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THESIS

Distortions of perceived event time:

Investigating characteristics of duration perception

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[Abstract] One of the great mysteries of our universe is time; it is also one of the great mysteries of our brain. Gaining insight into the perception of time and the role of attention therein is what this article aims to achieve. By executing a duration reproduction experiment involving two consecutive stimuli that are the same or different on varying levels (physical, semantic, or both) we aimed to determine the influence of these properties on the distortion of perceived event time. An overall debut effect (Pariyadath & Eagleman, 2007) was found as well as insight into the processing of stimuli that differ semantically or physically. This experiment has provided some insight into the way we perceive time and the methodology used to measure it and has opened a door for future research.

Introduction

A plethora of research has been done to determine the way in which people experience time. Various models have been proposed to represent the internal processing of information that leads to some form of time representation, a few of which will be discussed in this paper. The goal of this research is to illuminate the processes involved in time perception. Taking a look at information processing and capitalizing on well-documented distortions of event time as reported in the literature; in the hope that this interaction can show us how the human sensory system processes time. Specifically, this research focuses on the roles of physical and semantic properties of a visual stimulus in relation to the debut effect (Pariyadath & Eagleman, 2007) through a psychophysical experiment. Before doing so it is beneficial to review the methodologies, theories, and breakthroughs that have led up to this research.

Timing mechanisms

What makes you tick? Do you have an internal clock that keeps time for you? The existence of an internal clock is an ongoing debate the realm of time perception research. There are two schools of thought within the internal clock model: oscillatory processes and a pacemaker-counter device. Oscillatory processes are based on a non-linear system that can keep track of time spans that are marked with onset and offsets, taking into consideration the ability to synchronize and predict with the use of rhythm, particularly applicable to music and speech. This model relies on a series of sequential information that is attended to.

Pacemaker-counter devices are based on a linear counting device which keeps track of constant pulses. A prominent model in timing research that is based on a pacemaker-counter device is Gibbon's (1977) scalar expectancy theory (SET) which stems from his findings that animals can estimate the time between two events (through reinforcement) by utilizing the ratio of their expectations and outcomes. The model is based on the premise that real time can be calculated as the mean of a series of duration judgments (a linear relation) and that the variability increases linearly with the mean representation of time (Grondin, 2010). SET is depicted schematically in figure 1. Pulses are emitted by the pacemaker and the accumulator is responsible for counting these pulses. The key element is the switch between the pacemaker and the accumulator. When the switch is closed, information from the pacemaker is accumulated before being transferred into memory. The switch is controlled by attention, the more attention that is paid to time, the more pulses are accumulated.

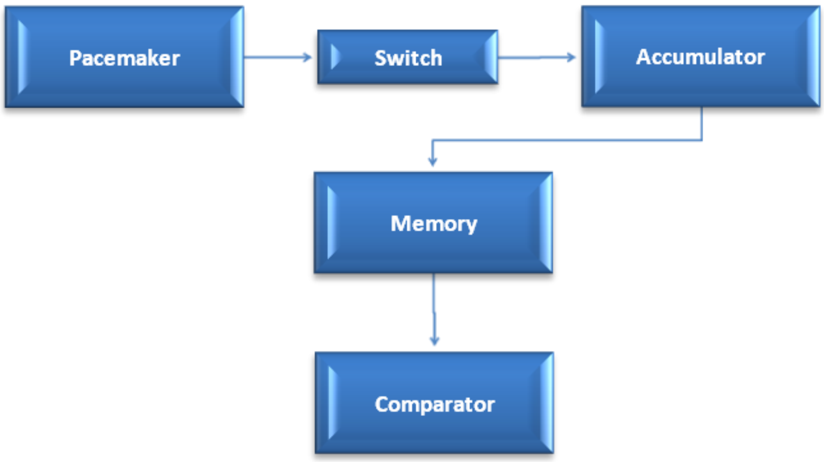

Figure 1. A simplified schematic overview of the scalar expectancy theory based on Grondin's (2010) model.

The temporal pacemaker that produces and tracks pulses, relying on a counter to deduce the duration of a time period, is also referred to as the internal clock (Treisman et al., 1990). Zakay and Block (1997) proposed that when performing a prospective timing task an attentional gate is opened when the onset stimulus is presented and closed when the end is signaled, followed by a calculation of the number of pulses experienced, conceding with the SET model's switch component.

Many researchers of human cognition argue that there is no need for such a clock to keep time, rather that humans have other cognitive mechanisms that relay elapsed durations. For example, Block and Zakay (2008) describe the contextual-change model, which is based on the theory that we encode the duration or length of time that has passed based on the number of events or changes that occur during that period of time. There a various examples in which researchers have demonstrated such processes by creating distortions in perceived time.

Fraisse (1984) described the ‘psychological present’ as existing within no more than 5 seconds, based on the idea that within that short time span there has not been sufficient opportunity to store the onset into memory. Prospective timing is a task that involves remembering the duration of a past event with prior knowledge of this timing aspect and is referred to by Block and Zakay (2008) as *experienced duration*. The current research utilizes prospective timing as it will be dealing with short durations in the milliseconds-to-seconds range and is geared towards an understanding of the automatic processes involved with time perception. Retrospective timing, on the other hand, involves a similar task except that the person is not given prior warning that a time-related judgment is to be made and is referred to as *remembered duration*.

Methodology

There are four main methods for measuring duration perception. Verbal estimation requires that the participant verbally specify the duration of a target (indicating how many seconds or minutes). The production method works differently; the participant is instructed to produce a stimulus interval based on an explicit instruction of seconds or minutes to be produced. However, the two most popular methods of measuring duration perception are comparison and reproduction. The comparison method consists of presenting participants with an initial interval and comparing it with a subsequent interval by judging whether it was longer or shorter. One form of the comparison method is the 2AFC task in which a target interval is compared to a standard interval. Although the comparison method can be very useful, a more subjective measure of duration perception also has its virtues. Having a participant reproduce the duration can provide a precise and more subjective insight into how we perceive time. For the purpose of determining the effect of physical and semantic properties on a distortion of time perception the reproduction method was chosen for this study.

Creating distortions of perceived event time may help to provide insight into underlying mechanisms of time perception. This research attempts to create such a ‘temporal illusion’ as a tool to determine characteristics of how perceived duration is influenced. A few examples of time dilation and expansion are discussed below.

Dilation and Expansion

Kanai & Watanabe's 2006 paper demonstrated that, within the visual modality, the first interval is perceived to be longer than the second, and also that the type of onset can expand subjective time. These two researchers found that the duration of a moving stimulus is perceived longer when it appears abruptly in comparison to a moving stimulus that is preceded by a stationary array.

Another example is a study by Kanai et al. (2007), where the authors demonstrate that a dynamic visual display could cause perceptual dilation of time. They show that the temporal frequency of a visual stimulus can calibrate or serve as an internal time keeping device, a moving stimulus was perceived longer than a stationary one even when they were presented for equal durations. This phenomenon of event-based timing is not exclusive to one modality. In fact, research into the auditory and visual interaction (examples) has shown that human timing relies on an interaction between modalities. When modalities are out of tune or out of sync they can be recalibrated to make sense. For example, when a tone is presented 10msec before a visual stimulus is presented, people will experience them as simultaneous, indicating that we are very capable of recalibrating or tuning in order to compensate for this lag and re-establish subjective simultaneity (Fujisaki et al., 2004).

Attention

Attention is a vital concept in research on temporal processing as many models and theories underline the important role that attention has. A distinction between attention to time and attention in time should be made. "Essentially, the literature on prospective timing reveals that attending to the flow of time increases perceived duration and, somewhat similarly, that being distracted from time results in the shortening of perceived time" (Grondin, 2010). Attention in time, on the other hand, is attention to particular stimuli and is the fascinating aspect that may be responsible for time distortions.

Tse et al. (2004) propose that the involvement of attention as well as how it influences the amount of perceptual information processed is responsible for the subjective expansion of time. He poses the question that this research aims to answer as well: "Is the expansion in perceived duration really an attentional effect, or is it simply a consequence of the amount of information processed?" *Oddball* stimuli were presented within a series of stimuli and were perceived as longer than the other, high-probability, stimuli in the series. They took measurements with multiple methodologies (method of constant stimuli, magnitude estimation, and reproduction) so as to verify the reliability of the results. From their results they suggest that the attentional allocation to the oddball causes time's subjective expansion (TSE). A ~120msec delay occurred before TSE set in during the presentation of the oddball, possibly explained by the time it takes for attention to orient to a stimulus. Other arguments for their conclusion include similar results when they used a series of various stimuli that fit in a semantic category, as well as the fact that they found similar results for both visual and audio stimuli.

Building on the abovementioned research by Tse et al., Pariyadath & Eagleman coined the term *debut effect* in their 2007 study on the effect of predictability on subjective duration. In attempt to determine whether time expands or contracts and what the role of attention is during duration illusions they preformed a series of experiments using repeated presentations of audio or visual stimuli that could include oddballs and unexpected stimuli as well as sets that involve sequences of numbers. One of the main conclusions was that increasing the saliency of an unexpected stimulus by including emotionally charged oddballs which are meant to attract attention more quickly does not enhance the duration dilation, suggesting that the oddball effect does not have to be a fundamentally attentional effect. This led to two experiments on the predictability of the stimulus. In the first experiment there were two conditions: one that included repeated stimuli (high predictability) and a second that included random stimuli. The researchers found that the first stimulus in the repeated condition was perceived as longer and that this effect did not occur in the random condition. Their last experiment aimed to determine whether there is a low or high-level criterion to which the stimuli predictability must adhere for the duration distortion to occur. Sequences of numbers (differing in shape, but sequentially predictable) and scrambled numbers were used. The same effect was found for the sequential number as was found for the repeated-presentation stimuli, implying that there is a higher cortical process involved in the predictability of successive stimuli.

This article aims to contribute insight into the extent of cognitive processing necessary to produce the effect of time expansion. We have conducted a psychophysical experiment to determine the roles of physical and semantic congruency in duration perception. The experiment is a prospective duration reproduction task. The main distinction of this research is the addition of a stimulus that has the same semantic value but different visual representation (capital vs. lowercase letters). The debut effect could be dependent on physical congruency (a-a) or semantic congruency (a-A), or combination of the two. A reliance on (or 'attention' to) the physical properties of the stimuli may indicate that there is some sort of readiness or adaptation occurring, whereas attention to semantic properties may indicate a higher-level, more conceptual process.

Methods

Apparatus

A MacPro1.1 computer with a refresh rate of 100Hz with a NVIDIA GeForce 7300 GT graphics card and a Sony color monitor. The experiment was programmed and presented via MATLAB. Participants were seated at ~75cm from the computer monitor and used the keyboard for making responses.

Subjects

Seven students of the University of Utrecht participated for credit or a small participation fee. All participants had normal or corrected-to-normal vision.

Stimuli

The screen was gray with a centered, white annulus (approximately 0.3° x 0.2°), which was present throughout the experiment. Stimuli were presented within the white ring and were the letters a through m (excluding the letters i, j, and l) presented in the capital and lowercase form. The letters were white, Helvetica font, and 40 pixels in diameter.

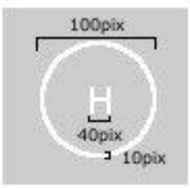

Figure 2. One of the stimuli and its dimensions in pixels.

Each trial consisted of an initial cue stimulus presented for 500msec followed by a 500msec pause. Target stimuli were then presented for durations ranging from 500 to 1,000ms (see figure 3 for a schematic overview of the task). We created conditions with varying letter combinations as shown in Table 1. The first two conditions were congruent on both physical and semantic aspects. Conditions 3 and 4 were semantically the same but physically different. Conditions 5 and 6 differed only semantically. Lastly, two conditions that differed on both physical and semantic properties were included.

Condition	1	2	3	4	5	6	7	8
Example	a-a	A-A	a-A	A-a	a-e	A-E	a-E	A-e

Table 1. Examples of each condition.

Task

The experiment consists of a dual task: reproducing the duration of the second stimuli as well as comparing the two stimuli. Participants were instructed to reproduce the duration of the second (target) stimulus by pressing the space bar on a keyboard directly following the presentation of the second stimulus. After the duration reproduction task participants indicated whether the first and second stimuli were the same (left arrow key) or different (right arrow key). Each participant completed 400 trials divided into two sessions of 10 blocks each.

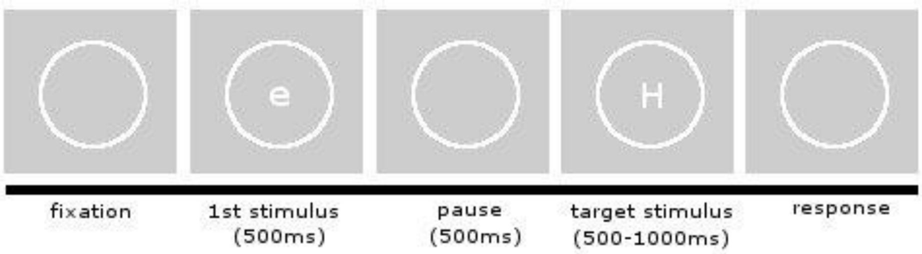

Figure 3. A schematic overview of the task.

Analysis

To determine the error (or bias) the reproduction time was subtracted from the duration of the target stimulus for each trial. The mean error (bias) per condition for each participant was calculated. These scores were then analyzed with a repeated measures ANOVA with a significance threshold of a< .05.

Results

Main effects

Figure 4 below shows the mean overestimation of all participants for each condition. On average, participants were biased to underestimating the durations, as reflected by the negative values. A one-way repeated measures ANOVA was conducted to compare the effect of same versus novel stimuli on reproduction responses in the various letter sequence conditions. A significant effect was found, $F(7,42) = 3.065$, $p= .01$. These results suggest that the type of condition does have an effect on perceived duration.

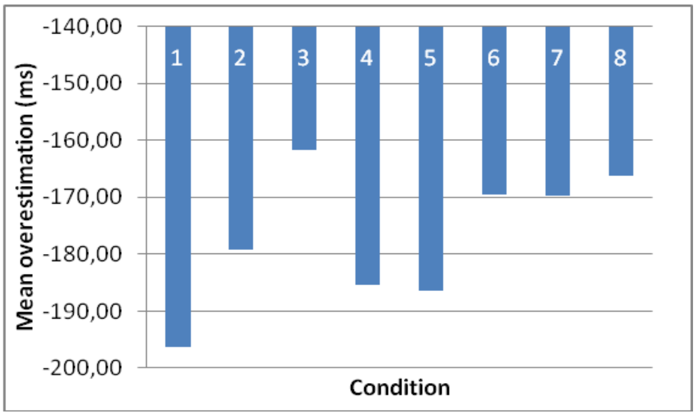

Figure 4. Mean overestimations of all participants for each condition.

The following sections will expand on comparisons of various conditions.

Debut-effect

Figure 5 shows the debut effect, that is, of the first two conditions in which both stimuli are identical in both physical and semantic properties versus all other combinations that contain incongruent stimuli. Here a one-way repeated-measures ANOVA indicates that there is a small but significant debut effect, $F(1,6) = 9.620$, $p = .02$.

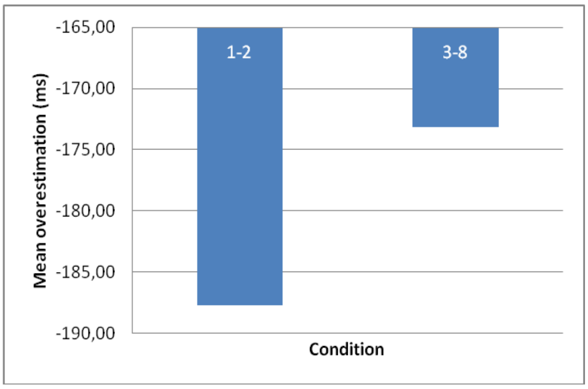

Figure 5. Mean overestimations of stimuli that are identical versus stimuli that differ semantically or physically.

Physical properties

The figure below shows the mean scores when conditions are paired based purely on their physical properties. We see a relatively large underestimation of lowercase letters (condition 1&5) as opposed to the other conditions that involve a capital letter. We also see that when a lowercase letter precedes a capital letter (condition 3&7) the underestimation is smallest.

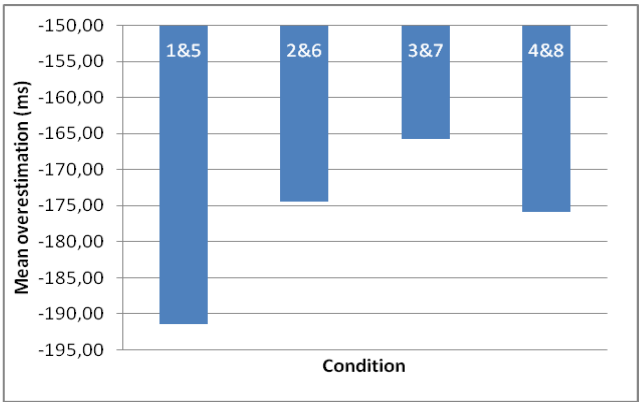

Figure 6. Mean overestimations based on both lowercase (1&5), both uppercase (2&6), from lowercase to uppercase (3&7) and from uppercase to lowercase (4&8).

Having a capital letter as the first stimulus seems to produce a similar underestimation regardless of whether the second letter is uppercase (condition 2&6) or lowercase (condition 4&8). Perhaps here the transition from small to large can be linked to the findings of a *magnitude effect* by Xuan et al. (2007) that non-temporal information such as the size of a stimulus can influence time perception. Xuan and his colleagues found that people are more likely to report more dots, larger dots or brighter dots as temporally longer than fewer, smaller or dimmer dots.

Semantic properties

The next figure shows the mean scores when the conditions are paired based on their semantic properties. In other words, the conditions that contain letters that are the same (regardless of whether they are capital or lowercase) are grouped together (condition 1-4), and those that are different are in another group (condition 5-8). $F(1,6) = 2.970$, $p = .14$.

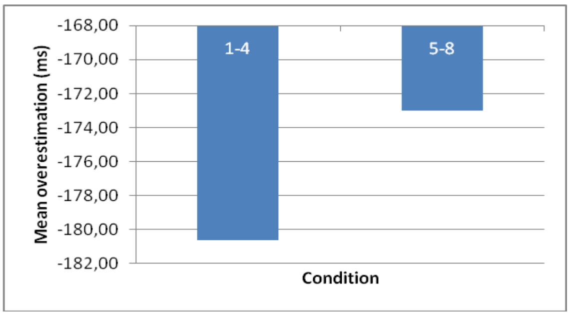

Figure 7. Mean overestimations based on conditions which include stimuli that are semantically the same (1-4) versus stimuli that are semantically different (5-8).

Discussion

This research was based on the assumption that the presentation of a novel stimulus produces a longer duration reproduction than the presentation of a same stimulus. With that in mind, we expected that this distortion of psychological time may be a result of automatic processing on a low-level or perhaps on a higher cortical level of processing.

Tse et al. (2007) put forward that an increased perceived duration is a direct function of increased information being processed. In other words, when there are more events taking place within a given interval, the duration will be perceived as longer because each event functions as a time reference. We attempt to explain the debut effect by determining if when more attention goes out to a particular feature, it would be less taxing to process that same feature again, decreasing the amount of information processed – perhaps a cueing effect. This led us to question which features may be responsible for the distortion.

The variability of the responses between and within subjects was rather high. As Grondin put it:

> "Even if a timing system provides a mean perceived duration that is close to the target over a series of trials, the system may be poor. It might provide a correct mean response, but the variability of information is high, with estimates being sometimes much briefer or much longer than those in real time. In other words, in many studies, it is not the mean estimates of the system that are of interest, but its capacity to minimize the variability over trials" (2010)

This statement brings into question the validity of the results.

Nonetheless, we did find a small but significant debut effect, as well as something that looked like the magnitude effect. These results give some insight into how time perception might (not) work and provide motivation for future research, incorporating different methodology such as a 2AFC task. Although Tse writes*: "It is known that the method of measurement can influence temporal judgments (Allan, 1979; Zakay, 1993). However, if the underlying effect is robust, it should manifest itself regardless of the method used to probe it"*, given the large amount of trials, variability within the trials, and the subjective quality of the reproduction task, there is a chance that the 2AFC method could provide more conclusive results.

Another possible explanation for the disappointing results could be that the dual task (indicating whether the two stimuli were the same or different) interfered or diverted attention away from the timing/reproduction task. Casini et al. (1992) concluded in their article that the ratio of estimated to real duration decreases as a function of the amount of information processed in a distracting secondary task. They found that duration is perceived as shorter when attention is paid primarily to the non-temporal task. Tse et al. (2007) also suggests this based on the model that prospective judgment requires attention to time; they constitute that when a concurrent task is more difficult there is less overestimation of duration because less attention is paid to the temporal cues.

Although the findings of the current research are not as conclusive as hoped, the experiment can be adapted to incorporate changes that may provide better results. Some suggestions include using different means of measurement, or different stimuli such as photographs (houses, buildings, etc), numbers or words (short words that contain the same letters but have different semantic properties). Research on subliminal visual stimuli would also be a very interesting direction to go into: can we manipulate the pacemaker with stimuli that are beyond our conscious awareness?

Reflection

Initially the goal of the research was to execute inter-modal experiments (audio and visual) to determine at which point during a stimulus time expands/contracts, i.e. closer to onset or offset. Based on research on the auditory chronostasis effect (Rose & Summers 1995, Hodinott-Hill et al. 2002) an experiment was designed and administered, but did not provide conclusive results. The participants were presented with a visual stimulus (a filled circle on the screen), during which an auditory beep was presented. The temporal location of the beep was varied within the visual stimulus (towards the beginning or end) and had various durations. Participants responded by reproducing the duration of the stimulus via a key press. In hindsight we realized that the experimental set-up did not necessarily measure what we were hoping to measure, as it was not possible to control for the time between the presentation of the auditory stimulus (which varied) and the moment of response. A few other set-ups were attempted but results were inconclusive.

From there we moved towards primarily visual experiments, including an attempt at manipulating the distortion with subliminal cues by changing the luminance of the stimuli, however after some piloting and further literature research we decided against it, as it would take much more time to develop and run the experiment.

Finally, we decided to explore the properties involved in time dilation by using letters as stimuli. In the first experiment we tested the reaction times to same and novel stimuli to determine if we could reproduce the debut effect with two stimuli being the same or the second being novel, as it is important to determine whether there is a difference in reaction time to same versus novel stimuli. Reason for this is to determine if we can reproduce Tse's (2004) and Pariyadath & Eagleman's (2007) findings that novel stimuli expand time using our own stimuli and moving away from the repeated presentation method.

Two students and one employee of the University of Utrecht voluntarily participated. All subjects had normal or corrected-to-normal vision. To determine whether a debut effect can be reproduced with our stimuli, participants were given two letters and instructed to respond as quickly as possible (key press) whether the second letter was the same or different in comparison to the first. Stimuli were lowercase letters a-f, the first letter was presented for 50msec, followed by a pause that lasted between 500-1500msec. This experiment showed that there is a small difference in reaction times to same versus novel stimuli. Novel stimuli produced a slightly longer reaction time. Despite a large variation that was present between subjects, we felt confident enough to continue on to the main experiment.

I have learned that good research takes time, through trial and error, and that not every theoretically awesome idea will provide equally awesome results. One has to be open-minded, patient and a little creative. It's a shame that there is no database for failed experiments, as I'm sure we could learn from other people's attempts before repeating their mistakes. What I'd like to know is the reason why most of the other research on this topic has used trains/series of multiple stimuli in a trial as opposed to our method of just two stimuli per trial.

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