), having taken finance courses (*TakenFin*), having taken statistics courses (*TakenStat*), and the sum of the CRT-7 score (*Sumcrt-7*) which we used to measure reasoning effort (Toplak et al., 2014).[10] Recall that each subject made choices between a payment in one week and payments over 10 different time horizons that differed from each other by 1 additional week. We denote these horizons by D7, D14, D21, D28, D35, D42, D49, D56, D63, and D70.[11] In the interval regression, each of these horizons generates an equation intercept and the coefficient can be seen as the elicited discount rate. The remainder of the coefficients in the interval regression can be interpreted as the marginal effect of each variable on discount rates (Harrison et al., 2002). As discussed in the previous section, there seems to be an effect of the high BPM condition on time perception. Thus, we categorized observations based on whether they were in the high metronome condition or not. The variable *Metronome* captures this and its estimated coefficient is positive and significant, suggesting that the higher tempo resulted in higher elicited discount rates. More specifically, being in the 65BPM condition yielded discount rates that were about 9% points higher (see Column (2) in Table 3). Being a female, having taken finance or statistics and the score in the CRT7 questionnaire had no effect on elicited discount rates.

In order to check the effects of tempo on the anticipated time delay of a reward, we estimated subjective future horizons, $\hat{s}_{horz_i} = E[\tau_{ic} d^{\eta_{ic}}]$ or $E[\tau_{it} d^{\eta_{it}}]$, before and after the tempo; where τ_{ic} and η_{ic} and τ_{it} and η_{it} represent the estimated values of τ and η in the control and treatment conditions, respectively; i indicates each subject and d represents the calendar horizon in days. We constructed a variable, Diff_$\hat{s}_{horz}$, which represents the changes in subjective future horizon due to the tempo or $E[\tau_{ic} d^{\eta_{ic}}] - E[\tau_{it} d^{\eta_{it}}]$. The results of the interval regression are shown in Columns (3) and (4) of Table 3.

[10] All tasks are similar to Collier and Williams (1999) and Harrison, Lau and Williams (2002). The instructions as well as a list of the variables and their descriptions can be found in the Appendix.

[11] The total number of binary choices between a smaller sooner and a larger later reward for each participant was 140; 14 lottery pairs each presented in 10 different horizons (5 horizons under white noise and another set of 5 horizons under tempo condition).

Table 3. The Effects of Treatment on Elicited Discount Rates

VARIABLES	(1)	(2)	(3)	(4)
D7	39.740***	46.646***	38.386***	39.671***
	(8.669)	(14.675)	(8.609)	(15.255)
D14	46.650***	53.571***	45.347***	46.653***
	(8.633)	(14.594)	(8.551)	(15.104)
D21	32.553***	39.386***	31.314***	32.481***
	(8.696)	(14.721)	(8.641)	(15.366)
D28	42.715***	49.591***	41.568***	42.804***
	(8.676)	(14.599)	(8.591)	(15.125)
D35	36.099***	42.980***	34.912***	36.132***
	(8.670)	(14.750)	(8.609)	(15.240)
D42	41.544***	48.441***	40.255***	41.512***
	(8.526)	(14.533)	(8.449)	(15.018)
D49	38.534***	45.415***	37.235***	38.466***
	(8.626)	(14.665)	(8.554)	(15.148)
D56	44.091***	50.912***	42.860***	43.998***
	(8.538)	(14.319)	(8.465)	(14.932)
D63	39.844***	46.740***	38.278***	39.539***
	(8.607)	(14.528)	(8.557)	(15.070)
D70	44.482***	51.311***	43.301***	44.492***
	(8.322)	(14.429)	(8.269)	(14.931)
Multiple	-1.922	-0.989	2.367	3.496
	(8.748)	(8.750)	(8.670)	(8.416)
Metronome	8.917**	9.109**		
	(3.953)	(4.018)		
Diff_$\hat{s}_{horz}$			-0.344**	-0.312**
			(0.144)	(0.144)
Older		5.557		2.767
		(3.475)		(3.367)
Female		-3.184		-3.489
		(3.505)		(3.399)
TakenFin		-6.082		-4.709
		(5.899)		(6.205)
TakenStat		3.190		4.339
		(3.460)		(3.377)
SumCRT7		0.457		1.009
		(1.210)		(1.218)
Observations	1,290	1,290	1,290	1,290

Estimated coefficients of interval regression with clustered standard errors by subject (138 clusters). Clustered robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.10.

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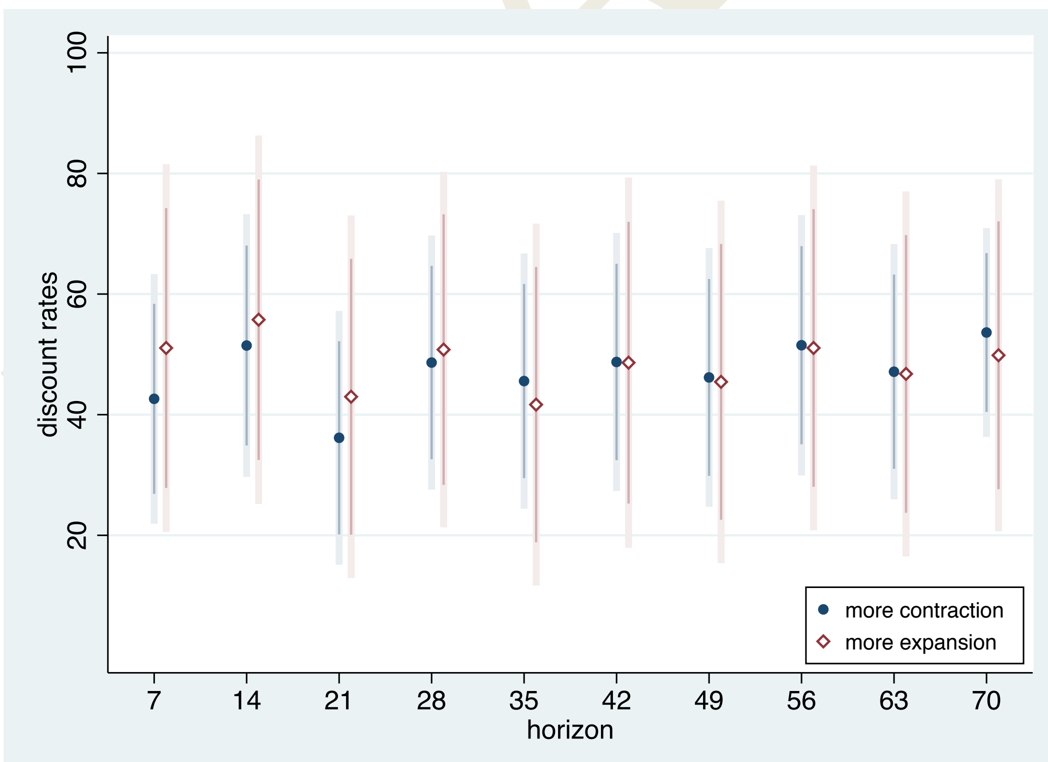
The results indicate a negative relationship between elicited discount rates and the variable Diff_$\hat{s}_{horz}$. The variable Diff_$\hat{s}_{horz}$ becomes more negative due to more time expansion. Thus, the negative coefficient suggests higher discounting when the perceived future horizons are seen as longer. More specifically, an extra day in subjective horizon due to tempo added just over 0.3 percentage points, on average, to the discount rate. We also segmented all choices into two groups (more expansion Diff_$\hat{s}_{horz} < 0$, and less expansion Diff_$\hat{s}_{horz} > 0$) to see if the estimated discount rates for a given horizon were larger when Diff_$\hat{s}_{horz} < 0$. Figure 5 exhibits the estimated coefficients of the elicited discount rates for each of the time horizons and their 99, 95, and 90 percent confidence intervals using the same control variables. The figure shows that for horizons of 7 – 28 days, more expansion rendered higher discount rates compared to more contraction. However, this pattern was not observed in the 5-week horizon and the 10-week horizons, suggesting that the effect of the induced time distortion interacted with the anticipated duration of time. Overall, the results confirm our prediction that induced time expansion renders more impatient choices.

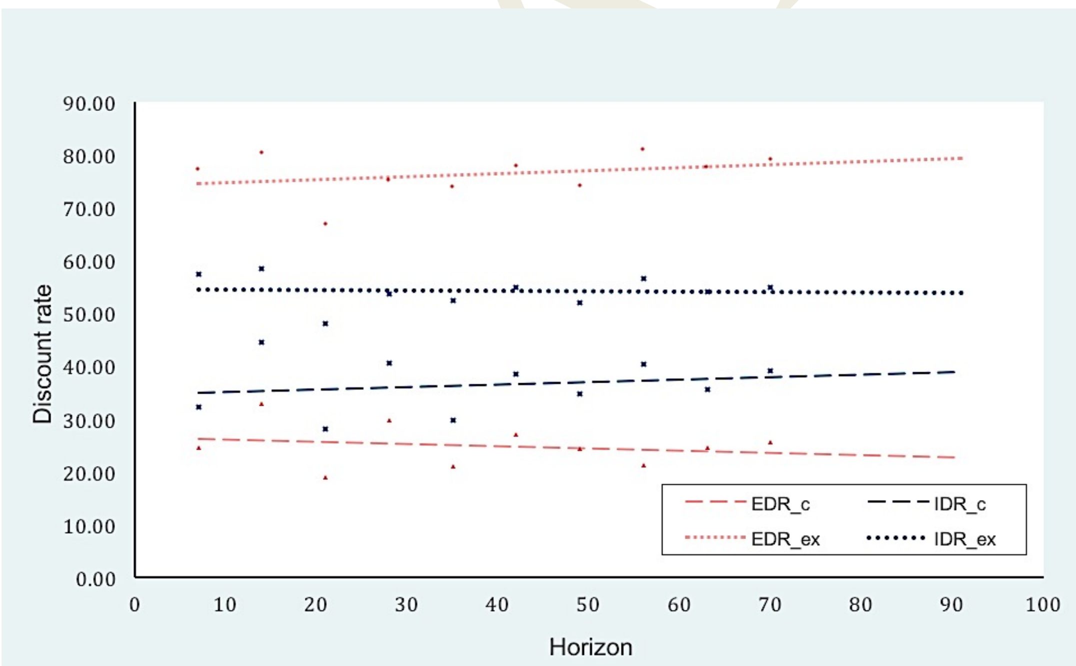
Figure 5. Estimated Coefficients for Discount Rates and CIs



Explicit & Implicit Discount Rates

It is possible to eliminate the effect of subjective time horizon on the measured discount rate. From equation 1, we know that $\rho\big(s(t)\big) = \rho(t).\tau\eta t^{\eta-1}$, where $\rho\big(s(t)\big)$ is the elicited or explicit discount rate (EDR) at time $s(t)$. Given that we have individual estimates of τ and η, we can calculate $\rho(t)$, or the implicit discount rate (IDR). Figure 6 shows both the EDR and IDR for the cases when the participants expanded time (dotted lines) and when participants contracted time (dashed lines) in *all horizons*. The lighter lines represent the point estimates of the EDRs for horizons 1-10 weeks, plus a 3-week linear forecast. The darker lines indicate the IDRs plus a 3-week linear forecast. The figures suggest that time distortions bias our estimated discount rates. Elicited discount rates are higher when there is expansion, and lower when there is contraction in all periods.[12] In addition, discount rates have a slight slope upwards (downwards) when subjects expand (contract) time. If we corrected for the time distortion, we would uncover discount rates that are closer in magnitude and have flatter slopes.

Figure 6: Forecasted Explicit Discount Rate and Implicit Discount Rate



[12] The idea that non-exponential discounting may be due to time distortion is also discussed in Bradford et al. (2013).

Consistency and Robustness

Part 7 of our experiment consisted of a set of piped questions to look for consistency patterns in choices. In this part, we asked subject to answer 10 questions (2 questions for each of the 5 time horizons D7, D21, D35, D49, and D63) based on their previous Part 2 answers (i.e., before the tempo). The purpose of this was to see if there were changes in time preference due to listening to tempos.

More specifically, suppose a subject switched to plan B in question 4 while listening to white noise. In odd-numbered questions of Part 7, we asked the subject to choose between the sooner earlier reward (plan A) and a future amount of money that was less than the amount for plan B in question 3. In even-numbered questions, we asked them to choose between the sooner earlier reward (plan A) and a future amount money that was greater than that for plan B in question 5. The assumption was that if listening tempos generated time contraction, then subjects would be accepting lower rates in the piped odd-numbered questions (i.e., they would be more likely to choose Plan B even if it paid less than previously). In contrast, if tempos generated time expansion, then subjects would be accepting higher rates in the even-numbered questions (i.e., they would be more likely to reject Plan B even if it paid more than previously). These helped us identify choice consistency and to double-check whether the treatment condition altered time preference.

Using the piped questions data, we estimated the probit model of the probability of a reversal due to the changes in subjects' time horizon: $Y = prob\ (reversal|\Delta\ s(t)) = \Phi(X\beta + \varepsilon)$, where Φ is the cumulative standard normal distribution function and X includes $\Delta\tau$ and $\Delta\eta$. When subjects changed their time preference in odd-numbered questions, the dependent variable was Y=1, if the estimated subjective time horizon decreased (i.e., there was an induced time contraction), otherwise Y=0. In contrast, the dependent variable was Y=1, if the estimated subjective time horizon increased (i.e., there was an induced time expansion) in even numbered questions, otherwise Y=0. Table 4 shows the results of this regression. In models (2) and (4) we also added a categorical variable to represent the metronome condition. As we expected, the coefficients of the first two columns are negative implying that an increase in η and/or τ (i.e., more time expansion) lead to a decrease in the probability of choosing lower interest rates. In contrast, the coefficients of last two columns are positive, suggesting that higher values of the

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time distortion parameters are correlated with higher probability of choosing a larger discount rate. In addition, faster tempo decreased (increased) the probability if choosing lower rates (higher rates). All in all, the probit regression shows that changes in time distortion parameters, $\Delta\eta$ and $\Delta\tau$, and the faster tempo affected the probability of time preference reversal in the predicted direction.

Table 4. The Probability of Altering Time Preference

	Choose lower rates (more patient)		Choose higher rates (less patient)	
VARIABLES	(1)	(2)	(3)	(4)
$\Delta\eta$	-5.000***	-4.577***	3.730***	3.930***
	(1.301)	(1.326)	(1.053)	(1.060)
$\Delta\tau$	-0.570***	-0.463***	0.377***	0.4000***
	(0.200)	(0.207)	(0.134)	(0.135)
Treatment		-0.314***		0.202***
		(0.135)		(0.027)
Constant	0.0912	0.417***	-0.00159	-0.188
	(0.112)	(0.182)	(0.089)	(0.130)
Observations	138	138	211	211

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10.

5. *Discussion*

Why does time sometimes seem to slow to a crawl, or seem to fly by? Research in psychology and neuroscience has shown that time perception is surprisingly prone to measurable distortions: namely, our perception of time is both expandable and contractible, and time perception can vary across contexts and across individuals. Yet, subjective time perception has not received substantial scrutiny in behavioral economics. This is surprising, because time plays a significant role in individual decision making and the recognition that time is a perceptual process susceptible to distortions may affect how we conceptualize inter-temporal choice.

In this paper, we take the point of view that time duration is a perceptual process captured by psychophysiological laws and we test the influence of induced time distortions on elicited discount rates.[13] We designed an experiment with three main goals. First, we sought to determine whether prospective time perception differed from the clock time. Second, we tested whether time distortions could be induced through small variations in tempo. Finally, we sought to determine whether induced time distortions affected elicited discount rates. Our results suggest that time distortions do happen and that a subtle external stimulus can generate changes not only in prospective time estimations, but also in elicited discount rates.

Although previous studies have linked time distortions to present-biased decisions and hyperbolic discounting, ours is the first experiment to show that a subtle exogenous change in the environment can influence elicited discount rates. More specifically, we found that higher tempo and its longer anticipatory time distance resulted in more impatience. In addition, while prior papers have found a link between time contraction and hyperbolic discounting, our approach is more flexible than others' in that we don't assume time contraction, but allow for diverse idiosyncratic patterns of subjective time perception, which may generate hyperbolic and hyperopic discounting. Thus, temporal choice inconsistencies can emerge due to the underestimation of time duration, the overestimation of time duration, and both underestimation and overestimation for different horizons.

What are the implications of our findings? We believe that this study can motivate behavioral economists to model time. So far, to better characterize experimental observations that reject the idea that individuals discount the future at constant rates, behavioral economists have overwhelmingly focused their efforts and attention on examining mathematical forms of the discount function that can best approximate observed behavior. This function fitting exercise has favored hyperbolic discounting and has generated a large amount of literature since the publication of David Lainson's (1997) seminal paper.[14] Yet, this progress has not brought us closer to explaining puzzling behaviors, such as: 1) the interval effect or subadditivity whereby

[13] The effect of time perception on inter-temporal decisions may be thought of as a projection bias (Loewenstein, O'Donoghue, & Rabin, 2003) whereby our current experience of time or how time feels like passing (i.e., too fast or too slow) can affect our 'imagined' future waiting time to receive a reward. In other words, prospective time distance is a perceptual process, and current changes in the internal clock speed affects how we evaluate the length of future time frames. The future time frames can be longer or shorter than the real calendar time delay.

[14] We found that an average of about 20 papers that included hyperbolic or quasi-hyperbolic discounting were published each year since then in the top 50 economics journals (see EconLit).

discount rates are higher the closer (in time) the outcomes are to one another (Scholten & Read, 2006, 2010), 2) context-dependent discounting whereby discounting is higher for smaller than for larger amounts, for gains compared to losses, for non-monetary outcomes compared to monetary rewards, and when individuals delay a reward compared to when they expedite it (Urminsky & Zauberman, 2016), 3) historical large variability in time preference parameter estimates (Frederick et al., 2002), and 4) excessive farsightedness or hyperopia (Keinan & Kivetz, 2008; Kivetz & Simonson, 2002).

We believe that the omission of the above puzzling behaviors in the mainstream discussion of hyperbolic discounting is puzzling, because the stated reason for why hyperbolic discounting had to be studied was that "*laboratory and field studies of time preferences find that discount rates are much greater in the short run than the long run"(Harris & Laibson, 2001, p. 935)*. Nevertheless, evidence suggests that this characterization is not observed all the time and under all circumstances. In this respect, we agree with Ariel Rubinstein's view that it would be more fruitful to take the psychology of intertemporal decision-making more seriously and explicitly introduce it in our models of decision-making (Rubinstein, 2003).

The methodological implications of this study are also noteworthy, as they suggest that with existing tools it is difficult to measure time preferences that are free from time distortions. Because current experienced time affects how we project future time durations and time distortions are not observable, we may want to adjust our measurement tools to minimize the effect of time distortions. Exactly how this can be achieved is a topic for future inquiry.

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References

Allman, M. J., & Meck, W. H. (2012). Pathophysiological distortions in time perception and timed performance. *Brain, 135*(3), 656-677.

Block, R. A., Hancock, P. A., & Zakay, D. (2000). Sex differences in duration judgments: A meta-analytic review. *Memory & cognition, 28*(8), 1333-1346.

Bradford, D., Dolan, P., & Galizzi, M. (2013). *Looking Ahead: Subjective Time Perception and Individual Time Discounting*. SSRN.

Brañas-Garza, P., Espinosa-Fernández, L., & Serrano-del-Rosal, R. (2007). Effects of gender and age on retrospective time judgements. *Time & Society, 16*(1), 99-118.

Brocas, I., Carrillo, J., & Tarraso, J. (2016). *How long is a minute?* University of Southern California Working paper.

Chanda, M. L., & Levitin, D. J. The neurochemistry of music. *Trends in Cognitive Sciences, 17*(4), 179-193. doi:10.1016/j.tics.2013.02.007

Coller, M., & Williams, M. B. (1999). Eliciting Individual Discount Rates. *Experimental Economics, 2*(2), 107-127. doi:10.1023/a:1009986005690

Drew, M. R., Fairhurst, S., Malapani, C., Horvitz, J. C., & Balsam, P. D. (2003). Effects of dopamine antagonists on the timing of two intervals. *Pharmacology Biochemistry and Behavior, 75*(1), 9-15.

Droit-Volet, S., & Gil, S. (2009). The time–emotion paradox. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1525), 1943-1953.

Droit-Volet, S., & Zélanti, P. S. (2013). Development of Time Sensitivity and Information Processing Speed. *PloS one, 8*(8), e71424.

Eagleman, D. M. (2008). Human time perception and its illusions. *Current opinion in neurobiology, 18*(2), 131-136.

Ebert, J. E. J., & Prelec, D. (2007). The fragility of time: Time-insensitivity and valuation of the near and far future. *Management Science, 53*(9), 1423-1438.

Eisler, H. (1976). Experiments on subjective duration 1868-1975: A collection of power function exponents. *Psychological Bulletin, 83*(6), 1154.

Frederick, S., Loewenstein, G., & O'Donoghue, T. (2002). Time discounting and time preference: A critical review. *Journal of economic literature*, 351-401.

Geoffard, P.-Y., & Luchini, S. (2010). Changing time and emotions. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*(1538), 271-280.

Glicksohn, J. (1996). Entering trait and context into a cognitive-timer model for time estimation. *Journal of Environmental Psychology, 16*(4), 361-370.

Glicksohn, J., & Hadad, Y. (2012). Sex differences in time production revisited. *Journal of Individual Differences, 33*(1), 35.

Goldstone, S., Lhamon, W. T., & Sechzer, J. (1978). Light intensity and judged duration. *Bulletin of the Psychonomic Society, 12*(1), 83-84.

Hancock, P. A., & Hancock, G. M. (2013). The effects of age, sex, body temperature, heart rate, and time of day on the perception of time in life. *Time & Society*, 0961463X13479187.

Harris, C., & Laibson, D. (2001). Dynamic Choices of Hyperbolic Consumers. *Econometrica, 69*(4), 935-957. doi:10.1111/1468-0262.00225

DRAFT

Harrison, G. W., Lau, M. I., & Williams, M. B. (2002). Estimating Individual Discount Rates in Denmark: A Field Experiment. *American Economic Review, 92*(5), 1606-1617. doi:doi: 10.1257/000282802762024674

Hoagland, H. (1933). The physiological control of judgments of duration: Evidence for a chemical clock. *The Journal of General Psychology, 9*(2), 267-287.

Hoagland, H. (1935). Pacemakers in relation to aspects of behavior.

Holt, C. A., & Laury, S. K. (2002). Risk Aversion and Incentive Effects. *American Economic Review, 92*(5), 1644-1655. doi:doi: 10.1257/000282802762024700

Ivry, R. B., & Hazeltine, R. E. (1995). Perception and production of temporal intervals across a range of durations: evidence for a common timing mechanism. *Journal of Experimental Psychology: Human Perception and Performance, 21*(1), 3.

Keinan, A., & Kivetz, R. (2008). Remedying Hyperopia: The Effects of Self-Control Regret on Consumer Behavior. *Journal of Marketing Research, 45*(6), 676-689. doi:10.1509/jmkr.45.6.676

Kim, B. K., & Zauberman, G. (2009). Perception of anticipatory time in temporal discounting. *Journal of Neuroscience, Psychology, and Economics, 2*(2), 91.

Kim, B. K., & Zauberman, G. (2013). Can Victoria's Secret change the future? A subjective time perception account of sexual-cue effects on impatience. *Journal of Experimental Psychology: General, 142*(2), 328.

Kivetz, R., & Simonson, I. (2002). Self-Control for the Righteous: Toward a Theory of Precommitment to Indulgence. *Journal of Consumer Research, 29*(2), 199-217. doi:10.1086/341571

Laibson, D. (1997). Golden Eggs and Hyperbolic Discounting. *The Quarterly Journal of Economics, 112*(2), 443-477. doi:10.1162/003355397555253

Laming, D. R. J. (1997). *The measurement of sensation*. Oxford ;: Oxford University Press.

Loewenstein, G., O'Donoghue, T., & Rabin, M. (2003). Projection Bias in Predicting Future Utility. *The Quarterly Journal of Economics, 118*(4), 1209-1248. doi:10.1162/003355303322552784

Loewenstein, G., & Prelec, D. (1991). Negative Time Preference. *The American Economic Review, 81*(2), 347-352.

Loewenstein, G., & Prelec, D. (1993). Preferences for sequences of outcomes. *Psychological review, 100*(1), 91.

Maricq, A. V., & Church, R. M. (1983). The differential effects of haloperidol and methamphetamine on time estimation in the rat. *Psychopharmacology, 79*(1), 10-15. doi:10.1007/bf00433008

Noulhiane, M., Mella, N., Samson, S., Ragot, R., & Pouthas, V. (2007). How emotional auditory stimuli modulate time perception. *Emotion, 7*(4), 697.

Park, J.-Y. (2016). *Time Perception and Decision-Making.* (PhD), Claremont Graduate University, Claremont, CA USA.

Pine, A., Shiner, T., Seymour, B., & Dolan, R. J. (2010). Dopamine, Time, and Impulsivity in Humans. *The Journal of Neuroscience, 30*(26), 8888-8896. doi:10.1523/jneurosci.6028-09.2010

Radu, P. T., Yi, R., Bickel, W. K., Gross, J. J., & McClure, S. M. (2011). A mechanism for reducing delay discounting by altering temporal attention. *Journal of the experimental analysis of behavior, 96*(3), 363-385.

DRAFT

Rammsayer, T. H. (1997). On the relationship between personality and time estimation. *Personality and individual differences, 23*(5), 739-744.
Ray, D., & Bossaerts, P. (2011). Positive Temporal Dependence of the Biological Clock Implies Hyperbolic Discounting. *Frontiers in Neuroscience, 5*(2). doi:10.3389/fnins.2011.00002
Read, D. (2001). Is time-discounting hyperbolic or subadditive? *Journal of risk and uncertainty, 23*(1), 5-32. doi:papers2://publication/uuid/1A953167-FA99-4CC7-915D-29013D06E513
Rubinstein, A. (2003). "Economics and Psychology"? The Case of Hyperbolic Discounting. *International Economic Review, 44*(4), 1207-1216. doi:10.1111/1468-2354.t01-1-00106
Sayman, S., & Öncüler, A. (2009). An Investigation of Time Inconsistency. *Management Science, 55*(3), 470-482. doi:doi:10.1287/mnsc.1080.0942
Scholten, M., & Read, D. (2006). Discounting by Intervals: A Generalized Model of Intertemporal Choice. *Management Science, 52*(9), 1424-1436. doi:10.1287/mnsc.1060.0534
Scholten, M., & Read, D. (2010). The psychology of intertemporal tradeoffs. *Psychological review, 117*(3), 925.
Steingrimsson, R. (2016). Subjective intensity: Behavioral laws, numerical representations, and behavioral predictions in Luce's model of global psychophysics. *Journal of Mathematical Psychology, 75*, 205-217. doi:http://dx.doi.org/10.1016/j.jmp.2016.06.004
Stevens, S. S. (1957). On the psychophysical law. *Psychological review, 64*(3), 153.
Takahashi, T. (2005). Loss of self-control in intertemporal choice may be attributable to logarithmic time-perception. *Medical hypotheses, 65*(4), 691-693.
Takahashi, T. (2006). Time-estimation error following Weber–Fechner law may explain subadditive time-discounting. *Medical hypotheses, 67*(6), 1372-1374.
Takeuchi, K. (2011). Non-parametric test of time consistency: Present bias and future bias. *Games and Economic Behavior, 71*(2), 456-478.
Toplak, M. E., West, R. F., & Stanovich, K. E. (2014). Assessing miserly information processing: An expansion of the Cognitive Reflection Test. *Thinking & Reasoning, 20*(2), 147-168. doi:10.1080/13546783.2013.844729
Urminsky, O., & Zauberman, G. (2016). The psychology of intertemporal preferences. *Blackwell Handbook of Judgment and Decision Making, George Wu and Gideon Keren (eds), Wiley-Blackwell*.
Van Hagen, M., Galetzka, M., Pruyn, A., & Peters, J. (2009, 2009). *Effects of colour and light on customer experience and time perception at a virtual railway station*.
van Wassenhove, V., Wittmann, M., Craig, A. D., & Paulus, M. (2011). Psychological and Neural Mechanisms of Subjective Time Dilation. *Frontiers in Neuroscience, 5*(56). doi:10.3389/fnins.2011.00056
Wearden, J. H., & Penton-Voak, I. S. (1995). Feeling the heat: Body temperature and the rate of subjective time, revisited. *The Quarterly Journal of Experimental Psychology, 48*(2), 129-141.
Wiener, M., Lee, Y.-S., Lohoff, F. W., & Coslett, H. (2014). Individual differences in the morphometry and activation of time perception networks are influenced by dopamine genotype. *NeuroImage, 89*, 10-22.

DRAFT

Wittmann, M. (2009). The inner experience of time. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1525), 1955-1967.

Wittmann, M., & van Wassenhove, V. (2009). The experience of time: neural mechanisms and the interplay of emotion, cognition and embodiment. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1525), 1809-1813.

Zauberman, G., Kim, B. K., Malkoc, S. A., & Bettman, J. R. (2009). Discounting time and time discounting: Subjective time perception and intertemporal preferences. *Journal of Marketing Research, 46*(4), 543-556.

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Appendix

Table A1: Example of Multiple Price List used in the Experiment

	Plan A "Receive in 1 week"	Plan B "Receive in 2 weeks"	AR	AER
Q1	3000.00	3002.88	5.00%	5.13%
Q2	3000.00	3005.76	10.00%	10.52%
Q3	3000.00	3008.64	15.00%	16.18%
Q4	3000.00	3011.53	20.00%	22.13%
Q5	3000.00	3014.41	25.00%	28.39%
Q6	3000.00	3017.30	30.00%	34.97%
Q7	3000.00	3020.20	35.00%	41.88%
Q8	3000.00	3023.09	40.00%	49.15%
Q9	3000.00	3025.99	45.00%	56.79%
Q10	3000.00	3028.89	50.00%	64.82%
Q11	3000.00	3031.79	55.00%	73.25%
Q12	3000.00	3034.37	60.00%	81.12%
Q13	3000.00	3037.60	65.00%	91.44%
Q14	3000.00	3040.51	70.00%	101.24%

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Table A2: Description of Variables

VARIABLES	Description
Treatment	Categorical variable representing treatment Category: 1 55BPM, 2 60 BPM, 3 65BPM
Metronome	Categorical variable representing high BPM Category: 1 65BPM, 0 otherwise
D7, D14, D21, D28, D35, D42, D49, D56, D63, D70	Binary indicators of the 7- day, 14- day, 21-day, 28- day, 35- day, 42- day, 49- day, 56-day, 63- day, 70-day time horizons, respectively
Multiple	Binary indicator that codes whether the subject gave responses in a multiple-horizon session
Older	Age category of the participant. Dummy: 0 if 18-21, 1 if older
Female	Sex of the participant. Dummy: 0 Male, 1 Female
TakenFin	Indicates whether the subject has taken finance. Dummy: 0 No, 1 Yes
TakenStat	Indicates whether the subject has taken statistics. Dummy: 0 No, 1 Yes
Sumcrt7	Sum of scores of 7-CRT Questions.
Diff_$\hat{s}_{horz}$	The difference between subjective anticipated horizon before and after the metronome. Values can be positive and negative.

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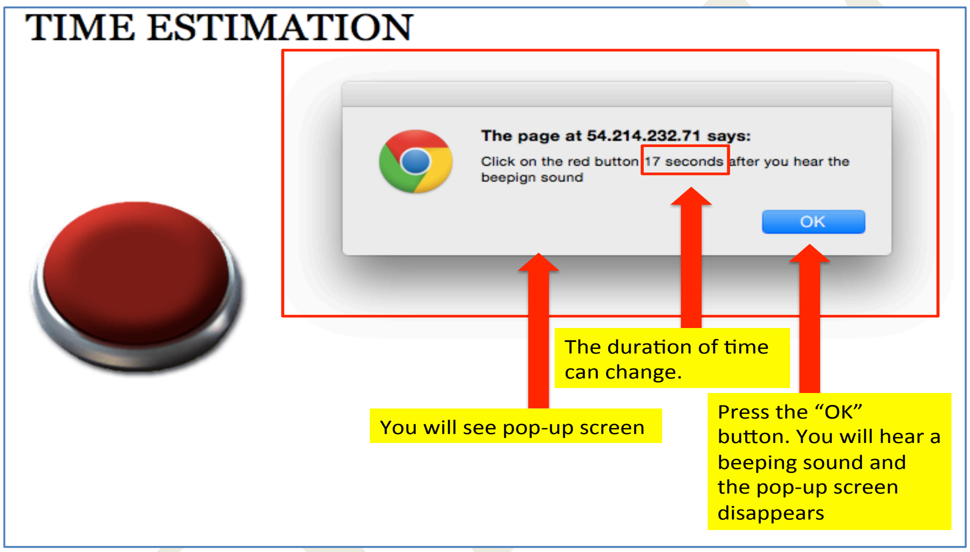
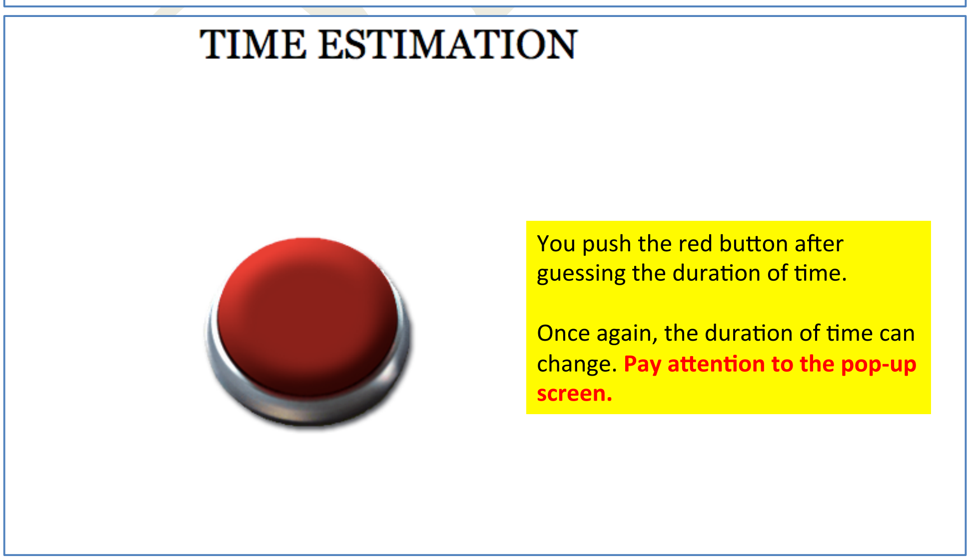
Figures A1: Presentation of Instructions Read Aloud

Three Kinds of Tasks

- Estimate duration of time
- Choice between two options
- Survey Questions

Note: You **are not allowed to see your wristwatch** & **to use your cellphone** for the entire experiment. Please put away watches and phones.





CHOOSE BETWEEN TWO OPTIONS

Please choose the option that you prefer in each pair. Amounts are in Exp$. (Note: AR=Annual Rate; AER= Annual Effective Rate. Amounts for Plan B are compounded daily).

	Plan A: "Receives in 30 days"	Plan B: "Receives in 60 days"	AR	AER
Q1	◉ 100.00	○ 100.21	2.50%	2.53%
Q2	◉ 100.00	○ 100.42	5.00%	5.13%
Q3	◉ 100.00	○ 100.63	7.50%	7.79%
Q4	○ 100.00	◉ 100.84	10.00%	10.52%
Q5	○ 100.00	◉ 101.05	12.50%	13.31%
Q6	○ 100.00	◉ 101.26	15.00%	16.18%
Q7	○ 100.00	◉ 101.47	17.50%	19.12%

This is an example: The amounts and days in the task will be different from these, but Plan A always pays a smaller sooner amount.

An annual effective rate (AER) is an interest rate that takes into account the effects of daily compounding.

Note: The Earnings slides were not shown during the public presentation.

Earnings

Earnings per estimated time in CENTS (¢) =

300 – | (Real Duration – Your Estimated Duration) |*10

If your estimated time duration is exactly equal to the real duration, you make $3 or 300 cents

The closer your estimated duration is to the real duration, the more money you make

Earnings

Earnings in Experimental Currency Units (ECU) =

The amount in Plan A at a sooner date

The amount in Plan B at a later date

Exchange rate: 30 ECU = 1 US$

Payment

- When you are finished, please raise your hand and one of us will approach you to check your earnings.
- After that, you may orderly approach the desk to be paid in cash today's payment and drop your envelope for future payment.
- For future payment we will email you with the exact times when you can pick up your envelope and earnings from this lab.

- This is **a brief version** of the instructions.
- Remember that your payments partly depend on your decisions. Thus, please carefully read the instructions on the computer screen.

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Receipt for Participating in Economic Experiments

Please fill out this form clearly. After you are done, please raise your hand and one of us will check your earnings.

Once the amounts are verified, please bring the form to the front for payment. If you are receiving future payment, we will place the moneys inside an envelope for future pick up. We will keep the envelope with your payment in this lab. We will contact you to let you know the exact times when you will be able to pick up your envelope.

Please keep this receipt for your records.

Date: _______________

Time: ______________

A. Earnings to be paid <u>today</u>:

Amount paid as show-up fee: ______

Amount earned during the experiment: ______

Total amount to be paid today: ______

B. Earnings to be paid in the <u>future</u>:

Amount earned during the experiment: ______ in _____ weeks.

C. Total Earnings (A+B): _______

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