Context Matters: Memories of Prior Times

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Chapter 7
General Discussion
Time in Context

Time in Context

What Time Can Tell about Memory Decline, Sexual Arousal, and other Psychological Phenomena

In life, everything circles around time. How long do I have to come up with a response to the question just posed by the man behind the counter in the Späti? Can I put a wash in the machine and still catch the train to work? Is the silence on the other side of the line an indication of our connection dropping, or is she just looking for words? In all these cases, timing hinges on our previous experiences. Given the daily witty exchanges with the Späti owner, I know that I should come up with a response quickly, whereas I know that a longer silence during the phone calls with my introverted friend are not exceptional. Thus, in different conversations similar durations could result in a very different evaluation. No matter which task, we expect actions to take a certain duration, an expectation that is defined by the context and formed by the earlier experiences within this context. This thesis describes a number of empirical and computational studies in which I explore how context influences our perception of time, how this context is reflected in memory, and how this intricate interaction of time and memory is affected in later stages of life.

Despite memory being a central component of timing theories since the onset of the academic study of time (Treisman, 1963), the influence of memory on timing has only sporadically been studied. For example, even though memory is one the three main components of the Scalar Timing/Expectancy Theory (SET), which is generally considered the keystone timing theory, studies have predominantly focused on "the clock" and were relatively oblivious to the role of the decision and memory components (Church et al., 1994; Gibbon et al.,1984). The clock component consists of a pacemaker and accumulator that interact to provide the system with a sense of time, and studies have focused on the mathematical regime that best describes the hypothetical pulse generation (e.g., Gibbon & Church, 1981; Taatgen, Van Rijn, Anderson, 2007), whether the transmission of pulses from pacemaker to accumulator is flawless or affected by secondary processes (Zakay, 2000), whether the capacity to time multiple intervals necessitates multiple clock systems (Van Rijn & Taatgen, 2008; Leak & Gibbon, 1995), how emotions influence the speed of the clock (Droit-Volet, & Meck, 2007), etc. This emphasis on the clock system is surprising when one considers that Vierordt's law, one of the best known "timing laws", describes how the perception of time is affected by other perceived durations (e.g., Lejeune, & Wearden, 2009). Studies that have focused on the memory component of the SET triad, mainly addressed how the memory system provided access to the single memory trace that is relevant to the timing task at hand (e.g., Jones & Wearden, 2003). However, this can hardly explain the timing subtleties introduced in the previous paragraph: Have I stored the timing of all previous exchanges with the Späti owner? How do I distinguish between the durations associated with different mundane household tasks?

Only recently has attention turned to how the memory system actively influences how humans and other animals act in time. For example, Bayesian observer models of timing assume that the memory of previous experiences, the prior, acts as a filter to reduce the trial-by-trial noise associated with actual duration perception. Depending on the implementation, this prior is either instantiated as a fixed component, assumed to be "hard-wired" in the brain of the participant for the duration of the experiment, or assumed to be updated with incoming information as the experiment progresses (e.g., Diyas et al., 2012; Taatgen & Van Rijn, 2011). Even though the latter approach might be a more truthful depiction of human performance as, obviously, a just perceived duration will exert a stronger momentary influence than a duration perceived years ago, the assumption of a prior that is stable over the duration of an experiment provides a number of analytical advantages. For example, when a fixed but parameterized distribution is assumed to represent all earlier experiences, we can estimate these parameters per participant and determine the relative contribution of the memory system for that specific participant. Theoretically, this is also possible with an updating memory system, but the additional degrees of freedom associated with an updating memory representation would require a large number of trials to accommodate a reliable model fit. Still, neither approach explains how the proper memory context is selected as neither approach explains how I switch from the short context in the Späti interactions to the long context in the phone calls. Even though the actual selection process is not addressed in this thesis, I have shown in Chapter 5 that even with very abstract, simple clues, people are able to quickly select the right context. This confirms that in real-life, when the context is defined by a much richer set of features, it should indeed not be difficult to select the right temporal context. In the other chapters of the thesis, I have focused on how the memory system influences temporal performance by, paradoxically, proposing a fairly simple task. As this task assesses timing performance without requiring memory updating, we can utilize this task to partial out clock variability and demonstrate that in older populations timing performance relies to a stronger extent on the memory processes, even in pre-clinical Alzheimer patients (i.e., amnestic Mild Cognitive Impairment patients). This contradictory finding - the stronger one's memory is affected, the more one relies on memory - can be explained by considering the dual role of the memory system. On the one hand, the prior provides a general context and is built up over the whole scope of the experiment. On the other hand, the memory system also needs to keep track, in a system that might resemble working memory, of the duration that is required for performance on the current task. When memory starts to fail, the impact of memory deterioration on the internal representation of the current duration might well be more severe than the impact on the more stable prior representation. Thus, a stronger reliance on more stable memory representations is a more rational approach when memory starts to fail.

Nevertheless, the proof of the pudding would be to replicate this result in healthy, young participants. Do people with better memory skills rely less on their prior representation than people whose memory system is more efficient? As the recent trace might be encoded in a working memory-like system, a most straightforward option would be to correlate an individual's working memory capacity with their prior parameters. However, one can wonder whether this capacity measure would provide the best index in this context: working memory capacity not just measures how well information is retained, but also how efficiently it is encoded (e.g., Unsworth, & Spillers, 2010; Kane, & Engle, 2000) and is at least partially dependent on strategy use (e.g., Hilbert et al., 2015; Nijboer et al., 2016). Interestingly, Sense et al. (2016) have recently published work in which a quantification of memory performance is presented that well predicts the accuracy with which memory traces are encoded, but that does not correlate with working memory capacity. This quantification is derived from an adaptive learning system (Van Rijn, Van Maanen, Van Woudenberg, 2009) in which a rate of forgetting is estimated for the learning materials. This rate of forgetting is calculated on the basis of both accuracy and the speed by which answers are given to a cue. Obviously, the rate of forgetting will be influenced by learner-specific strategies or background knowledge, but the observation that this measure highly correlates with memory performance yet not with working memory capacity or measures of general intelligence provides a promising avenue for indexing a pure form of memory encoding. It would therefore be highly informative to assess whether memory reliance in interval timing tasks is a function of the rate of forgetting estimated in an adaptive learning session.

To summarize, in this thesis I demonstrate that *Context Matters*, and that *Memories of Prior Times* influence how we perceive the present, and that we can only understand how time drives our everyday functioning when we understand how a timing system interacts with a memory system. The work in this thesis only scratches the surface of these processes - for example - even though clinical population studies and mathematical accounts of the interaction of memory and time are addressed, it does not address the neurological foundations of interval timing. Yet, even without knowing all the intricate details of how interval timing is instantiated, I would like to argue and discuss that time could be a tool to increase our understanding in other fields, which could be one way to propel timing into the real-world.

Given this thesis' focus on memory, I will first focus on how the role of memory in timing can be used in applied or clinical settings. In the introduction, however, I also focused on how arousal and attention modulate the subjective perception of time. Of these two, attention might be less suited for usage in applied settings. For one, to be useful in applied settings it will be necessary to quantify the magnitude of the modulator, which is notoriously difficult for "attention" as it is a highly diffuse theoretical concept. Moreover, even though it is clear that forms of divided attention have an impact on temporal performance, literature has not reached consensus on how attention actually interferes with the timing processes. I will therefore first focus on how the role of memory in interval timing can be utilized to provide an indirect measure of memory performance and decline, and second discuss how the arousal-driven modulations of time might be used as an index of other psychological phenomena.

In older age, memory starts to decline (e.g., Wang et al., 2011; Small 2001; Anderson et al., 2008, but also see Ramscar et al., 2014), a process which is frustrating at times, yet often benign. However, in about 16 % of the population (Petersen et al., 2018), this develops into Mild Cognitive Impairment (MCI), a diagnosis based on observed cognitive impairments that are more severe than what could be expected based on the interaction between age and education, yet that are not severe enough to affect normal daily activities. MCI is subdivided into nonamnestic MCI, if other faculties than memory are also affected, and amnestic MCI (aMCI), in which memory loss is the predominant symptom. About 50% of the patients initially diagnosed with aMCI are diagnosed with Alzheimer's disease in later years. Given this development, it is pertinent for aMCI patients to have their symptoms regularly re-evaluated, which is reflected in the Alzheimer's Association's guidelines that suggest a re-evaluation every 6 months (Alzheimer's Association, 2019). One of the assessments during these re-evaluation sessions are memory tests such as the ones included in the MoCA (Nasreddine et al., 2005) and the CERAD (Morris et al., 1989). In these assessments, patients are presented a number of words or images, and are asked - after a certain time that is typically filled with executing other psychological tests - to recall said items. Obviously, for many patients, this process is rather stressful as they perceive the memory test as one that they can either pass or fail, instead of a test that is just intended to provide an index of their functioning. Moreover, the setup of the test provides participants with direct insight in their functioning, as participants are well aware that they saw, say, 8 items but notice that they can only recall a few. This increases anxiousness and fear of failure, which negatively influences the accuracy of said tests. But there are also a number of methodological issues with memory tests as the MoCA and the CERAD. For example, the resolution of these tests is relatively limited as with a test of 8 items, participants typically either recall none of the items, or report between 5 or 8 items. Moreover, if participants are asked to take these tests once every 6 months, care should be taken that unique items of equal difficulty are presented at each test, requiring a large number of carefully constructed test batteries.

Virtually all memory tests that are used in clinical settings adhere to this template, yet the work in this thesis provides a foray into a new, more indirect type of memory measurement. In Chapter 4, I demonstrated that timing performance correlated with clinical MCI diagnosis. This is hardly surprising, as timing performance is well known to be affected in many clinical domains (for a review, see Paraskevoudi et al., 2018). Yet, in these earlier studies it has typically been argued that the "clock" component of the temporal system is affected, for example by arguing that in older age the clock "slows down" (e.g., Wearden et al., 1997; Gooch et al., 2009; Wild-Wall et al., 2009). Using the 1-second task presented in Chapter 3, however, we argue that the effects observed in Chapter 4 are the behavioral signatures of affected memory functioning. Additionally, by fitting Bayesian observer models (Chapter 6), I demonstrated that the observed behavioral patterns are best explained by assuming variability in how the memory system influences temporal performance. Interestingly, pilot data obtained in the context of a practicum of a Master course at the University of Groningen suggest that similar patterns can be observed in healthy young adults: their rate of forgetting as assessed with the earlier discussed adaptive learning system shows a similar correlation with temporal performance as observed in healthy aged controls and MCI patients. These results suggest that one could also use a timing task to index memory functioning, using prior reliance as indicator of a compensational process to counter more brittle memory skills.

Even though the argument in favor of using prior reliance in timing tasks as a measure of memory functioning is far removed from proper clinical validation, using timing tasks instead of traditional memory assessment methods have clear advantages. First and foremost, the purpose of the task is completely opaque from the perspective of the patient as the instruction just focuses on reproducing a presented duration as accurately as possible. Second, this task is relatively straightforward to administer. Even though older participants sometimes have to be instructed in more detail than the younger participant group, none of the aMCI patients tested in the scope of this thesis failed to perform the task adequately. Third, this task has shown only very limited training effects, evidenced by no or only very limited influence of sequential block order even when longer sessions are repeated on a single or subsequent days (as opposed to conventional tests for memory dysfunctions (e.g., learning and retrieval of word lists) that show clear effects of repeated assessments; see e.g. Dikmen et al., 1999). Thus, there is no evidence that a single version of this task could not be administered during each 6-month re-evaluation of clinical symptoms. Moreover, as a relatively small number of trials is sufficient to assess the influence of the context on temporal performance, this task does not need to take significantly longer than existing memory assessments. Apart from the application of this method to aMCI, Alzheimer's Disease, or other memory-affected patient groups, this method might also provide an index in other clinical populations. For example, it could be used as a measure of cognitive performance in kidney patients, a group that is characterized by a subtle but extended decrease of cognitive functioning while on dialysis (Elias et al., 2013). The relative immunity to training effects would allow for the use of timing tasks at regular and relatively short intervals (i.e., twice a month) to track cognitive decline at high precision. In sum, the combination of a timing task for clinical memory assessment and the assessment of a patient's prior reliance using Bayesian observer models might provide a useful addition to the toolkit of clinical practitioners.

Another potential field of application is associated with the arousal-based modulations of subjective time. In the literature, arousal is typically modulated by presenting participants with emotional stimuli such as pictures selected from the IAPS picture database (e.g., Angrilli et al., 1997; Droit-Volet et al., 2004; Effron et al., 2006; Lui et al., 2011) or frightening sound effects (e.g., Halbertsma & Van Rijn, 2016). The rationale of these studies is that the increased arousal associated with the presented stimuli are directly reflected in a speeding up of the clock, resulting in dilated perception of time. This link could prove to be fertile in a number of clinical application domains in which aspects of arousal or emotional processing are affected. An interesting application is in the study of sexual arousal. The measurement of sexual arousal either is based on answers on a response scale, or on relative invasive measurements, typically by measuring genital response (Althof et al., 2017). Each of these measures emphasizes the sexual context, something which is problematic in clinical settings aimed at treating patients with a dysfunctional relationship with sexuality. However, based on the well-established link between arousal and clock speed, timing tasks could provide an indirect measure of sexual arousal, allowing for the measuring of a sexual response without providing additional emphasis on its nature.

Following a similar rationale, timing tasks could also be used in the context of post-traumatic stress disorder, as it has been demonstrated that the internal perception of time is sped up during reactivation of earlier traumatic events (e.g., Vicario, & Felmingham, 2018; Schauer, & Elbert, 2015). By estimating the extent to which subjective time is affected during subsequent therapy sessions, therapists might be able to more accurately estimate therapy progress, allowing for more targeted intervention sessions. In addition, similar techniques might be used in other clinical settings, such as the treatment of fear (e.g., arachnophobia, see Waits and Sharrock, 1984).

Unlike the previous examples, where observed temporal modulations are utilized as an index of psychological functioning, modulations of time can also be used as an instrument to influence subjective experience. An elegant example in this domain is the study by Pomares et al. (2011) in which participants were subjected to painful stimuli while they were presented with an analogue clock indicating the passing of time using the second hand. As research has shown (for a recent study, see Rey et al., 2017), time dilates with pain. The mechanistic explanation of this effect is that the internal clock starts to run faster as a function of pain, which means that a fixed, objective duration feels as a subjectively longer duration in pain, then when not in pain. Pomares et al. suggested that there could be a mutual interaction, with the subjective intensity of pain also being determined by the perceived passing of time. To test this hypothesis, Pomares et al. (2011) presented participants with a fixed pain stimulus and either a normally running clock, or a slowed down clock. Although the intensity of the painful stimulus and the objective duration were kept identical, participants reported significantly reduced pain when the perception of time was shortened (as an objective 30 second interval would now have lasted on 20 "seconds" on the slowed clock). Obviously, these results also indicate that temporal distortions could be used as an index of pain, but even more interestingly, this also suggests that by using a similar paradigm, the induction of temporal distortions could also affect subjective arousal or emotional state. For example, in patients who report difficulties in becoming cognitively aroused during sexual stimulation, the presentation of a sped-up clock might yield a more intense perception of physical sexual arousal, resulting in increased cognitive arousal. Likewise, a slowed-down clock in PTSD patients during the reactivation of a stressful event might evoke a reduced intensity of stress-related feelings. This could provide an alternative explanation of the success of eye-movement desensitization techniques (e.g., Seidler & Wagner, 2006) currently used for PTSD patients as it has been shown that eye movements reduce the subjective accumulation of time (Morrone et al., 2005).

Concluding, even though interval timing tasks have been mostly used as a stand-alone tool for the study of the human sense of time, I have sketched a number of potential domains of application where time could provide a contribution in practical, real-life settings. By harnessing the synergy between pure research-focused and clinical applications, both fields would benefit as it would provide new tools for practitioners while at the same providing researchers with new data collected outside the confines of the lab cubicles that has driven, but also constrained the development of theories of how time is used in the real-world.

Knowing the importance and omnipresence of time, the links between timing and other psychological phenomena might not be surprising. Yet, most of the work on interval timing has focused on "basic research", and in this thesis I have made only a small step toward a further integration, as I demonstrate that in fact memories of temporal instances are not lost, even when our memory starts to fail. By continuing to exert their influence on the perception of time, temporal performance provides us with a potential litmus of affected cognitive functioning.