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Prospective and Retrospective Timing Processes: Theories and Methods

İleriye Yönelik ve Geriye Dönük Zamanlama Süreçleri: Teoriler ve Yöntemler

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ABSTRACT

We experience a flow of time in everyday life. However, according to modern physics, time does not flow. In the psychology and neuroscience literature, different models and explanations have been made to try to answer the question of what time is besides an illusion of flow and to figure out how time is perceived. Different methods have also been used to learn how time is handled and to test how accurate these models are. People process time in two ways: implicitly and explicitly. We are talking about explicit timing when estimating the time interval length. Another distinction, according to the measurement method of time perception paradigms, is between prospective and retrospective time estimations. Although there are theorists who claim that these two methods involve similar cognitive processes, it is thought that different cognitive processes serve to experience and remember a time, depending on whether time perception is measured by the prospective or retrospective time estimation methods. This brings to mind different method-dependent constraints and advantages. As with any other kind of perception study, the method chosen for time perception research should fit the question being asked. This review presents a selective review of time perception studies to make it easier for a researcher planning to study time perception to choose the appropriate method for the study question. The time perception processes and related evidence were examined using prospective and retrospective time estimation measurement methods. But it's important to note that the time perception models and methods talked about in this review are only a small part of a very large field.
Keywords: Time perception, time estimation paradigms, duration judgments

ÖZ

Gündelik hayatta bir zaman akışı tecrübe etmekteyiz. Ancak, modern fiziğe göre zamanın akışı söz konusu değildir. Bir akış yanılsaması dışında zaman nedir sorusuna yanıt bulabilmek ve zaman algısı ile ilişkili süreçleri anlamak için psikoloji ve sinirbilim literatüründe çeşitli modeller ve açıklamalar geliştirilmiştir. Zamansal bilginin nasıl işlediğini anlamak ve bu modellerin doğruluğunu test etmek için de çeşitli prosedürler benimsenmiştir. İnsanlar, zamanı örtük (implicit) ve açık (explicit) olmak üzere 2 şekilde işlemektedir. Zaman aralığının uzunluğuna yönelik tahmin yürütüldüğünde açık (explicit) zamanlamadan bahsetmekteyiz. Zaman algısı paradigmalarında ölçüm yöntemine göre diğer bir ayrımsa ileriye yönelik (prospektif) ve geriye dönük (retrospektif) zaman tahminleridir. Bu iki yöntemin benzer bilişsel süreçleri içerdiğini iddia eden teorisyenler olsa da, zaman algısı ileriye yönelik ve geriye dönük zaman tahmini yöntemlerinden hangisi ile ölçüldüğüne göre farklı bilişsel süreçlerin deneyimlenen ve hatırlanan süreye hizmet ettiği düşünülmektedir. Bu da yöntem bağımlı farklı kısıtlar ve avantajları akla getirmektedir. Diğer tüm algı çalışmalarında olduğu gibi zaman algısı araştırmalarında da prosedürün seçimi araştırmanın sorusuna uygun olmalıdır. Bu derleme zaman algısı üzerine çalışma yapmayı planlayan bir araştırmacının çalışma sorusuna uygun yöntemi seçmesini kolaylaştırmak üzere zaman algısı araştırmalarının seçici bir incelemesini sunmaktadır. Zaman algısının süreçleri ve bunlara ilişkin kanıtlar ileriye yönelik ve geriye dönük zaman tahmini ölçüm yöntemlerine göre gözden geçirilmiştir. Ancak bu incelemede tartışılan zaman algısı modellerinin ve yönteminin alanın yalnızca bir bölümünü temsil ettiğini, alanın oldukça geniş olduğunu belirtmek gerekmektedir.
Anahtar sözcükler: Zaman algısı, zaman tahmini paradigmaları, süre tahmini

Introduction

Cognitive science struggles to comprehend abstract concepts such as time (Barsalou 2008). The time cannot be seen, touched, or heard. However, we are discussing time. Even though the empirical evidence in this work is new, time is not something that has never been looked into before. William James noticed more than a hundred

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years ago that when we pay attention to time, it seems to pass more slowly. He stated that focusing on time increases our perception of duration while focusing on non-temporal information decreases our subjective time estimates (James 1890). Therefore, he observed more than a century ago that time flies when we're having fun and stops when we're waiting for a loved one.

Most time perception research (Grondin et al. 2020) that looks at how people estimate how long an event lasts is based on stimulus-based duration estimation. In the psychology literature, duration estimation is studied more often (Block and Grondin 2014). Duration estimation is tested using both prospective timing and retrospective timing paradigm (Brown 1985).

Under any circumstances, it is impossible to know exactly how long an event or stimulus will last. We're talking about the illusion of perceived time, which happens when the length of time that a person thinks an event or stimulus lasts is different from how long it lasts. Research indicates that the same duration can be perceived at different times and rates, and there is often a difference between subjective and objective duration, even though precise timing is essential for many daily activities (Hellstrom and Rammsayer 2015). How time is experienced and how subjective time perception arises has been studied by researchers investigating the psychophysics of time for years. While methods have improved over time, some basic findings about duration estimation that varies according to the characteristics of the stimulus are now well established.

Perceived duration can be perceived as longer or shorter depending on many factors, including changes in stimulus characteristics. We also know that non-temporal stimuli presented in different modalities can affect time estimates. For example, the size of a visual stimulus can manipulate perceived time (Ono and Kawahara, 2007). An increase in the magnitude of a number affects time estimates in the direction of perceived time as longer (Vicario, 2011). The fact that auditory stimuli are perceived as longer than visual stimuli of the same duration (Wearden, 1998) also suggests that there are different mechanisms for sensory and motor timing.

In this review, firstly, some basic views about the processing of temporal information are discussed. Secondly, the cognitive processes and methodological differences involving time perception measured by prospective and retrospective time estimates are addressed. Lastly, it is mentioned that temporal information can differ depending on the characteristics of the perceiver.

Explanations about the Processing of Temporal Information

We operate time in a wide range, from microseconds to 24 hours. It is thought that each of the time scales has a separate function. Processing of temporal information is required in daily activities, from high-level cognitive skills such as decision-making, planning, and speech to the sleep-wake cycle (Buhusi and Meck 2005). Time perception is an inseparable part of cognition. Therefore, understanding time perception requires understanding it in conjunction with other cognitive abilities and working memory mechanisms, similar to memory and attention mechanisms. For example, brain structures known as supra-chiasmatic nuclei, help to measure time to enable vital activities such as sleep-wake and hunger-satiety to function properly. The circadian rhythm that regulates the day-night period is not very flexible and gets disrupted by jetlag which causes some psychosomatic problems when travel exceeds a few hours (Moore and Eichler 1972).

When considering timing at the level of milliseconds and below, it has been reported that simultaneity is experienced when the interval between two auditory stimuli is less than approximately 2-3 ms, and temporal order judgments cannot be made until the interval between the stimuli is approximately 20-30 ms (Hirsh and Sherrick 1961). However, recent studies have shown that the spatial position of sound is processed quite accurately within the auditory system and microsecond differences in the transmission of sound to both ears can be distinguished (Joris and Yin 2007). It is thought that this fine adjustment of temporal processing is important for localizing sound sources. However, millisecond timing also plays an important role in regulating perceptual and motor activities such as motor coordination, speech, and speech recognition (Buhus and Meck, 2005).

In the literature, debates about time perception are centered around whether different time scales are processed and represented by internal or assigned systems. Some researchers claim that humans understand abstract components through their interaction with the world and that abstract knowledge is represented as directly experienced information. It is thought that the abstract phenomenon of time is processed with more concrete information and experiences in the field (Boroditsky and Ramscar 2002, Ramscar et al 2009). The view of structuring based on experience has been formulated in different ways. According to one formulation, the knowledge of abstract fields is directly related to the body and thus abstract concepts are represented directly through image schemas and motor schemas (Lakoff and Johnson 1999).

Another widespread view suggests that time is understood through more concrete information and experiences in the field, time is structured along with space. The concept of a "mental timeline" has been proposed to conceptualize the mental representation of time through a spatial reference frame (Stocker 2012). It is thought that people tend to place life events along an imaginary timeline and associate temporal concepts with spatial locations (for example, past = back, future = forward) (Eikmeier et al. 2015)

The right hemisphere can interpret both the right and left visual fields at the same time, but the left parietal lobe can only interpret the right visual field. When there is a lesion in the right hemisphere for any reason, left hemineglect can happen. This is a neuropsychological condition that makes it hard to see the left side of your visual field and makes you not pay attention to it. Recent research indicates that neglect is not restricted to the visual sense alone. People with left hemineglect did not remember the stimuli they had associated with the past (Saj et al. 2014). This was seen when they were asked to remember the stimuli they had associated with the past. This clinical study demonstrates that space has a functional role in time comprehension.

The resulting space-time congruence effect is often attributed to a culturally salient localization of temporal information along a mental timeline. Results in reaction time (RT) studies have also reported support for the space-time congruence effect. Responses to temporal information are faster when organized spatially congruently as compared to when it is incongruent. The congruence effect has been shown when stimuli related to the past are shown on the left and stimuli related to the future are shown on the right (Winter et al. 2015).

As discussed in classical memory research, it is thought that the most complex form of episodic memory, known as mental time travel, takes place along this mental timeline (Tulving 2002). Memory is connected to a special network comprising the medial temporal lobe (MTL) centers, including the hippocampus formation and cortical regions in the retrosplenial and posterior singular cortex (Kravitz et al. 2011). Hippocampal activity observed through neurophysiological methods suggests that information about both space and time is processed together (Eichenbaum 2014, Moser et al. 2017). The connection between navigation and memory functions at the MTL level has led to the suggestion of a phylogenetic continuity among neural mechanisms. Studies using animal models also support the role of the hippocampus in remembering durations (MacDonald et al. 2014), further supporting the idea that memory is a fundamental component in the perception of time.

One of the fundamental debates in the perception of time is whether the mechanisms of temporal information are centralized in the brain or distributed in a system (Ivry and Spencer 2004). The absence of a selective physiological mechanism for representing temporal information has made the neural foundations of time perception controversial. Research shows that tasks involving only the sensorimotor system can be performed relatively automatically, while tasks that involve working memory and attention, known to involve the prefrontal and parietal modules, require more cognitive involvement. The right dorsolateral prefrontal cortex (DLPFC) is known to be strongly associated with working memory (Wager and Smith 2003). The DLPFC region is also thought to be necessary for cognitively controlled time measurement. Studies of Parkinson's patients with unilateral deficits affecting the prefrontal cortex have shown that lesions in this area disrupt cognitive timing (Harrington et al. 1998).

Another classic approach is the internal clock theory or pacemaker-accumulator model, which points to the effect of attention on time perception. This model, based on psychophysical studies by Treisman (1963), suggests that temporal information is processed by a clock-like mechanism. According to this model, temporal information is processed by sending it to a pacemaker that generates rhythmic signals and an accumulator that stores these signals. While working memory stores the current rhythmic signals generated by the pacemaker, reference memory stores previously learned signals. In the decision phase, estimates are generated by comparing the signals in working and reference memory with the duration that is thought to correspond to the temporal interval. According to this model, as the rate of signals accumulated in the accumulator increases, perceived time increases (Allman et al. 2014, Mioni 2014, Basgol et al. 2021).

This model seems to be able to help explain both the effect of attention and the effect of physiological changes such as arousal on time estimation (Grondin 2010). When dual-task situations are considered, directing more attention to a non-transient task means paying less attention to time, resulting in fewer pulses and the perceived duration will be shorter (Zakay and Block 2004). Similarly, the newness of the stimulus can affect the perceived duration. People perceive the duration of a familiar task as shorter than that of a new and different task. A new stimulus is expected to be perceived as long as it is processed for a longer duration than the familiar stimulus (Basgol et al. 2021). Similarly, the newness of the stimulus can affect arousal and attention. Neural activation size codes the duration of the stimulus and determines the perceived duration of the stimulus. The fundamental concept here is "predictability" (Pariyadath and Eagleman 2007).

Recent research on time perception has reported results that question the existence of an internal clock and have shown time distortions that vary according to the characteristics of the stimulus (Terao et al. 2008, Ayhan et al. 2011). In parallel, some researchers, based on findings that contradict the internal clock theory, argue that time is coded by peripheral systems like color, size, or movement and that it can be modified in a certain visual field. This has led to the idea of a "time pathway" (Alaşhan and Ayhan 2021).

Neuroscience-based models aimed at understanding the neural mechanism of time refer to the role of brain areas such as the cerebellum (Ivry and Keele 1989), the complementary motor area (Macar et al. 2006), and the right prefrontal cortex (Lewis and Miall 2006) in the perception of time.

Since the coordination of complex movements, estimating how long it will take to perform specific tasks, and other timing tasks are varied, it would not be expected that the same brain system would be used in all timing tasks. Research in this field has also shown that sensory regions of the brain are also involved in temporal processing (Bueti et al. 2008). It is thought that different temporal durations are processed by different mechanisms for motor and non-motor timing measurements (Spencer et al. 2003).

Time Estimation Paradigms

Research on time perception makes a distinction between two paradigms, prospective and retrospective (Block et al. 2018). In the prospective paradigm, the person has information about the duration of the stimulus or event they will be estimating. In the retrospective paradigm, the person only learns the duration of the stimulus after it has ended. Some researchers have compared the methodologies of retrospective and prospective time estimation (Zakay 1993, Zakay and Block 1997). While some theorists claim that these two methods involve similar cognitive processes (Brown and Stubbs 1992), the consensus is that different cognitive processes are involved in the time estimation task depending on the method used (Zakay and Block 2004).

In the prospective paradigm, attention is divided between transient and non-transient information processing. Therefore, researchers who use these models generally approach their research question by taking attention processes into account. In contrast, in the retrospective paradigm, the research question is examined in the context of memory processes (Zakay 1993).

The difficulty of information processing affects primarily prospective predictions, whereas it is thought to have little or no effect on retrospective predictions. On the other hand, it has been reported that stimulus complexity affects retrospective predictions, but not prospective predictions (Block and Zakay 2004).

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In prospective tasks, the amount of mental load required for a task can manipulate the perceived duration of time (Zakay and Block 1996). Participants will receive more strikes to the accumulator as they pay more attention to temporal processing. When attention is directed elsewhere, fewer strikes will be collected in the accumulator. As a result, the duration of a stimulus or event will be perceived as shorter than it is (Johnson and MacKay 2019). When making retrospective predictions, attention will be directed away from time, triggering the encoding of more non-temporal information, resulting in an overestimation of the elapsed time.

In prospective tasks where individuals are aware that they will be making time predictions, the attention resources for the time prediction will decrease when the stimulus is attention-grabbing and will lead to the duration being perceived subjectively as shorter. In retrospective tasks where individuals were not aware that they would be making time predictions, the duration will be reconstructed using previously encoded information accessed from memory (Zakay and Block 1996).

According to literature, studies investigating the effects of emotions on prospective time estimation have reported that individuals tend to estimate time as longer in emotional conditions. This finding is explained by the arousal effect. During emotional conditions, high arousal leads to an increase in the rate of rhythmic pulses and this increase causes time to be experienced as slower (Johnson and MacKay 2019)

In a study conducted to understand emotional-coding processes in memory, the presentation durations of taboo and neutral words were compared with the perceived subjective durations. The results showed that taboo words were better remembered than neutral words and that the presentation duration of taboo words was perceived as longer than that of neutral words. It is thought that this is because people can remember more contextual information about taboo words than about neutral words, therefore in retrospective evaluations, people will rate the taboo durations as longer than the neutral durations. During time estimates, most of the information is more accessible for taboo than for neutral words, providing a cue that facilitates time decisions (Johnson and MacKay 2019). More research is needed in this field, as it is not yet clear why some emotional stimuli are understood through arousal mechanisms and others through attention mechanisms.

On the other hand, it is also seen that the duration of intervals is important in time perception studies. Research on the duration of intervals shows that processing of longer intervals requires the support of cognitive resources, while processing of shorter intervals is more sensory-based (Lewis and Miall 2003). Short time intervals can be preferred to exclude cognitive factors such as attention and working memory required for long time intervals. If the research question is about exploring temporal abilities rather than the effects of cognitive processes in temporal processing, using an explicit counting strategy for seconds and above intervals, it would be more suitable to select durations below 1300 milliseconds (Mioni 2018).

Prospective Time Estimation

As mentioned in the previous topic, in the prospective paradigm, the participant is given prior information that they will be making a time estimation. Knowing that the participant will be estimating the duration of a stimulus implies that explicit attention is involved in the encoding of the duration.

In the literature, verbal estimation and time production tasks are traditionally accepted and commonly used techniques (Bindra and Waksberg 1956, Guay and Salmoni 1988, Hancock and Block 2012). In the verbal estimation method, after the presentation of the stimulus, participants are asked to provide a numerical estimate of the duration of the stimulus. In the task of verbally estimating time, language processing and memory mechanisms are used (Zakay and Block 2004).

The main limitation of the verbal estimation task is that it relies on words, or numbers, and these can create a linguistic limit. Also, time perception will be contaminated by linguistic and semantic labels associated with traditional units of time (Hancock and Block 2012). Indeed, it has been reported that people tend to use rounded numbers in their time estimations (Grondin 2010). This variability should also be considered when evaluated from a developmental perspective, specifically in studies with children, and the understanding of what hour and minute means, or age appropriateness.

In the time reproduction task, participants are asked to press a button as a directive to mark the start and end of the estimated duration after the presentation of the stimulus. In other words, the participant is reproducing the duration of the stimulus again. The time reproduction task is a method that can be applied to children in developmental studies. However, the limitation of the time reproduction method is that the duration created can be affected by factors such as the desire to finish earlier and impatience (Block et al. 2018).

The time reproduction task can be designed in the form of requiring the production of a specific duration, for example producing three seconds, or in the form of reproducing the duration of the stimulus remaining on the screen. Reproducing the duration of the stimulus remaining on the screen includes the processes of encoding the target duration and reproducing it, which means that attention and working memory processes are involved (Block and Zakay 1997).

Another task of prospective timing is comparing the presentation duration of the stimulus with a fixed duration. Presenting increasing or decreasing trials at certain points above or below the perceived threshold is a variation of other classic threshold determination research. The researcher must make decisions such as the size of correct and incorrect responses and how many trials are needed for the operational definition of the threshold (Block and Reed 1978).

Another prospective timing task is a procedure that includes comparing two or more reference durations. In this method, participants are familiarized with two reference durations, short and long. After the familiarization stage, participants are asked to decide which of the two reference durations, short or long, is closest to the presentation duration of the stimulus. In the literature, this method is widely used as the bisection task method.

In the less-used "rating" method, more than two reference durations are presented. The experiment begins with familiarization with the durations. Participants are asked to estimate which of the familiarized reference durations is closest to the duration of the stimulus. While in the two-interval method, participants are asked to estimate which of the two standard durations (for example, 1200 ms for long and 600 ms for short) the stimulus is closest to, in the "rating" method, participants are asked to make predictions for consecutive multiple standard durations (for example, 800 ms, 1000 ms, 12000 ms, etc.) (Hoopen et al. 2008).

Retrospective Time Estimation

In the retrospective paradigm, the participant is not previously aware of the timing estimation task. Therefore, in retrospective estimates, temporal information is implicitly encoded. This task is based on remembering the duration of the stimulus displayed, so it is thought that temporal information is processed along with memory-related processes. In this context, it is thought that variables requiring cognitive load do not affect retrospective estimates, while variables affecting encoding and retrieval in memory affect perceived duration (Block et al. 2018).

Although evidence is still limited, research on time perception in individuals with memory disorders supports the role of memory in the formation of retrospective duration estimation. In the retrospective duration production task, amnesic patient H.M. produced shorter estimates compared to the control condition for time intervals between 200 and 300 seconds (Richards 1973). Alzheimer's patients also tend to perceive durations as shorter compared to the control group of the same age (El Haj et al. 2013). If more encoded information results in longer retrospective duration estimates, it can be concluded that individuals who have difficulty encoding new memories should produce shorter retrospective duration estimates than control participants (Johnson and MacKay 2019).

In retrospective timing, the method of reproduction and verbal estimation methods are also used. When time is reproduced retrospectively, participants are not given prior information about the presentation duration of the stimulus that will be reproduced. Although this method is not preferred for long presentations, it is more commonly used in the retrospective paradigm. When people are asked to make numerical estimates (in seconds and minutes), these estimates are highly variable. As contextual changes increase, it has been reported that the perceived duration lengthens (Block and Reed 1978). However, it has also been reported that duration estimates may be more accurate when events have a regular and predictable tempo (Boltz 1998).

When the same stimulus is shown consecutively and for two equal durations, the first presentation is perceived as being longer than the second presentation. This result is associated with the fact that the initial environmental factors, emotional state, stimulus, and other contextual elements contain more novelty in the second presentation than in the first (Block and Gruber 2014). In other words, the perception of the first presentation as being longer is explained by the presence of greater and more novel contextual changes during the first duration.

Retrospective estimates are challenging to study with a single trial because it is a procedure in which individuals do not know beforehand that they will be estimating duration. The fact that the study consists of a single trial makes it difficult to make inferences about the variability of time perception concerning the stimulus.

Change in Temporal Knowledge Based on Age and Gender

In contrast to the literature on comparing time estimation paradigms, there are relatively few studies on the relationships between individual factors and their findings are inconsistent. For example, while perceived time is known to change with age, research results on the effects of age on time estimates are inconsistent. Some studies have reported that time is perceived as passing faster as one gets older (Winkler et al. 2007), while another study found that age does not affect time estimates for short durations and simple tasks (Block et al. 1998). However, in a study that measured using a prospective paradigm, older adults (those over 60) were found to make longer estimates for verbal tasks compared to younger adults and these estimates were more variable (Block et al. 1998). In a study using a retrospective paradigm, older adults were found to estimate shorter durations compared to young adults (Vanneste and Pouthas 1995).

When looking at the effect of gender, studies have shown that women tend to have longer and more variable time estimates for short durations and simple tasks compared to men. However, these findings may vary depending on the method of time estimation (such as verbal estimation against reproducing a time interval) or the paradigm used. When using complex stimuli, such as the time it takes to read a passage of text, women tend to make longer retrospective time estimates than men (Block et al. 2000). Another study found that men tend to perceive the duration of negative stimuli as longer than women (Mioni et al. 2018)

Conclusion

In research on time perception, various views and models have been discussed in the light of different research, pointing to the different mechanisms of different temporal durations, such as the coordination of complex movements for processing temporal knowledge, and the estimation of how long it will take to perform certain tasks. Additionally, evidence based on sensory, perceptual, attentional, and memory processes has been examined depending on the measurement method chosen.

In studies using simple tasks for short durations from milliseconds to minutes, prospective time estimates were found to be longer (Block and Zakay 1997). Various experimental research has confirmed this effect (Bisson and Grondin 2013). Additionally, as the difficulty of a task increases, prospective time estimates decrease and retrospective estimates increase (Block et al. 2010). This trend is generally explained by participants paying attention to environmental information related to their time estimation processes in a prospective-time condition. This distinction between paradigms leads researchers to believe that prospective-time estimates primarily depend on attentional processes and retrospective estimates of memory.

A recent study examined both prospective-time and retrospective paradigms simultaneously to provide a new perspective on the relationship between time estimates and individual factors. The study found that individuals who made longer time estimates in the prospective-time paradigm made shorter time estimates retrospectively compared to others (Bisson and Grondin 2020).

The distinctions between prospective-time and retrospective tasks highlight the importance of taking into account the activation of different attention and memory resources when choosing a timing task. In this context, time estimates under prospective time and retrospective conditions, which are respectively affected by attention and memory processes, have been discussed. While more research is needed, evidence on brain areas and processes related to time has also been reviewed. Future research should focus on more clinical findings, comparative methodological studies, and imaging studies to deepen the understanding of these processes. Additionally, the connection between individual factors (such as personality dimensions, and emotional state) and the subjective impressions of time passage seem important in determining the boundaries of prospective time and retrospective paradigms.

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