As time goes by: Studies on the subjective perception of the speed by which time passes

Naarmate de tijd verstrijkt: Studies over de persoonlijke beleving van de snelheid waarmee de tijd verstrijkt
(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor
aan de Universiteit Utrecht
op gezag van de rector magnificus,
prof. dr. G.J. van der Zwaan,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen op
vrijdag 27 maart 2015 des middags te 2.30 uur

door

Xiaoqian Li
geboren op 27 maart 1985
te Shanxi, China

Promotor: Prof. dr. G.R. Semin

Co-promotor: Prof. dr. M. Häfner

ISBN 978-94-6295-119-8
Printed by Uitgeverij BOXPress

This research was funded by the China Scholarship Council in 2010.

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Contents

Chapter 1

Introduction

1.1 Introduction

People constantly experience time passing despite the fact that they cannot really see it, hear it, smell it, taste it or touch it. Interestingly, even when they can read time through objective timekeepers like clocks and calendars, their experiences often diverge from these objective measurements. For example, people tend to subjectively represent more important future events (e.g., a big exam) closer to now than less important events (e.g., a regular class) even if the events are equally far away from them in time. Moreover, people also experience duration and the speed of time passage rather subjectively: There is almost never enough time on a busy day whereas time seems to stand still on one of these endless boring days. Or as beautifully put by the mastermind Einstein in relativity: "When you are courting a nice girl an hour seems like a second. When you sit on a red-hot cinder a second seems like an hour." Phenomena like these have intrigued many researchers to investigate the nature of the subjective experience of time (or *psychological time*) and also motivated this thesis, which is dedicated to study the subjective perception of the speed of time passage.

Before giving a detailed account of the content of the present investigation, I would like to start off with a more general definition of what exactly the subjective perception of time entails. According to Block (1990), psychological time consists of three major aspects: Succession, intervals, and temporal perspective. *Succession* refers to the sequential occurrence of events, from which people may perceive successiveness and temporal order, such as when they try to remember the chronological order of events during their last holidays. *Intervals* contain the continuous occurrence of events. Depending on how many chronological events are included into a sequence, the length of intervals (i.e., duration) increases. Lastly, the *temporal perspective* refers to the perception and distinction between past, present and future. In what follows, I shall briefly summarize the most important investigations into each of the three domains and their main findings.

Research on psychological time as succession. In the literature on psychological time, researchers have been somewhat less concerned with time as succession than with time as intervals, which is the reason that I will describe the research on intervals at some greater detail at the end of this section. Research on the succession aspect of psychological time has been grounded primarily in models of biopsychological and sensory-perceptual processes. For instance, the experience of successiveness has been investigated by classic studies that examined the temporal resolution of perception systems. Hirsh and Sherrick (1961) found that the presentation of two brief auditory stimuli separated by less than 2 ms produced the experience of successiveness. Moreover, the experience of temporal order has been investigated by the same authors. It was found that trained observers can reliably discriminate the temporal order of two events if the interval separating the events is about 20 ms for auditory, visual, and tactile stimuli (Hirsh & Sherrick, 1961).

Research on psychological time as temporal perspective. Although our immediate experience of time is limited to now, our perception of time is populated by the experience of the past and the future as well. So far, the most influential work on the temporal perspective aspect of psychological time comes from Construal Level Theory of psychological distance (Liberman, Trope, & Stephan, 2007). It examines people's temporal perspective in terms of temporal distance, which refers to the psychological distance from the present to the past or the future. It was found that construing events in high-level terms (e.g., describing *why* a person would perform an activity) fosters a perception of the more distant future than construing events in low-level terms (e.g., describing *how* a person would perform an activity; Liberman, Trope, McCrae, Sherman, 2007). It was also found that the perception of temporal distance to a future event is shaped by the effort that one has to invest to realize the event (Jiga-Boy, Clark, & Semin, 2010): More effortful future events (e.g., organizing a wedding) were perceived as temporally closer than less effortful events (e.g., buying concert tickets) when there was a fixed deadline. Causality is another factor that can influence people's perception of temporal distance. People judge pairs of causally related events to occur closer together in time than pairs of causally unrelated events that were, however, separated by the exact same time interval (Faro, McGill, Hastie, 2005).

Compared to succession and temporal perspective, intervals have been studied much more intensely. This might be the case because the length of intervals is measurable due to their physical references (i.e., seconds, minutes, etc.). Be that as it may, because of this focus and because the present thesis is also mainly studying the intervals component of time experiences, I shall now turn to a detailed discussion of how intervals have been studied. Research on intervals has so far mainly focused on how people make judgments about the length of intervals (referred as *duration judgments* below). In the following, I shall first briefly summarize the research on duration judgments, and then propose a new approach to studying time judgments of intervals, namely *judgments of the speed of time passage*, which are about how fast time is passing in the intervals rather than how long the intervals last.

1.2 The traditional approach to studying time judgments of intervals: duration judgments

Early research on duration judgments focused on how *accurately* people can make judgments about the length of intervals. This research was trying to identify the "basic unit" of duration that people can accurately judge. This basic unit is called "indifference interval" in Vierordt's Law (1868). According to

Vierordt's Law, intervals that are shorter than the indifference interval tend to be overestimated, and intervals that are longer than the indifference interval tend to be underestimated (Fraisse, 1963; Woodrow, 1934; 1951). However, no congruent indifference interval was found by this research; estimations varied considerably across different investigations: From 0.7 s (Fraisse, 1963) to 3.25 s many different indifference intervals were found empirically (Treisman, 1963; Woodrow, 1934, 1951).

Soon afterwards, researchers brought attention to various factors that bias people's duration judgments. For example, it was found that the number of stimuli presented in a given time interval can influence people's duration judgments. People judge the duration of a filled interval (i.e., a time interval where stimuli are presented) as longer than an empty interval (i.e., a time interval where no stimuli is presented) of the same duration (*filled duration illusion*; Buffardi, 1971; Goldfarb & Goldstone, 1963; Thomas & Brown, 1974; see for a review of the major studies in Ihle & Wilsoncroft, 1983). Other features of stimuli such as modality and complexity were also found to influence people's duration judgments (see a review by Allan, 1979). Later research started looking into how affective factors influence duration judgments. For example, it was found that people judge the duration of emotional sounds as longer than neutral sounds of the same duration (Noulhiane, Mella, Samson, & Pouthas, 2007); presentations of positive pictures were judged as lasting longer than presentations of negative pictures if they were highly arousing, whereas presentations of negative pictures were judged as lasting longer than presentations of positive pictures if they caused low arousal (Angrilli, Cherubini, Pavese, & Manfredini, 1997).

Other research has looked into the influence of spatial information on duration judgments. This research is derived from linguistic metaphors that integrate spatial information while referring to temporal information, for instance when people say a *long* day or a *short* vacation. Research has found that spatial information about distance can influence people's duration judgments. As such, longer spatial distances were judged as lasting longer than shorter spatial distances even if their real duration was equal (Casasanto & Boroditsky, 2008). Interestingly, it was also found that duration information does not influence spatial judgments. People's judgments about the length of the lines were made regardless of their presented duration (Casasanto & Boroditsky, 2008). This suggested that the influence of spatial information to duration judgments is not bidirectional.

Many cognitive models have been proposed to explain these observed biases on duration judgments. Typically, two types of models, *attentinon-based models* and *memory-based models*, are distinguished by the experimental paradigms used in the research (Zakay & Block, 2004). On the one hand, attention-based models are applied in the prospective paradigm where participants know in advance they need to judge the duration of a time period. On the other hand, memory-based models are applied in the retrospective paradigm where participants do not know they need to judge the duration of a time period until the time period has elapsed. In the prospective paradigm, as participants know in advance that they need to judge duration of intervals after the task, they could divide their attention between non-temporal information (time-unrelated task) and temporal information during the task. According to attention-based models, duration judgments are a function of the amount of attention on temporal information. The more attention is paid to temporal information, the longer lasting the interval is judged. Such attention-based models have been supported considerably by research that manipulated the allocation of attention between non-temporal and temporal information (Block & Zakay, 1996; Brown, 1997; Frankenhauser, 1959).

In the retrospective paradigm, duration judgments rely on the information retrieved from memory. According to memory-based models, duration judgments are therefore best characterized as a function of the amount of stored information (Ornstein, 1969; Block, 1974; 1986; Fraisse, 1963; Poynter, 1983). For example, the storage size model argues that duration judgments are a function of the amount of the memory storage space generated for processed information in an interval (Ornstein, 1969). The contextual-change model, another memory-based model, argues that duration judgments are a function of the amount of contextual changes that are encoded and stored in memory (Block & Reed, 1978; Block, 1989, 1990).

1.3 Do duration judgments tell us all about time judgments of intervals?

Duration judgments are essential time judgments of intervals; however, they are not the only time judgments that people can form about intervals. People do not only have a sense of how long time lasted (i.e., 5 minutes, 10 seconds), but also of how fast time passed by (i.e.,very slow, very fast). These latter judgments about how fast time passes are referred to as judgments of the speed of time passage in this thesis. Compared to the extensive research on duration judgments, far less research has directly looked into these judgments. First, this might be the case because, unlike duration judgments that have objective references (i.e., seconds, minutes, etc.), judgments of the speed of time passage are rather subjective and cannot be measured objectively. Secondly, judgments of the speed of time passage are typically correlated with duration judgments: A shorter duration is usually perceived as passing faster than a longer duration. Some research has used this association between duration judgments and judgments of the speed of time passage to infer people's judgments of the speed of time passage from duration judgments (Dancert & Allman, 2005, Campbell & Bryant, 2007, Tipples, 2010, Droit-Volet et al., 2010).

For instance, Campbell and Bryant (2007) investigated how affect influences time perception in the stressful experience of skydiving. Novice skydivers were asked to report their levels of fear and excitement (on scales from

0 to 100, *0 = "not at all frightened" or "not at all excited", 100 = "very frightened" or "very excited"*) both before the jump and after landing. They were also asked to estimate how long they thought the entire experience had lasted. The researchers found that duration judgments of the event positively correlated with levels of fear before and during the jump, and negatively correlated with levels of excitement before and during the jump. Consequently, they argued that increased fear was associated with the perception of time passing by slowly whereas increased excitement was associated with the perception of time passing by quickly.

However, there is reason to believe that speed of time passage is not solely depended on duration judgments. For example, a 60-minute lecture should be perceived as passing by more slowly than a 30-minute lecture, but a very interesting 60-minute lecture might be perceived as passing by even faster than a very boring 30-minute one. This suggests that judgments of the speed of time passage do not only depend on duration judgments, but also depend on other factors, which could interfere with the otherwise strong association between judgments of the speed of time passage and duration. Therefore, it is worthwhile to investigate the speed of time passage independently from duration judgments, which is what we did in the present thesis.

1.4 The current approach to studying time judgments of intervals: Judgments of the speed of time passage

All experiments in the present thesis were designed to investigate the processes underlying judgments of the speed of time passage. The guiding idea in the design of the studies was to find out how people make judgments of the speed of time passage and if these judgments can be systematically influenced by other factors. In order to achieve this goal, we used the same paradigm across all four empirical chapters. Specifically, participants in all experiments were presented with a number of short time intervals (ranging from 18 s to 84 s) in which different stimuli were presented. After each interval, they were asked to provide their judgments about how fast time was passing during this trial on a 9-point scale where 1 indicates time passing by very slowly and 9 indicates time passing by very fast. From Chapter 2 to Chapter 5, we first investigated the underlying mechanism of how people make judgments of the speed of time passage, and then investigated how peoples' judgments of the speed of time passage can be influenced by various factors. In what follows, I shall provide brief overviews over the empirical chapters and the main findings.

Overview of the chapters

Chapter 2: Judging the speed of time passage: Attention and engagement. In this chapter, we investigated the underlying mechanism of judging the speed of time passage. We propose an attentional model on judgments of the speed of time passage: Judgments of the speed of time passage are a reversed function of attention on temporal information. The more attention is paid to temporal information, the more slowly time should be perceived as passing. When there is more concurrent non-temporal information going on, less attention is allocated to temporal information, thus time is perceived as passing by faster. I will present data from five experiments that are largely in line with such a model. Specifically, across the five experiments, participants were presented with different numbers of stimuli in fixed intervals, and they judged time as passing faster when there were more stimuli in the intervals. Moreover, we found that this effect was mediated by how engaged participants were in the presented trials. When more stimuli were presented, participants got more engaged in the trials, which led them to judge time as passing by faster. In addition, this chapter contains the first empirical evidence that the association between judgments of the speed of time passage and duration judgments is not very reliable: in some conditions the correlations between them were very weak, and in some conditions the correlations even disappeared.

Chapter 3: Beyond attention?! The roles of presentation frequency and comparison frame in judging the speed of time passage. This chapter builds on Chapter 2 and addresses two alternative explanations to the results of our first line of research. Specifically, as we presented our stimuli at regular intervals in Chapter 2, presenting more stimuli also resulted in faster presentations (i.e., at a higher frequency). Hence, our participants might have used this speed cue as a basis of their judgments. When stimuli were presented faster, they judged time as passing faster. We therefore explicitly investigated the role of presentation frequency on judgments of the speed of time passage in Chapter 3. In Experiment 1, we presented different numbers of stimuli (few vs. many) either at different frequencies or at the same frequency (i.e., frequency). We found that when stimuli were presented at the same frequency, time was still judged as passing faster when more stimuli were presented, but the effect was smaller compared to when stimuli were presented at different frequencies. This result indicates that it was attentional processes that people relied on to make judgments of the speed of time passage, but meanwhile presentation frequency of stimuli also played a role in the judgments. In Experiment 2, we manipulated the presentation frequency of stimuli fully independently of the number of stimuli, and again found that time was judged as passing faster when stimuli were presented at higher frequencies and in a greater number.

The second alternative explanation we addressed in this line of research has to do with the research paradigm that we implemented. Specifically, we varied our independent variables (e.g., number of stimuli) exclusively in within-subject designs in all previous experiments. Stated differently, we always provided our participants with a reference frame that they could relate their speed judgments to. In order to test how crucial the role of such a reference frame is for our findings, we used a between-subject design in Experiment 3.

Over and above this methodological change, we manipulated the number of stimuli (fewer vs. more) and the regularity at which the stimuli were presented (regular vs. irregular). According to the attentional model, as more attention would be attracted to more stimuli (than fewer stimuli) and irregularly presented stimuli (than regularly presented stimuli), time should be judged as passing faster when more stimuli are presented and when stimuli are presented irregularly. Results of the experiment showed, however, that the subjective speed of time passage was this time unaffected by the amount of information presented (i.e., the number of stimuli). Presentation regularity, on the other side, did have a significant impact on the subjective experience of time passage: Time was judged as passing faster when stimuli were presented irregularly as compared to when they were presented regularly. These interesting findings will be discussed with respect to how well they fit the attentional model of time experience we favor.

Chapter 4: *Unpredictability gives time wings*. In Chapter 4, we were interested in the influence of the (un-) predictability of events taking place in intervals on judgments of the speed of time passage. Specifically, we differentiated two types of unpredictability: temporal unpredictability and content unpredictability. Temporal unpredictability pertains to when people do not know *when* a specific event is to happen, whereas content unpredictability pertains to when people do not know *what* will happen next. In Experiment 1 and 2, we manipulated temporal unpredictability and content unpredictability, respectively. To manipulate temporal unpredictability, we presented stimuli regularly or irregularly. When stimuli were presented regularly, participants could easily learn the pattern of the presentation and predict the timing of the upcoming stimuli, whereas when stimuli were presented irregularly, it was less plausible for participants to predict the timing of the upcoming stimuli. To manipulate content unpredictability, we presented the same stimuli or different stimuli sequentially in each trial; when the presented stimuli were the same, the upcoming stimuli were predictable to participants, whereas when the stimuli were different, the upcoming stimuli were unpredictable to participants. Congruent results were found in the two experiments. Time was judged as passing faster for both temporally unpredictable stimuli and content wise unpredictable information. These results are in line with our attentional take on the experience of time passage: Unpredictable stimuli attract attention. In turn, less attention is being paid to temporal information. Consequently, when participants were presented with unpredictable stimuli, time seems to pass by faster than when participants were presented with predictable information.

Chapter 5: Left-to-right movements accelerate speed of time passage. In Chapter 5, we investigated the relationship between spatial information and judgments of the speed of time passage. Specifically, we investigated how the spatial direction of movements influences judgments of the speed of time passage. We manipulated the spatial direction of moving stimuli (left-to-right vs. right-to-left), and found that time was judged as passing by faster when participants saw the left-to-right movements as compared to when they were presented with right-to-left movements. Though this effect was weak and sometimes even disappeared, it can be considered a reliable weak effect according to the meta-analysis we ran on the basis of our five experiments. This pattern seems consistent with previous findings of “left-to-right biases”. For example, it was found that people judged left-to-right movements as faster, more powerful and more beautiful (Maass, Pagani, & Berta, 2007).

The typical explanation for such left-to-right biases is the left-to-right reading and writing direction in the Western world. This explanation is supported by findings indicating that the left-to-right bias can be reversed into a “right-to-left bias” if the experiments are conducted in cultures where people read and write from right to left. Interestingly, we were unable to reverse our left-to-right bias, even when we ran the study with Farsi readers and writers or under a mirror-writing manipulation. The effect was also not reversed in another study in which we remapped the past and the future (i.e., past on the right and future on the left) in a learning procedure in Experiment 3. We therefore end this last empirical chapter by speculating about potential sources of this robust left-to-right bias in the perception of (the speed of) time passage.

1.5 Conclusions and implications

Across the four empirical chapters of this thesis, we focused on a previously neglected type of time judgments about intervals, namely judgments of the speed of time passage. In particular, we set out the research in this thesis to investigate the underlying mechanisms of judgments of the speed of time passage and a number of factors that potentially influence these judgments. Taken together, our results clearly speak to the notion that attentional processes play a crucial role in the experience of how fast time subjectively passes by. The more attention is being allocated to non-temporal information, the faster time seems to pass by. We thereby extend the role of attention shown previously in models on duration judgments to judgments of the speed of time passage. Moreover, we found that judgments of the speed of time passage can be influenced by various factors such as the presentation frequency of stimuli, whether they are presented in a comparison frame or not and whether or not the presented stimuli were predictable.

Most importantly, the present research thereby underlines the necessity to study psychological time more broadly than before. Research should not only focus on duration judgments but also and independently on judgments of the speed of time passage. Such an extension is not only necessary because we showed that both judgments are, at least under certain circumstances, independent, but also because this knowledge might be applicable to various domains.

First, there might be an interesting link of our research to research on so called flow experiences: It is often described people losing track of time accompany flow experiences. Drawing on the general attentional model and our findings, this anecdotal evidence could be interpreted as bundled attention on what people are busy with. This speculation is further supported by the revealed mediation effect in Chapter 2, which showed that when people paid more attention on the time-unrelated task, they got more engaged in the task, and *therefore* felt time passing faster.

Second, besides understanding phenomena such as flow experience, knowledge about the processes driving the subjective experience of time passage also be applied to situations in which people want to modify the perception of the speed of time passage. For instance, people usually want to experience time passing faster when they are waiting. Whereas people seem to do intuitively the right thing by devoting their attention to “time killers” (e.g., their phones) when they are waiting for the bus, this is certainly less the case in other, more important situations. People quickly lose their patience when they are waiting for emergency help. Potentially, this is the case because time seems to be the only thing that matters. Therefore, general information provided while waiting, or even filling in forms might help people to keep their patience. Similar techniques could also be used in less emergent situations in which our patience is often tested : In order to have people feel the waiting time for a traffic light to turn green faster, instead of displaying boring static red lights, some more information could be included in the traffic lights so that people’s attention can be distracted from the waiting. For example, recently a dancing traffic light has been introduced in Lisbon, Portugal. It allows random pedestrians to enter an oversized traffic light studio, dance, and their moves were displayed in real time on the traffic lights outside.

In other situations, people want the opposite, namely sometimes they want to experience time as passing more slowly. A typical example of such a situation is when people are under time pressure. This often happens in a working environment when people have to meet a deadline. If managers want to take some pressure off their employees, they could use some techniques suggested by the present thesis. For instance, managers could arrange tasks in a more regular pace so that tasks appear more predictable to employees, resulting in a perception of slower time passage.

Chapter 2

Judging the speed of time passage: Attention and engagement

Abstract

Past research on subjective time judgments mainly focused on duration judgments (i.e., how long time lasted), and overlooked judgments of the speed of time passage (i.e., how fast time passed). The present research was designed to systematically investigate the subjective judgments of both the speed of time passage and duration, their potential relation and the cognitive processes underlying the judgments of speed of time passage. Specifically, we investigated the roles of attention and engagement levels in making judgments of the speed of time passage. Across five experiments, we found that when more attention was paid to the non-temporal information (i.e., presented stimuli), time was judged as passing faster. This finding was confirmed by a meta-analysis of the five experiments. Furthermore, this effect was found to be mediated by the degree to which participants were engaged in the task. In addition, we found no reliable correlation between judgments of the speed of time passage and duration judgments. Overall, the current research suggests that both attention and engagement play important roles in judging the speed of time passage; when people pay more attention to non-temporal information, they get more engaged, and judge time as passing faster.

2.1 Introduction

All our perceptual, intellectual and emotional experiences are intertwined with time. Not surprisingly, hundreds of timekeepers have been created, ranging from the burning of a candle to our common modern electric clocks, for people to mark time. Besides the objective measurement of time by these devices, people also have the intuitive awareness of time — the subjective perception of time. For instance, we can judge how long a past event lasted without knowing its true duration; we can also feel that one event passed fast but the other one passed slowly even if they had the same objective duration.

The subjective perception of time has intrigued psychologists for decades, predominantly leading to investigations of subjective duration judgments of certain time intervals. Despite the fact that this research put forth interesting findings and models, its focus on duration judgments may have eclipsed research on another interesting subjective representation of time, namely the experienced speed of time passage. It is therefore still unclear if time can only be judged in terms of how long it lasted or if it can independently of the latter judgment also be judged in terms of how fast it passed. The present research was designed to systematically investigate the subjective judgments of both the speed of time passage and duration, their potential relation and the cognitive processes underlying the subjective judgments of speed of time passage. We will start out with a brief review of research on subjective duration judgments. Then, we will try to build an argument for why it is necessary to investigate the judgment of speed of time passage independently of duration judgments, and, lastly, come up with a hypothesis about how judgments of the speed of time passage can be determined.

Early research on the subjective perception of time focused on how accurate *duration judgments* can be. It has been well documented that people cannot always give accurate judgments of duration (Fraisse, 1963; Woodrow, 1934, 1951). For example, according to Vierordt's Law (1868), only the duration of certain intervals —"indifference intervals" — can be accurately judged. Intervals shorter than indifference intervals tend to be overestimated, whereas intervals longer than indifference intervals tend to be underestimated (Fraisse, 1963). Soon afterwards, researchers brought attention to the fact that people's duration judgments can be distorted easily. Various kinds of distortion have been observed under different conditions. For example, it has been found that the number of stimuli that fill in a given interval could influence the duration judgments of the interval: A classic finding is that a *filled interval* is perceived as longer than an *empty interval* of the same true duration (*filled duration illusion*; Buffardi, 1971; Goldfarb & Goldstone, 1963; Thomas & Brown, 1974; see for a review of the major studies, Ihle & Wilsoncroft, 1983). To account for these effects on duration judgments, researchers have developed different cognitive models.

Two types of cognitive models on duration judgments have been distinguished by the experimental paradigms used in the respective research (Zakay & Block, 2004). *Attention-based models* are applied in *the prospective paradigm* where participants know in advance they need to judge the duration of a time period, whereas *memory-based models* are applied in *the retrospective paradigm* where participants do not know they need to judge the duration of a time period until the time period has elapsed. In the prospective paradigm, as participants know in advance that they need to judge duration of intervals after the task, they could divide their attention between *non-temporal information* (i.e., a time-unrelated task) and *temporal information* during the task. According to attention-based models, duration judgments are a function of the amount of attention on temporal information. The more attention is paid to temporal information, the longer the duration is judged. The allocation of attention to temporal information varies according to the allocation of attention to non-temporal information. The more attention is given to non-temporal information, the less attention is allocated to temporal information. Such attention-based models have been supported considerably by research that manipulated the allocation of attention between non-temporal information and temporal information (Block & Zakay, 1996; Brown, 1997; Frankenhauser, 1959; Macar, 1994; Priestly, 1968; Zakay, Nitzan, & Glicksohn, 1983).

The attention allocation between temporal information and non-temporal information can be manipulated in different ways. One of them is to manipulate the amount of non-temporal information — more non-temporal information could attract more attention to it. For instance, Hicks and colleges (1976) manipulated attention to different amounts of non-temporal information processing by asking their participants to either sort cards into a single stack, into two stacks by color (i.e., one for red and one for black), or into four stacks by suit. Asking participants afterwards to judge how long they had spent on dealing the cards (with them knowing that they would be asked this question) revealed that the duration judgments decreased monotonically with the amount of non-temporal information increasing during a 42-second interval.

Unlike the prospective paradigm, in the retrospective paradigm, the duration judgments must mainly rely on the information retrieved from memory. According to memory-based models, duration judgments are therefore characterized as function of the amount of stored information (Block, 1974, 1986; Fraisse, 1963; Ornstein, 1969; Poynter, 1983). The storage size model (Ornstein, 1969) is representative of the memory-based models. It proposes that duration judgments are function of the amount of the memory storage space generated for processed information in an interval. Direct support for this model can be found in the so called filled duration illusion: Compared to empty intervals, a larger memory storage space is generated for filled intervals because more information (i.e., stimuli) is processed, so the duration judgments of filled intervals are longer than that of empty intervals.

These two cognitive models, attention-based models and memory-based models, have been able to explain a variety of results obtained in the research on duration judgments. However, in comparison to the extensive research on duration judgments, notably little effort has been made to directly look into the subjective *judgments of the speed of time passage* thus far. Some research has tried to draw conclusions on the perception of the speed of time passage from the duration judgments with the assumption that longer duration is associated with the perception of slower time passage, and shorter duration judgments are associated with the perception of faster time passage (Campbell & Bryant, 2007, Dancert & Allman, 2005; Droit-Volet, Bigand, Ramos, & Bueno, 2010; Tipples, 2010).

Although duration and the speed of time passage are closely linked concepts, we argue that it is not a reliable way to understand the speed of time passage from the duration judgments, as the following example may illustrate: a 60-minute lecture is usually perceived as passing more slowly than a 30-minute lecture, but a very interesting 60-minute lecture might be perceived as passing even faster than a very boring 30-minute one. This suggests that judgments of the speed of time passage not only depend on duration judgments, but also depend on other factors, which could break the association between the judgments of speed of time passage and the duration judgments. Therefore, it is worthwhile to investigate the speed of time passage independently rather than inferring it from duration judgments. Accordingly, the interesting question is, what is driving the perception of the speed of time passage. Does this subjective representation of time also depend upon attentional processes?

The present line of research focuses on subjective judgments of the speed of time passage. In particular, we aimed to extend the role of attention shown for duration judgments to judgments of the speed of time passage, and examine how the amount of non-temporal information influences the judgments of the speed of time passage. We postulated that judgments of the speed of time passage are a reversed function of the amount of attention on temporal information: the more attention is paid to temporal information, the more slowly time should be perceived as passing. When there is more concurrent non-temporal information going on, less attention is allocated to temporal information, thus time is perceived as passing faster. Moreover, we hypothesized that this effect is mediated by how engaged people are by the non-temporal information: The more non-temporal information people process, the more engaged they get in the task they are working on, ultimately leading them to experience time as passing by faster.

In the following studies, we manipulated the amount of non-temporal information for fixed temporal intervals by presenting different numbers of stimuli, and assessed judgments of the speed of time passage as the main dependent variable. We expected that when more stimuli were presented, then time would be judged as passing by faster, and when fewer stimuli were presented, then time would be judged as passing by more slowly. Furthermore, we had participants' engagement levels assessed in order to test our mediation hypothesis; it was expected that the presentation of more stimuli would engage participants more and the presentation of fewer stimuli would engage participants less. In addition, to test the reliability of inferring the judgments of speed of time passage from the duration judgments, we also assessed participants' duration judgments; correlation analysis was conducted between the judgments of speed of time passage and the duration judgments to reveal their possible relation.

2.2 Method

Overview. Five experiments were conducted to explore the influence of different numbers of stimuli presented in temporal intervals of fixed duration upon judgments of the speed of time passage. In addition to judgments of the speed of time passage, the conventional dependent variable duration judgment was also included. Two factors *interval duration* and *number of stimuli* were manipulated in within-subject designs. Different interval duration was used in order to generalize the possible effects of the number of stimuli on the judgments of the speed of time passage. Moreover, the effect of interval duration was also expected to constitute a manipulation check: in the current neutral experimental setting, when the duration of an interval was longer, it was expected to be judged as passing more slowly (i.e., the speed of time passage) and lasting longer (i.e., duration). Different numbers of stimuli were manipulated in a linear pattern. The five experiments varied in conditions and types of stimuli in order to obtain a comprehensive observation of the possible effects of the number of stimuli on the judgments of the speed of time passage (see Table 1 for the overview of the designs). Besides, participants' engagement levels were also measured as a potential mediator, through which presentation of different numbers of stimuli brings about different perception of the speed of time passage.

Table 1 *Overview of the designs of Experiment 1-5*

Experiment	Type of stimuli	Interval duration (s)	Number of stimuli
1	Beeps	18, 51, 84	0, 30, 60
2	Circles	18, 51, 84	0, 30, 60
3	Beeps and circles	18, 51, 84	0, 30, 60
4	Beeps and circles	18, 51, 84	0, 10, 20, 30, 40, 50, 60
5	Beeps and circles	18, 51, 84, 117	0, 20, 40, 60, 80, 100

Participants. Students from Utrecht University participated in the studies in exchange for course credit or monetary reward. Participants were considered not taking experiments seriously if they had any missing or extreme judgments on duration (e.g., 0 or 518833s in Experiment 1) and were eliminated from data analyses. With this restriction, 4 participants were dropped from Experiment 1; 1 participant was dropped from Experiment 2; 5 participants were dropped from Experiment 3; and 1 participant was dropped from Experiment 5. As a result, the data analyses were based on the remaining 56 participants in Experiment 1 (age *M* = 20.9, *SD* = 4.4; 20 males), 59 participants in Experiment 2 (age *M* = 20.5, *SD* = 2.9; 20 males), 58 participants in Experiment 3 (age *M* = 21.8, *SD* = 4.4; 18males), 71 participants in Experiment 4 (age *M*= 20.9, *SD* = 3.7; 31 males) and 64 participants in Experiment 5 (age *M* = 21.3, *SD* = 3.4; 21 males).

Procedure. Participants were told the goal of the studies was to investigate attentional processes. They were informed that they would hear beeps from headphone (in Experiment 1), or see circles in the center of computer screen (in Experiment 2), or hear beeps from headphones and see circles in the center of computer screen at the same time (in Experiment 3 to 5). Each trial was initiated by pressing the SPACE bar. Stimuli (beeps, circles or both) were presented regularly in each interval. The duration of each stimulus was 100 ms. A practice trial of 30 s with 30 stimuli was always introduced before the experimental trials in each experiment. The type of stimuli in the practice trial accorded with that in the following experimental trials. To prevent participants from simply using a counting strategy to judge a trial's duration, two three-digit numerals at random temporal intervals were also presented in the center of the screen (in Experiment 1), or via headphone (in Experiment 2), or at the bottom of the screen and via headphone at the same time (Experiment 3 to 5). Participants were asked to read these numerals out loud immediately after they saw or hear them.

After each trial, participants were asked to answer the questions on the speed of time passage (*How fast did time pass while you were doing this trial?*), duration (*How long do you think this trial lasted?*) and engagement levels (*How engaged were you in this trail?*). Participants gave their judgments of speed of time passage and engagement levels on 9-point scales (from 1 = *"very slow"* or *"not engaged at all"* to 9 = *"very fast"* or "*very engaged"*) and gave their duration judgments by writing down the number of seconds.

2.3 Results

Considering the general variance of participants' subjective perception of time, the data analyses of the five experiments were conducted with linear mixed models, comprising of fixed effects and random effects (McCulloch & Searle, 2001). The fixed effects were composed of the fixed intercepts, the effects of interval duration, the effects of number of stimuli, and the interaction effects between interval duration and number of stimuli; the random effects were the random intercept, which was the most consistent structure across the experiments. All models were estimated using restricted maximum likelihood, with Satterthwaite approximation for the degrees of freedom. The *F*-test was evaluated for obtaining statistical significance (West, Welch, & Galecki, 2006). The independent variables interval duration and number of stimuli were analyzed as categorical variable and continuous variable, respectively. The models were applied to the three dependent variables: judgments of speed of time passage, duration judgments and engagement levels. The Table 2, 4 and 6 summarize the descriptive statistics, including means and standard deviations across five studies, for judgments of speed of time passage, duration judgments and engagement levels, respectively. The following section of results first presents the findings on each dependent variable of all the single studies, and then is followed by the results of the meta-analyses of the five experiments on judgments of speed of time passage and duration judgments; subsequently the results of mediation analysis with engagement levels as the mediator are presented, and we conclude with the results of correlation analysis between judgments of the speed of time passage and duration judgments.

2.3.1 Judgments of the speed of time passage

By inspecting the means of judgments of the speed of time passage across five experiments, we found that the judgments of the speed of time passage decreased with the increasing interval duration (see the upper panel in Table 2). This observation was confirmed by the significant fixed effects of the interval duration on the judgments of the speed of time passage (see the column “Duration” of Table 3). It was consistent with our expectation that when intervals were longer, they should be judged as passing by more slowly. These results can be taken as a manipulation check.

Table 2 *Means (M) and standard deviations (SD) of the judgments of the speed of time passage in Experiment 1-5.*

		Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Factor	Condition	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Duration (s)	18	6,76 (.17)	6.22 (.23)	6.71 (.15)	6.16 (.17)	6.40 (.20)
	51	4,24 (.15)	4.16 (.18)	4.46 (.18)	3.97 (.15)	4.47 (.17)
	84	3,17 (.19)	3.30 (.17)	3.19 (.16)	2.94 (.13)	3.50 (.15)
	117	-	-	-	-	2.73 (.16)
Number	0	4.35 (.13)	4.17 (.16)	4.49 (.17)	4.06 (.15)	3.78 (.13)
	10	-	-	-	4.07 (.18)	-
	20	-	-	-	4.09 (.15)	4.03 (.15)
	30	4.76 (.15)	4.68 (.17)	4.57 (.15)	4.43 (.14)	-
	40	-	-	-	4.46 (.16)	4.20 (.16)
	50	-	-	-	4.68 (.17)	-
	60	5.06 (.15)	5.74 (.20)	5.31 (.19)	4.71 (.17)	4.43 (.17)
	80	-	-	-	-	4.53 (.18)
	100	-	-	-	-	4.70 (.18)

Note. Cells are filled with “-” if conditions are not included in the respective designs. Higher numbers of means indicate faster speed of time passage. Duration = Interval duration; Number = Number of stimuli.

Table 3 *Fixed and random effects of judgments of the speed of time passage in Experiment 1-5.*

	Fixed effects								**Random effects**	
	Intercept		Duration		Number		Interaction		Intercept	
Experiment	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	Ward *Z*	*p*
1	348.99	<.001	33.46	<.001	13.93	<.001	.60	.55	2.09	.036
2	320.57	<.001	33.28	<.001	10.32	.001	.90	.41	4.47	<.001
3	328.82	<.001	31.09	<.001	23.03	<.001	.44	.64	3.97	<.001
4	652.08	<.001	80.32	<.001	35.70	<.001	1.41	.24	5.23	<.001
5	530.04	<.001	77.66	<.001	54.62	<.001	3.87	.009	5.06	<.001

Note. Duration = Interval duration; Number = Number of stimuli.

More importantly, we found that the judgments of the speed of time passage increased with the increasing number of stimuli (see the lower panel in Table 2). This observation was confirmed by the significant fixed effects of the number of stimuli on the judgments of speed of time passage (see the column "Number" of Table 3). These results supported our hypothesis that time is judged as passing faster when more stimuli are presented.

The interaction effect between interval duration and number of stimuli was only found significant in Experiment 5 (see the column "Interaction" of Table 3), suggesting that the effects of the number of stimuli on the judgments of the speed of time passage were different in different interval duration. Separate analyses with linear mixed models for each duration found the fixed effects of the number of stimuli significant on the judgments of the speed of time passage in duration of 51 s, 84 s and 117 s (ps < .01), revealing that the judgments of the speed of time passage increased with increasing number of stimuli; the fixed effect of the number of stimuli was not significant on the judgments of the speed of time passage in duration of 18 s ($F < 1$).

2.3.2 Duration Judgments

Similar to judgments of the speed of time passage, a clear pattern of duration judgments was observed from the manipulation of interval duration. Duration judgments were found to increase with the increasing interval duration (see the upper panel in Table 4), confirming by the significant fixed effects of the interval duration on duration judgment (see the column "Duration" of Table 5). This again confirmed that participants had a clear perception of time with the current manipulation.

Table 4 *Means (M) and standard deviations (SD) of the duration judgments (s) in Experiment 1-5.*

		Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Factor	Condition	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Duration (s)	18	22.21 (2.23)	19.10 (.97)	21.25 (1.15)	22.80 (.53)	23.88 (1.67)
	51	44.13 (3.51)	44.83 (2.25)	41.13 (2.30)	49.55 (1.09)	57.83 (4.25)
	84	65.67 (4.94)	67.97 (3.48)	64.45 (4.04)	74.86 (2.28)	86.82 (5.60)
	117	-	-	-	-	121.65 (7.62)
Number	0	42.38 (3.39)	44.90 (2.53)	36.79 (2.50)	41.78 (2.65)	65.55 (5.53)
	10	-	-	-	48.60 (3.98)	-
	20	-	-	-	53.75 (5.29)	74.17 (4.96)
	30	45.89 (3.69)	44.42 (2.36)	46.59 (2.41)	51.90 (5.37)	-
	40	-	-	-	47.94 (4.07)	72.92 (5.05)
	50	-	-	-	45.91 (3.68)	-
	60	43.75 (3.37)	42.58 (1.73)	43.45 (2.70)	53.59 (5.73)	76.24 (5.12)
	80	-	-	-	-	75.31 (4.54)
	100	-	-	-	-	71.08 (.4.61)

Note. Cells are filled with "-" if conditions are not included in the respective designs. Higher numbers of means indicate longer duration. Duration = Interval duration; Number = Number of stimuli.

Table 5 *Fixed and random effects of duration judgments in Experiment 1-5.*

	Fixed effects								**Random effects**	
	Intercept		Duration		Number		Interaction		Intercept	
Experiment	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	Ward *Z*	*p*
1	102.26	<.001	20.72	<.001	.25	.62	.27	.77	4.61	<.001
2	243.00	<.001	43.12	<.001	.98	.32	1.26	.29	3.86	<.001
3	134.78	<.001	26.51	<.001	11.32	.001	.61	.54	4.70	<.001
4	114.74	<.001	48.68	<.001	3.18	.075	.77	.46	5.53	<.001
5	198.37	<.001	90.14	<.001	3.06	.080	.13	.95	5.26	<.001

Note. Duration = interval duration; Number = Number of stimuli.

However, the patterns of the effects of number of stimuli on duration judgments were less straightforward than those on judgments of the speed of time passage (see the lower panel in Table 4). The fixed effects of the number of stimuli on the duration judgments were found to be significant in Experiment 3 and marginally significant in Experiment 4 and 5, but not significant in

Experiment 1 and 2 (see the column "Number" of Table 5). By looking over the means of duration judgments through different numbers of stimuli in Experiment 3, 4 and 5 (see the third, fourth and fifth columns of the lower panel in Table 4), we found that duration judgments of empty intervals (intervals with 0 stimuli) were always shorter than that of any filled interval (intervals with any number of stimuli). Simple comparisons between empty intervals and each filled interval in these three experiments confirmed this observation (see Table 2 of additional materials for the results of paired comparisons). Furthermore, we found that if empty intervals were not included into the models, the fixed effects of number of stimuli became not significant in Experiment 3, 4 and 5 (marginally significant in Experiment 3, p = .080, showing that intervals with 60 stimuli were judged shorter than the intervals with 30 stimuli). These results seemed to suggest that number of stimuli could only influence judgments of a fixed duration at an all-or-none level: if an interval is filled with any number of stimuli, it is perceived longer than an empty interval; but the number of stimuli in a filled interval does not seem to influence its duration perception systematically.

No significant interaction effects were found between the interval duration and the number of stimuli on the duration judgments in all the five experiments (see the column "Interaction" of Table 5).

2.3.3 Engagement levels

Across the five experiments, we found that participants' engagement levels decreased with the increasing interval duration (see the upper panel in Table 6). This observation was confirmed by the significant fixed effects of interval duration on the engagement levels (see the column "Duration" of Table 7). More importantly, as expected, participants' engagement levels increased with the increasing number of stimuli (see the lower panel in Table 6). The fixed effects of the number of stimuli on the engagement levels were found to be significant across the five experiments (see the column "Number" of Table 7).

Table 6 *Means (M) and standard deviations (SD) of engagement levels in Experiment 1-5.*

		Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Factor	Condition	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Duration (s)	18	6.58 (.22)	6.30 (.25)	6.72 (.17)	5.59 (.19)	6.29 (.22)
	51	5.45 (.23)	5.28 (.23)	5.56 (.19)	4.44 (.20)	5.04 (.20)
	84	4.83 (.21)	4.96 (.26)	5.28 (.21)	3.99 (.22)	4.59 (.20)
	117	-	-	-	-	4.26 (.22)
Number	0	5.39 (.22)	5.36 (.22)	5.60 (.18)	4.55 (.22)	4.76 (.21)
	10	-	-	-	4.50 (.23)	-
	20	-	-	-	4.63 (.22)	4.86 (.19)
	30	5.72 (.23)	5.48 (.23)	5.78 (.18)	4.66 (.19)	-
	40	-	-	-	4.64 (.21)	5.07 (.20)
	50	-	-	-	4.83 (.21)	-
	60	5.94 (.21)	5.71 (.25)	6.17 (.18)	4.89 (.19)	5.13 (.19)
	80	-	-	-	-	5.19 (.23)
	100	-	-	-	-	5.27 (.21)

Note. Cells are filled with "-" if conditions are not included in the respective designs. Higher numbers of means indicate higher levels of engagement. Duration = interval duration; Number = Number of stimuli.

Table 7 *Fixed and random effects of engagement levels in Experiment 1-5.*

	Fixed effects								**Random effects**	
	Intercept		Duration		Number		Interaction		Intercept	
Experiment	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	Ward *Z*	*p*
1	374.91	<.001	16.97	<.001	13.75	<.001	2.50	.083	4.66	<.001
2	412.62	<.001	17.87	<.001	7.67	.006	2.54	.080	5.09	<.001
3	603.89	<.001	11.58	<.001	16.11	<.001	.33	.72	4.65	<.001
4	477.24	<.001	11.63	<.001	9.84	.002	7.08	.001	5.68	<.001
5	534.15	<.001	24.95	<.001	20.73	<.001	.51	.67	5.38	<.001

Note. Duration = interval duration; Number = Number of stimuli.

The interaction effects between the interval duration and the number of stimuli on the engagement levels were found significant in Experiment 4 and marginally significant in Experiment 1 and 2 (see the column "Interaction" of

Table 7). In Experiment 1, we found the significant fixed effect of number of stimuli on engagement levels in duration of 84 s but not in duration of 18 s or 51 s. In Experiment 2, we found the significant fixed effects of number of stimuli on engagement levels in all duration of 18 s, 51 s and 84 s. In Experiment 4, we found the significant fixed effect of number of stimuli on engagement levels in duration of 18 s but not in duration of 51 s or 84 s. Given the results of the overall interaction effects were rather incongruent, they were not included in the further discussion.

2.3.4 Meta-analysis

To summarize the effects of number of stimuli on judgments of the speed of time passage and duration judgments, meta-analyses on the basis of the five experiments were performed.

2.3.4.1 Meta-analysis on judgments of the speed of time passage

Preparation of dataset. To conduct the meta-analysis, we regarded the independent variable number of stimuli as categorical variable and decomposed it into different numbers of pair comparisons. For example, Experiment 1 contained comparisons between no stimuli condition and 30 stimuli condition, comparisons between no stimuli condition and 60 stimuli condition, and comparisons between 30 stimuli condition and 60 stimuli condition. As a result, 45 comparisons were generated from the five studies (3 pairs of comparisons from Experiment 1; 3 pairs of comparisons from Experiment 2; 3 pairs of comparisons from Experiment 3; 21 pairs of comparisons from Experiment 4; 15 pairs of comparisons from Experiment 5; see the overview of comparisons in Table 1 of additional materials). Linear mixed models were used to analyze each comparison with the fixed and random intercepts, the fixed effects of interval duration, the fixed effects of number of stimuli, and the fixed interaction effects between interval duration and number of stimuli. Table 1 of the additional materials shows the effects on the judgments of the speed of time passage from all the comparisons, including mean differences, standard errors and significance levels (*p* values).

Due to the fact that the magnitudes of comparisons were different from each other (e.g., the difference between no stimuli condition and 60 stimuli condition is bigger than that between no stimuli condition and 30 stimuli condition), we further grouped all the comparisons into three categories. When the difference of number of stimuli in the comparison was smaller than 30 (e.g., 0 vs. 20 in Experiment 4), it was categorized into *small difference group*; when the difference of number of stimuli in the comparison equaled to 30 (e.g., 0 vs. 30 in Experiment 1), the comparison was categorized into *medium difference group*; when the difference of number of stimuli in the comparison was larger than 30 (e.g., 0 vs. 60 in Experiment 1), the comparison was categorized into *big difference group* (see Table 1of additional materials for the overview of group categorization).

Calculation of effect sizes. Hedges's *g*, which is a variation of Cohen's *d*, was chosen as the effect size indicator because it can correct the slight bias from small samples, and is therefore considered a more conservative effect size measure (Hedges, 1981; Hedges & Olkin, 1985). This measure can be computed from mean difference, standard error and sample size. The interpretation of Hedges's *g* can adopt Cohen's suggestions to Cohen's *d* (Cohen, 1988): an effect size of 0.2 to 0.3 is considered a small effect, around 0.5 a medium effect, and 0.8 to infinity a large effect. Effect size was computed for each comparison (see Table 1of additional materials).

Meta-analytic computations. Two statistical models are available for meta-analysis, the *fixed-effect model* and the *random-effect model*. According to Hedges and Vevea (1998), the fixed-effect model is appropriate for the inferences that extend only to the studies included in the meta-analysis, whereas the random-effect model is appropriate for the inferences that generalize beyond the studies included in the meta-analysis. Because the current meta-analysis only intended to make inferences of the effect-size parameters in the five experiments we have conducted, fixed-effect models were chosen for the overall analysis and subsequent analysis. All analyses were conducted using *Comprehensive Meta-Analysis 2.0* program.

Results. The mean effect size based on a fixed-effect model was found to be $g = .29$; the 95% confidence interval (95% CI) was 0.26 (lower) to 0.33 (upper), with a highly significant associated z score ($z = 15.51$, $p < .001$). According to Cohen's criterion, this can be considered a small effect. A chi-square test of homogeneity of effect size was highly significant, χ^2 (44) = 96.50, $p < .001$, indicating heterogeneity. A further moderator analysis was conducted to attempt to account for variation in the observed effect sizes.

The moderator analysis was conducted with three categories of groups (i.e., small difference group, medium difference group and big difference group). The category of group was found to be a significant moderator of the effect, χ^2 (2) = 53.05, $p < .001$. Big difference group led to a larger effect ($g = .45$) than medium difference group ($g = .28$), and medium difference group led to a larger effect than small difference group ($g = .14$). These results indicated that the effect of number of stimuli on judgment of speed of time passage was larger when the difference between the numbers of stimuli was bigger in the comparison.

Overall, the results of the meta-analysis confirmed the effect that the judgments of the speed of time passage increased with the increasing number of stimuli, which we have found in all the single studies conducted; furthermore, this analysis demonstrated that the effect size depends on the magnitude of the difference between the numbers of stimuli.

2.3.4.2 Meta-analysis on duration judgments

Like the meta-analysis on judgments of the speed of time passage, we decomposed the effects of number of stimuli on duration judgments into 45 comparisons (see Table 2 of additional materials). The comparisons were further grouped into two categories. One category was the comparison between empty interval condition and filled interval condition, and the other category was the comparison between any two filled interval conditions. The same linear mixed models were used as in the case of the judgments of the speed of time passage. Table 2 of the additional materials shows the effects on duration judgments from all the comparisons, including mean differences, standard errors and significance levels (*p* values). The calculation of effect sizes and the meta-analytic computations were the same as we did for the judgments of the speed of time passage.

Results. The mean effect size based on a fixed-effect model was $g = .075$; the 95% confidence interval (95% CI) around this estimate had a lower limit of 0.039 and an upper limit of 0.11. The effect was significantly different from zero, $z = 4.05$, $p < .001$. A chi-square test of homogeneity of effect size was highly significant, χ^2 (44) = 121.11, $p < .001$, indicating heterogeneity. A further moderator analysis was conducted to attempt to account for variation in the observed effect sizes.

A moderator analysis was conducted with two categories of groups (i.e., groups of comparisons between empty interval condition and filled interval condition, and groups of comparisons between any two filled interval conditions).

The category of groups was found as a significant moderator of the observed effects, χ^2 (1) = 57.48, p < .001. The group of comparisons between empty-interval condition and filled-interval condition had a mean estimated effect size of *g* = .263 and *SE* of .031. According to Cohen's criterion, this can be considered a small effect. The effect was significantly different from zero, *z* = 8.50, *p* < .001, with the 95% confidence interval (95% CI) of 0.20 (lower) to 0.32 (upper). The group of comparisons between any two filled-interval group yielded a mean estimated effect size of *g* = -.030 and *SE* of .023. This estimate was not significantly different from zero, *z* = -1.30, *p* = .19.

The meta-analysis results confirmed our observation that the number of stimuli influenced the duration judgments between empty intervals and filled intervals, but not between any filled intervals. Importantly, this analysis clearly revealed that the comparisons between empty intervals and filled intervals induced significant effects on the duration judgments, whereas the comparisons between any two filled intervals induced no effects. Overall, the results suggested that people tend to perceive filled intervals longer than empty intervals with the same duration, but the number of stimuli in filled intervals doesn't necessarily influence their duration judgments.

2.3.5 Mediation analysis

To test our hypothesis that engagement mediates the effect of the amount of non-temporal information on judgments of the speed of time passage, mediation analyses were conducted across five experiments, comprising the number of stimuli as the independent variable, judgments of the speed of time passage as the dependent variable, and engagement levels as the mediator (see Figure 1).

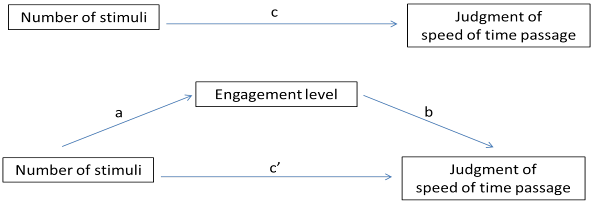

Figure 1 Illustration of mediation of engagement levels between number of stimuli and judgments of the speed of time passage.

As all variables were measured employing a repeated-measures design, mixed models were used to estimate the mediation model. As shown by Kenny, Korchmaros and Bolger (2003), the mediation effect in mixed models is a function of both the fixed effects and the covariance of the random effects. In our case, the mediation effect of engagement is a function of the fixed effect of number of stimuli on engagement, the partial effect of engagement on judgments of the speed of time passage keeping the number of stimuli constant, and the covariance between the random effect of number of stimuli on engagement and engagement on judgments of the speed of time passage. Thus, to set up a proper model for the mediation analysis we first investigated the fixed and random effects of the mediation model on the full sample obtained pooling together the five experiments.

The first model features number of stimuli as independent variable and judgments of the speed of time passage as dependent variable. The effect of number of stimuli and the intercept of the model was set as random across participants. Estimation suggested that only the intercept showed a non-zero variance. In particular, setting the effect of number of stimuli on judgments of the speed of time passage as fixed allowed the model to fit, showing random variability only in the intercepts (σ^2 =12404.98, icc = .15, χ^2 = 474.53, p < .001). Thus, in the overall sample, no random variability was observed for the overall effect of number of stimuli on judgments of the speed of time passage. Logically, this result suggested that the mediational effect — being a portion of the overall effect — should not be random. In fact, a model with number of stimuli as independent variable and engagement as dependent variable showed random variability only in the intercepts (σ^2 =34935.207, icc =.48, χ^2 = 2582.184, p < .001) and none in the regression coefficients. Hence, the components of the mediation effects were not randomly varying in our sample, and the mediation model depends only on the product of the fixed products.

After establishing the random structure of the mediation model, to estimate the model we adapted a simultaneous modeling approach (Bauer, Preacher, & Gil, 2006; MacCallum, Kim, Malarkey, & Kiecolt-Glaser, 1997) to the present case. To obtain an inferential test for the mediated effect, we examined a large samples t-test obtained with the simultaneous modeling approach and the bootstrap (with 1000 samples) confidence interval (95%) of the mediated effect. Different methods of obtaining the confidence interval agreed on this conclusion.

Results. Across all five experiments, the overall fixed effect of number of stimuli on judgments of the speed of time passage was positive and statistically significant (i.e., path *c* in Figure 1), B = 1.39, F (1, 4825.85) = 80.23, p < .001. The fixed effect of number of stimuli on engagement was positive and significant (i.e., path *a* in Figure 1), B = .85, F (1, 4808.73) = 55.35, p < .001, and so was the partial effect of engagement on judgments of the speed of time passage, keeping constant the effect of number of stimuli (i.e., path *c'* in Figure 1), B = 0.67, F (1, 4098.35) = 2034.53, p < .001. Thus the mediated effect was of 0.58, with bootstrap confidence interval of 0.55 – 1.19. As the confidence interval did not encompass zero, we deem the effect as statistically significant. The same conclusion can be obtained using the large sample F-test on the meditated effect, F (1, 9457.88) = 7.22, p = .007. These results confirmed our hypothesis that the increasing amount non-temporal information increases participants' engagement levels, and further increases judgments of the speed of time passage.

2.3.6 Correlation analysis

To check the reliability of inferring the judgments of the speed of time passage from the duration judgment, correlation analyses between the judgments of the speed of time passage and the duration judgment were conducted. To capture data dependency, the correlation has been estimated for each experiment using a mixed model with intercepts as random coefficient across subjects.

The judgments of the speed of time passage and duration judgments were negatively correlated across five experiments (i.e., r varied from -.54 to -.67; see the first row in Table 8); however, the correlation greatly reduced if controlling for the duration of intervals, with partial correlations ranging from -.057 to -.250 (see the second row in Table 8). These results indicated that it was not always reliable to infer judgments of the speed of time passage from duration judgments, especially when the information of actual duration is missing.

Table 8 *Correlation analyses between judgments of the speed of time passage and duration judgments in Experiment 1 to 5*

Correlation	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Overall	-.59*	-.63*	-.67*	-.57*	-.54*
Partial	-.21*	-.15	-.25*	-.16*	-.057*

* $p < .001$.

2.4 Discussion

The subjective perception of time has been noted by psychological researchers for a long time; however, while most of research has focused on the subjective duration judgments, very little research has investigated the subjective judgments of the speed of time passage. The current line of research aimed to investigate how attentional processes influence judgments of the speed of time passage, with a special interest in examining the role of engagement in mediating the effect. The results of five experiments showed that time was perceived as passing faster when more attention was paid to non-temporal information, and further revealed the role of the engagement as a mediator. These results support our hypothesis that judgments of the speed of time passage are a function of the amount of attention on the non-temporal information, and engagement mediates this effect.

Although engagement has been investigated widely in classroom learning (Corno & Mandinach, 1983), in organization performance (Salanova, Agut, & Peiró, 2005), in group cooperation (Tyler & Blader, 2003) or in political participation (Galston, 2001), this is, to our knowledge, the first time that it is investigated in the domain of time perception. We found that engagement mediated the effect of the amount of attention on the judgments of the speed of time passage: when the time-unrelated task attracts more attention, people get more engaged in it, and consequently they experience time as passing faster. Together with the fact that engagement is closely intertwined with different psychological components that influence time perception, such as attention, memory and emotion, it suggests that engagement might play an important role in shaping the perception of time. Further research on the subjective perception of time could be conducted with engagement level as an important variable.

The present studies first extend the role of attention to the judgments of the speed of time passage. We argue that the less attention is paid to time passage, the faster time is perceived as passing. This argument is comparable to the judgment of physical speed – a moving object (e.g., a car) can be judged as fast when little attention is paid to it. In addition, the moderator analysis in our meta-analysis demonstrated that the difference in the amount of attention on time passage gave rise to the difference in judgments of the speed of time passage; the bigger the difference in the amount of attention on the time passage, the bigger the difference in the judgments of the speed of time passage between the temporal intervals.

The overall findings of the role of attention on judgments of the speed of time passage indicate that controlling the amount of attention on time passage is a way of changing the perception of the speed of time passage. For certain events, influencing people's subjective perception of the speed of time passage could bring a better experience. For example, restaurants normally want customers to experience faster-passing waiting time, especially for the customers in the waiting line. According to the current research, restaurants could provide more information (e.g., menu) or service (e.g., free snacks, TV with interesting news) to divert customers' attention from the time passage during the wait, which is likely to result people perceiving time as passing faster. Another example is holiday experience. People normally don't want to experience time passing too fast when they are on holiday. To slow down the perception of the speed of time passage, they could arrange fewer activities during the holiday, so they could pay more attention to the "flow of time", which brings about slower perception of time passing. Another straight-forward and interesting extension of the present work could be the so called flow experiences: It directly follows from our findings that whatever turns attention to temporal information should make time be perceived as passing by more slowly. Consequently, timing people with, for instance, time-punch machines is probably not a very good idea, at least if one wants one's employees to get "in the flow".

It is somewhat surprising that we didn't find the duration judgments decreased with the increasing number of stimuli as predicated by attention-based models; instead, we found the duration of filled intervals was judged as longer than that of empty intervals (i.e., filled duration illusion). Even though this finding seems consistent with memory-based models, the duration of filled intervals didn't reveal a stable increasing or decreasing pattern with the increasing number of stimuli. The non-monotonic pattern of duration judgments was not the first time to be found (Hogan, 1975; Jones & Natale, 1973; Ornstein, 1969). For instance, in one of Ornstein's studies (Ornstein, 1969), participants were shown six figures in different ranked complexity. The results showed that the increase in stimulus complexity lengthens the experience of duration only up to a point and then further increases no longer have any effect. We speculate that although according to attention-based models, attention is supposed to play a dominant role in judging duration in the prospective paradigm, memory might also play an important role when there is clear difference in the amount of stored information in memory (i.e., empty intervals vs. filled intervals). Future research needs to test out this possibility more carefully.

The relation between judgments of the speed of time passage and duration judgments was another interest of the current line of studies. Judgments of the speed of time passage was found to be negatively correlated with duration judgments, but the correlation became rather weak when controlling for the duration of intervals. This indicates that the assumed association between the speed of time passage and duration greatly depends on the actual duration of intervals; when the information of the actual duration of intervals is missing or less salient, to infer the speed of time passage from the duration judgments becomes less reliable. This finding also partly corroborates the idea of Wearden (2008) that "the two [i.e., *passage of time judgments* and *retrospective timing*, which is comparable to judgments of the speed of time passage and duration judgments in our research, respectively] might not be reliably related at all". In one of his studies, Wearden (2005) found that people judged a film time passing faster and lasting longer than the (same) time that was spent in the waiting room. This finding is consistent with the common sense that people could feel a busy day passing very fast, and it seems to last very long at the same time. Both factual and empirical evidence suggest that the best way of understanding the speed of time passage is not to infer it from the duration, but rather to investigate it independently.

Although the current data showed that judgments of the speed of time passage and duration judgments are not reliably correlated, in daily life people usually have a mixed feeling about duration and the speed of time passage: when they say “the class lasted so long”, they also mean “time passed so slowly in the class”. We speculated that when people judge duration in a subjective manner (i.e., with the idea of long or short), duration judgments and judgments of the speed of time are more closely related than that when people judge duration in an objective manner (i.e., with objective reference of seconds, minutes, etc.). To test this speculation, we conducted a supplementary experiment with the same design as Experiment 1. Differently, three groups of participants were recruited, and each group was asked to give one type of time judgments: judgments of the speed of time passage (How fast did time pass when you were doing this trial? 1-*very slowly*, 9-*very fast*), objective duration judgments (How long do you think this trial lasted? Answering with number of seconds), or subjective duration judgments (How long do you think this trial lasted? 1-*very short*, 9-*very long*). A correlation analysis was performed with these three types of time judgments. The result revealed a low negative correlation between judgments of the speed of time passage and objective duration judgments (r = -.18, p < .05), which was similar to the correlation we obtained across the five previously reported experiments. Interestingly, we found a higher negative correlation between judgments of the speed of time passage and subjective duration judgments (r = -.47, p < .001). These results support our speculation that judgments of the speed of time passage and subjective duration judgments are more closely related. This could also explain the daily observation that people have mixed feelings of time being long/short and passing slow/fast. In addition, we found that subjective duration judgments and objective duration judgments had a low positive correlation (r = .28, p < .001), which indicated that the two duration judgments are relatively independent from each other. The overall results from this supplementary experiment further supported our finding that judgments of the speed of time passage and objective duration judgments were not reliably correlated; more importantly, they shed light on the difference between subjective duration judgments and objective duration judgments. Further research could go deeper to understand this distinction.

In conclusion, across five experiments we found the function of attention on the judgments of the speed of time passage. As expected, the judgments of the speed of time passage increased with the decreasing amount of attention on time passage. This finding could stimulate practical strategies for managing the perception of time passage to induce better life experiences. Future research could look into more factors that influence the perception of the speed of time passage, and explore the possibilities of changing the perception of time passage. In addition, we found the role of engagement on the effect of attention on the subjective judgment of the speed of time passage. Further research could investigate more the function of engagement on time perception. Moreover, we found that the judgments of the speed of time passage and duration judgments correlated weakly with each other when controlling for the duration of intervals. This finding confirms that inferring the speed of time passage from duration is not reliable, and suggests the best way of understanding the speed of time passage is to investigate it independently.

Additional materials

Table 1 *Descriptive statistics of meta-analysis on judgments of the speed of time passage of Experiment 1-5.*

Experiment	Sample	Comparison	Group	Mean difference (positive direction)	Standard Error	*p*	Hedges' s *g*
1	56	0 vs. 30	medium	,405	0,183	0,028	0,292
		0 vs. 60	big	,708	0,160	0,000	0,583
		30 vs. 60	medium	,304	0,172	0,079	0,233
2	59	0 vs. 30	medium	,452	0,134	0,001	0,433
		0 vs. 60	big	,514	0,149	0,001	0,443
		30 vs. 60	medium	,062	0,144	0,668	0,055
3	58	0 vs. 30	medium	,080	0,171	0,638	0,061
		0 vs. 60	big	,816	0,169	0,000	0,626
		30 vs. 60	medium	,736	0,138	0,000	0,691
4	71	0 vs. 10	small	,014	0,148	0,924	0,011
		0 vs. 20	small	,033	0,147	0,823	0,026
		0 vs. 30	medium	,371	0,163	0,024	0,267
		0 vs. 40	big	,404	0,153	0,009	0,310
		0 vs. 50	big	,624	0,157	0,000	0,467
		0 vs. 60	big	,653	0,175	0,000	0,438
		10 vs. 20	small	,019	0,128	0,884	0,017
		10 vs. 30	small	,357	0,142	0,013	0,295
		10 vs. 40	medium	,390	0,140	0,006	0,327
		10 vs. 50	big	,610	0,155	0,000	0,462
		10 vs. 60	big	,638	0,164	0,000	0,457
		20 vs. 30	small	,338	0,132	0,015	0,301
		20 vs. 40	small	,371	0,119	0,002	0,366
		20 vs. 50	medium	,592	0,135	0,000	0,515
		20 vs. 60	big	,620	0,146	0,000	0,499
		30 vs. 40	small	,033	0,141	0,815	0,027
		30 vs. 50	small	,254	0,139	0,070	0,215
		30 vs. 60	medium	,282	0,136	0,040	0,243
		40 vs. 50	small	,221	0,149	0,139	0,174
		40 vs. 60	small	,249	0,145	0,087	0,202
		50 vs. 60	small	,028	0,160	0,860	0,021
5	64	0 vs. 20	small	,250	0,132	0,059	0,234
		0 vs. 40	big	,418	0,130	0,001	0,397
		0 vs. 60	big	,656	0,125	0,000	0,648
		0 vs. 80	big	,750	0,139	0,000	0,666
		0 vs. 100	big	,918	0,139	0,000	0,816
		20 vs. 40	small	,168	0,122	0,170	0,170
		20 vs. 60	big	,406	0,137	0,003	0,366
		20 vs. 80	big	,500	0,141	0,000	0,438
		20 vs. 100	big	,668	0,139	0,000	0,594
		40 vs. 60	small	,238	0,125	0,058	0,235
		40 vs. 80	big	,332	0,136	0,015	0,301
		40 vs. 100	big	,500	0,113	0,000	0,546
		60 vs. 80	small	,094	0,133	0,481	0,087
		60 vs. 100	big	,262	0,122	0,033	0,265
		80 vs. 100	small	,168	0,143	0,240	0,145

Table 2 *Descriptive statistics of meta-analysis on duration judgments of Experiment 1-5.*

Experiment	Sample	Comparison	Group	Mean difference	Standard Error	*p*	Hedges' s *g*
1	56	0 vs. 30	empty-filled	3,518	2,748	0,202	0,169
		0 vs. 60	empty-filled	1,375	2,622	0,600	0,069
		30 vs. 60	filled-filled	-2,143	2,880	0,458	-0,098
2	59	0 vs. 30	empty-filled	-,486	2,669	0,856	-0,023
		0 vs. 60	empty-filled	-2,328	2,428	0,341	-0,123
		30 vs. 60	filled-filled	-1,842	1,842	0,339	-0,128
3	58	0 vs. 30	empty-filled	9,805	2,120	0,000	0,599
		0 vs. 60	empty-filled	6,667	1,989	0,001	0,434
		30 vs. 60	filled-filled	-3,138	1,785	0,080	-0,228
4	71	0 vs. 10	empty-filled	6,822	3,160	0,032	0,253
		0 vs. 20	empty-filled	11,967	3,105	0,000	0,452
		0 vs. 30	empty-filled	10,122	3,847	0,009	0,309
		0 vs. 40	empty-filled	6,164	3,571	0,080	0,203
		0 vs. 50	empty-filled	4,131	2,307	0,074	0,210
		0 vs. 60	empty-filled	11,808	3,841	0,002	0,361
		10 vs. 20	filled-filled	5,146	3,232	0,112	0,187
		10 vs. 30	filled-filled	3,300	4,003	0,410	0,097
		10 vs. 40	filled-filled	-,657	3,856	0,865	-0,020
		10 vs. 50	filled-filled	-2,690	3,176	0,397	-0,099
		10 vs. 60	filled-filled	4,986	3,872	0,199	0,151
		20 vs. 30	filled-filled	-1,845	3,597	0,608	-0,060
		20 vs. 40	filled-filled	-5,803	3,457	0,094	-0,197
		20 vs. 50	filled-filled	-7,836	3,245	0,016	-0,284
		20 vs. 60	filled-filled	-,160	3,165	0,960	-0,006
		30 vs. 40	filled-filled	-3,958	4,245	0,352	-0,109
		30 vs. 50	filled-filled	-5,991	3,828	0,118	-0,184
		30 vs. 60	filled-filled	1,685	4,051	0,678	0,049
		40 vs. 50	filled-filled	-2,033	3,562	0,569	-0,067
		40 vs. 60	filled-filled	5,643	4,091	0,169	0,162
		50 vs. 60	filled-filled	7,676	3,906	0,050	0,231
5	64	0 vs. 20	empty-filled	8,621	3,405	0,012	0,313
		0 vs. 40	empty-filled	7,375	3,445	0,033	0,264
		0 vs. 60	empty-filled	10,691	3,273	0,001	0,403
		0 vs. 80	empty-filled	9,758	3,452	0,005	0,349
		0 vs. 100	empty-filled	5,535	3,124	0,077	0,219
		20 vs. 40	filled-filled	-1,246	3,340	0,709	-0,046
		20 vs. 60	filled-filled	2,070	3,259	0,526	0,078
		20 vs. 80	filled-filled	1,137	3,563	0,750	0,039
		20 vs. 100	filled-filled	-3,086	3,165	0,330	-0,120
		40 vs. 60	filled-filled	3,316	3,242	0,307	0,126
		40 vs. 80	filled-filled	2,383	3,509	0,497	0,084
		40 vs. 100	filled-filled	-1,840	3,120	0,556	-0,073
		60 vs. 80	filled-filled	-,934	3,438	0,786	-0,034
		60 vs. 100	filled-filled	-5,156	3,089	0,096	-0,206
		80 vs. 100	filled-filled	-4,223	3,353	0,209	-0,156

Chapter 3

Beyond attention?!

The roles of presentation frequency and comparison frame in judging the speed of time passage

Abstract

In Chapter 2, we manipulated the number of stimuli in a fixed duration and found that time was judged as passing faster when more stimuli were presented. However, there are two methodological issues that need to be further addressed. First, we used within-subjects designs throughout the experiments. This manipulation comes with the problem that participants are provided with a reference for their judgments. Second, we presented stimuli in a regular manner within a fixed duration in all the experiments; thus, when more stimuli were presented, the stimuli were also presented faster (i.e., at a higher frequency). This gives rise to the possibility that participants might have used the frequency as a cue to judge the speed of time passage. The present research in Chapter 3 was designed to examine both of these confounds experimentally. In line with our hypotheses, results from Experiment 1 and 2 showed that both presentation frequency and number of stimuli affected judgments of the speed of time passage independently. These findings strengthen our argument about the role of attention in judging the speed of time passage. Results from Experiment 3 showed a strong effect of whether or not participants were provided with a reference frame in judging the speed of time passage. We argue that this finding further suggests the relative nature of judgments of the speed of time passage.

3.1 Introduction

Apparently, the perception of time is more than simply reading one's watch: Time is also a highly subjective experience and as such influenced by many psychological factors. Amongst the most well studied variables influencing how much time people think a certain event took is the amount of attention turned to either temporal or non-temporal information. Specifically, previous research established the fact that the more attention is allocated to temporal information (e.g., staring at the clock while waiting for the bus) the longer time intervals are perceived to last. Conversely, the more attention is allocated to non-temporal information (e.g., observing other people waiting for the bus) the shorter the same period of time is experienced. In a recent line of research, we (Li, Häfner, Garrido, Gallucci, & Semin, 2014) extended this line of reasoning from typically investigated duration judgments to judgments of the speed of time passage and show that time also subjectively passes by faster the less attention is devoted to matters concerning time passage itself. As such, we showed that the simple amount of information being processed influences how fast time subjectively passes by: The more stimuli we presented, the faster time subjectively passed by for our participants.

Despite the fact that our findings perfectly match and extend previous work, there are two methodological issues in our, but also in previous research, that need to be addressed. First, along with many others, we manipulated the allocation of attention exclusively within participants (see also, Khoshnoodi, Motiei-Langroudi, Omrani, Diamond, & Abbassian, 2008; Poynter & Homa, 1983; Thomas & Brown, 1974; Tse, Intriligator, Rivest, & Cavanagh, 2004). This common methodology comes, however, with the problem that participants are provided with a reference frame for their judgments. This seems to be particularly the case when people make judgments of the speed of time passage as these judgments lack objective timing references (i.e., seconds, minutes, etc.).

For example, if people experience a present event as passing by fast, they often do so by comparing the actual event to a similar previous event. But what if there is no similar previous event, or stated differently, what if we manipulated attention allocation between instead of within participants? Is time passage then experienced more accurately?

Apart from this very common problem in research on the perception of time intervals, the way we manipulated attention allocation (i.e., the sheer number of available non-temporal information) opens up alternative explanations: We presented our different amounts of stimuli regularly across the same time intervals in all the reported experiments. Hence, when more stimuli were presented, we did not only present more stimuli, but we also presented them in faster succession (i.e., at a higher frequency). This gives rise to the possibility that participants might have used the frequency as a cue to judge the speed of time passage. When stimuli were presented faster, they might have judged time as passing by faster; when stimuli were presented slower, they might have judged time as passing more slowly.

Overview of the studies

The present studies were designed to address both confounds experimentally. In particular, we conducted three experiments in order to disentangle presentation frequency (Experiment 1 and 2) and comparison frame (Experiment 3) from the role of attention in the subjective experience of the speed of time passage. Experiment 1 was designed to investigate the role of frequency: In half of the conditions, we replicated our earlier methodology, that is, we presented different numbers of stimuli (few vs. many) across the same time interval. Therefore, the more stimuli we presented the higher the frequency at which we presented them (i.e., different frequency). In the other half of the conditions, we presented different numbers of stimuli at the same frequency by manipulating the intervals between stimuli (see also Fig. 1). We hypothesized that both the number of stimuli and the frequency at which we present the stimuli should independently influence judgments of the speed of time passage. This hypothesis was also tested in Experiment 2.

In Experiment 3, we used a between-subjects design to see how strong the effect of having a comparison frame would be. To test the role of attention in judging the speed of time passage when comparison is not available, besides number of stimuli, we also included another factor that could influence attention allocation — presentation regularity of stimuli. When stimuli are presented irregularly, they should attract more attention than regularly presented stimuli. Taken together, it was expected that time would be judged as passing by faster when more stimuli were presented and when stimuli were irregularly presented. However, if this attentional model relies on a comparison frame, these effects would not be expected to appear when the comparison frame was removed.

3.2 Experiment 1

3.2.1 Method

Design and Participants. A 2 (number of stimuli: few vs. many) * 2 (presentation frequency: different vs. same) within-subject design was used. 43 participants (age M = 22.56, SD = 6.26; 21 males) were recruited from Utrecht University in exchange for course credit or a small monetary reward.

Materials and Procedure. As in the previous research (Li et al., under review), we used synchronized beeps via headphone and circles presented in the center of the computer screen as stimuli. The duration of each stimulus was 100 ms. 30 or 60 stimuli were presented either regularly or in chunks of 51 s (see the illustration in Figure 1). When stimuli were presented regularly, they were evenly distributed throughout the 51 s, thus the presentation frequency was different for 30 stimuli and 60 stimuli — 60 stimuli (i.e., 1.18 Hz) were presented faster than 30 stimuli (i.e., 0.59 Hz). When stimuli were presented in chunks, both 30 and 60 stimuli were presented in 10 chunks with 3 stimuli and 6 stimuli in each chunk, respectively. The stimuli in all chunks were presented with the same between-stimuli intervals of 300 ms, thus presentation frequency was equal in both conditions (i.e., 3.33 Hz). The 10 chunks in both conditions were evenly distributed throughout the 51 s.

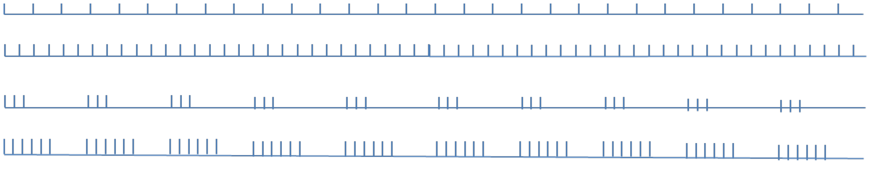

Figure 1 Illustration of the stimuli presentation in Experiment 1

Two trials were presented for each condition. In total, participants were thus randomly presented with 8 experimental trials. Before this presentation, two additional intervals of 30 s were presented as practice trials. In one practice trial, 30 stimuli were regularly distributed in 30 s; in the other practice trial, 15 stimuli were equally chunked into 5 chunks with between-stimuli intervals of 900 ms and between-chunks intervals of 3900 ms. To prevent participants from simply using a counting strategy to estimate an interval's duration, they were also visually presented with two three-digit numbers at random temporal intervals at the bottom of the screen. Participants were asked to read these numbers out loud immediately after they appeared on the screen. Each trial ended with a sound, which was a markedly distinctive one from the stimulus beeps.

After each trial, participants were asked to provide their judgments on the speed of time passage (*How fast did time pass when you were doing this trial?*) on a 9-point scale (from *1-very slowly* to *9-very fast*). Moreover, duration judgments were also included as a dependent variable. Participants were asked to provide their judgments on duration (*How long do you think this trial lasted?*) by writing down the number of seconds they thought the trial had taken as accurately as possible.

3.2.2 Results

Mean responses were calculated by averaging the responses to the two trials of the same condition. Repeated measures analyses of variance were conducted for each DV (i.e., judgments of the speed of time passage and duration judgments) with number of stimuli and presentation speed of stimuli as the two independent variables.

Judgments of the speed of time passage

The effect of number of stimuli on judgments of the speed of time passage was found significant, F (1, 42) = 23.28, p < .001, η_p^2 = .36, 95% CI [-1.21, - .50], showing that time was judged as passing faster when more stimuli were presented (M_{30} = 4.15, SD = .17; M_{60} = 5.00, SD = .21). The main effect of presentation frequency of stimuli was also found significant, F (1, 42) = 6.28, p = .016, η_p^2 = .13, 95% CI [-.75, -.08], revealing that participants perceived time as passing by faster when stimuli were presented at the same frquency (M_{same} = 4.78, SD = .19) than when they were in different frequencies ($M_{\text{different}}$ = 4.37, SD = .19). As stimuli in the same frequency condition were presented at a higher frequency (3.33 Hz) than those presented in the different frequencies conditions (1.18 Hz and 0.59 Hz) this findings provide evidence that presentation frequency is also a direct cue to the speed of time passage. The higher the presentation frequency, the faster time seems to pass by.

Moreover, the interaction between the number of stimuli and presentation frequency was found to be significant, F (1, 42) = 4.84, p = .033, η_p^2= .10. Simple contrasts show, however, that the effects of number of stimuli holds across all frequency conditions, but the effect was bigger when stimuli were presented at different frequencies mean difference $_{(30\text{-}60)}$ = -1.15, $p < .001$, 95% CI [-1.59, -.71] than when stimuli were presented at the frequency, mean difference $_{(30\text{-}60)}$ = -0.56, $p = .018$, 95% CI [-1.02, -.10].

Duration judgments

Neither main effects of number of stimuli or presentation type nor the interaction between them were found significant on duration judgments, all *p*s > .10.

3.2.3 Discussion

In this experiment, we presented different numbers of stimuli either at different or at the same presentation frequency in order to control for the potentially confounding influence of presentation frequency on experienced time passage. And in fact, we found two independent effects. On the one hand, we replicated our earlier finding that the more information is presented, the faster time seems to pass by. On the other hand, we also find that information that is presented at a higher frequency (i.e., faster) also leads to experiences of faster time passage. Hence, these results back up our earlier results by showing that these were not solely driven by presentation frequency. Even though presentation frequency and number of stimuli were confounded, both factors contribute independently to judgments of the speed of time passage.

In order to replicate the finding that presentation frequency influences the experience of time passage, we conducted Experiment 2, in which we manipulated differences in frequency in a more straightforward manner.

3.3 Experiment 2

3.3.1 Method

Design and Participants. A 2 (presentation frequency of stimuli: low vs. high) * 2 (number of stimuli: few vs. many) within-subjects design was used. 34 participants (age M = 20.65, SD = 3.12; 18 males) were recruited from Utrecht University in exchange for course credit or monetary reward.

Materials and Procedure. The same type of stimuli were used as in Experiment 1. 30 and 60 stimuli were presented in 10 chunks across 51 s, with 3 stimuli and 6 stimuli in each chunk, respectively (see Fig. 2). The high presentation frequency was controlled with between-stimuli intervals in chunks being 200 ms (i.e., 5 Hz), and the low presentation frequency was controlled with between-stimuli intervals in chunks being 400 ms (i.e., 2.5 Hz). This time, the 10 chunks in each condition were randomly distributed across the 51 s in order to rule out an effect of the different intertribal intervals (i.e., pauses).

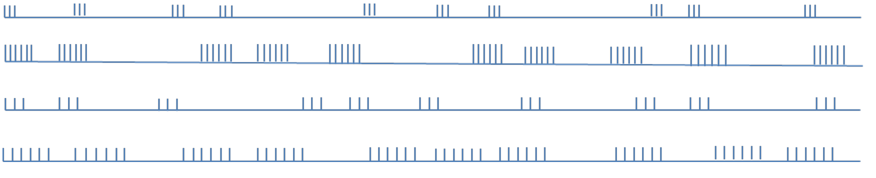

Figure 2 Illustration of the stimuli presentation in Experiment 2

Two trials were presented for each condition. In total, participants were randomly presented with 8 experimental trials. Two preliminary intervals of 30 s were given as practice trials. 30 stimuli were presented in 10 chunks with between-stimuli intervals being 300 ms (i.e., 3.33 Hz). Chunks were distributed regularly in one trial and randomly in the other trial. As for the rest we implemented the same procedure as in Experiment 1. After each trial, participants were asked to answer the questions about the speed of time passage and duration as in Experiment 1.

3.3.2 Results

Mean responses of DVs were calculated by averaging responses to the two trials of the same condition. Repeated measures analyses of variance were conducted for each DV (i.e., judgments of the speed of time passage and duration judgments) with presentation frequency and number of stimuli as the two independent variables.

Judgments of the speed of time passage

The main effect of presentation frequency of stimuli was found significant on judgments of the speed of time passage, F (1, 33) = 18.55, $p < .001$, $\eta_p^2 = .36$, 95% CI [.40, 1.12], showing that time was judged as passing faster when stimuli were presented at a higher frequencies (M_{high} = 5.00, SD = .24; M_{low} = 4.25, SD = .20). The main effect of number of stimuli was also significant, F (1, 33) = 7.79, p = .009, $\eta_p^2 = .19$, 95% CI [-1.03, -.16], showing that time was judged as passing faster when more stimuli were presented (M_{30} = 4.33, SD = .22; M_{60} =4.93, SD = .23). No interaction was found between presentation speed of stimuli and number of stimuli on judgments of the speed of time passing, $F < 1$.

Duration judgments

The main effect of presentation speed of stimuli was found to be significant on duration judgments, F (1, 33) = 9.43, p = .004, $\eta_p^2 = .22$, 95% CI [2.17, 10.70], showing that time was judged as shorter when stimuli were presented at a high speed (M_{high} = 42.29, SD = 3.86; M_{low} = 48.73, SD = 5.41). Neither the main effect of number of stimuli nor the interaction between presentation speed of stimuli and number of stimuli was found significant on duration judgments, Fs < 1.

3.3.3 Discussion

Again we found two independent effects. On the one hand, we once more replicated our basic effect that the sheer number of stimuli being presented affect the experience of time passage: The more non-temporal information is being presented, the faster time seems to pass by. On the other hand, we also show that the frequency at which information is being presented can also be used as a direct cue to the experience of time passage. The denser (i.e., higher frequency) the information comes in, the faster people think time passes by.

Moreover, we found that, similar to Experiment 1, duration judgments were not influenced by our number of stimuli manipulation. However, this time, duration judgments were found to be shorter when stimuli were presented at higher frequencies. Interestingly, this finding is inconsistent with previous findings indicating that faster moving stimuli increase duration judgments (Kanai, Paffen, Hogendoorn, & Verstraten, 2006; Kaneko & Murakami, 2009). These previous findings were usually explained by the change model (Fraisse, 1963). According to the change model, experiencing more changes would prolong duration judgments; so when stimuli were moving faster, they induced more changes, time was therefore judged as longer. In the current research, however, although stimuli were presented with different speeds, no changes happened during the presentation — the same stimuli always appeared at the same place. This might result in that we didn't find the increasing pattern of duration judgments with faster presented stimuli.

The current finding of decreasing pattern of duration judgments with faster presented stimuli is in line with attentional models. Usually, faster stimuli catch more attention, and, therefore, when stimuli were presented faster, more attention was paid to non-temporal information and less attention was paid to temporal information, so time was judged as shorter. However, future research needs to test these speculations more carefully.

Even though Experiments 1 and 2 show that our previous findings were also driven by different presentation frequencies, taken together, they once more point to the general role of attention: The more attention is paid to non-temporal information, the faster time seems to pass by. However, up to now, this conclusion can only be drawn under the presupposition that participants are provided with a reference frame. Stated differently, up to now, we, along many others, manipulated all our variables exclusively in within participants designs. But does the number of stimuli still play a role when we take away such a reference frame? Experiment 3 was designed to investigate this question. Specifically, in order to test the role of attention in judging the speed of time passage when comparison is not available, besides number of stimuli, we also included another factor that could influence attention allocation — presentation regularity of stimuli. When stimuli are presented irregularly, they should attract more attention than regularly presented stimuli. Taken together, it was expected that time would be judged as passing by faster when more stimuli were presented and when stimuli were irregularly presented. However, if this attentional model relies on a comparison frame, these effects would not be expected to appear when the comparison frame was removed.

3.4 Experiment 3

3.4.1 Method

Participants and Design. A 2 (number of stimuli: 30 vs. 60) * 2 (presentation regularity of stimuli: regularly vs. irregularly) *between*-participants design was used. 164 (age $M = 21.01$, $SD = 3.40$; 59 males) participants were recruited from

Utrecht University, with 41 participants in each condition. They received either course credit or money as rewards.

Materials and Procedure. The same type of stimuli as in Experiment 1 and 2 were used in Experiment 3. In each trial, 30 or 60 stimuli were presented regularly (i.e., at regular between-stimuli intervals) or irregularly (i.e., at irregular between-stimuli intervals) in a fixed duration of 51 s. The trial in each condition was presented twice to each participant. Two additional trials of 30 s with 30 stimuli were given as practice trials. The stimuli in practice trials were of the same type as those in experimental trials. They were presented regularly in one trial and irregularly in the other. The same procedure and questions after each trial were applied to Experiment 3 as that in Experiment 1 and 2.

3.4.2 Results

A 2 (number of stimuli) by 2 (presentation regularity of stimuli) analysis of variance was conducted for each DV (i.e., judgments of the speed of time and duration judgments) with number of stimuli and presentation regularity of stimuli as two independent variables.

Judgments of the speed of time passage

A main effect of presentation regularity of stimuli was found on judgments of the speed of time passage, F (1, 160) = 5.58, p = .019, η_p^2 = .034, 95% CI [-1.20, -.11], showing that time was judged as passing faster when stimuli were presented irregularly (M_{regular} = 4.35, SD = .20; $M_{\text{irregular}}$ =5.01, SD = .20). Although it seemed that time was judged as passing faster when more stimuli were presented (M_{30} = 4.56, SD = .20; M_{60} = 4.81, SD = .20), this difference was not significant, F < 1. The interaction between presentation regularity of stimuli and number of stimuli was not significant on judgments of the speed of time passage, F < 1.

Duration judgments

A trend of presentation regularity of stimuli was found on duration judgments, F (1, 160) = 2.78, p = .098, η_p^2 = .017, 95% CI [-.83, 9.77], showing that time was judged as longer when stimuli were presented regularly (M_{regular} = 47.97, SD = 1.90; $M_{\text{irregular}}$ = 43.50, SD = 1.90). Neither the main effect of number of stimuli nor the interaction between number of stimuli and presentation type of stimuli was found significant on duration judgments, Fs < 1. The weak effect of presentation type of stimuli on duration judgments supported the attentional model on duration judgments. When stimuli were presented irregularly, they attracted more attention, and less attention was paid to temporal information, therefore time was judged as shorter.

3.4.3 Discussion

In this experiment, we aimed to examine if the role of attention in judging the speed of time passage that was found in Li et al's (under review) research is only effective if people are provided with a reference of comparison. Therefore, the present research was conducted without such a reference frame, in a between-subjects design. To manipulate attention allocation, besides the number of stimuli that was also previously used in Li et al's research, we also manipulated the regularity at which stimuli were presented. We reasoned, and found that irregularly presented stimuli should attract more attention and thus be associated with time passing by fast.

Whereas we were able to find the latter effect in the present study, the typical "number-effect" disappeared. Without a comparison frame (i.e., in a between participants design) the sheer number of presented information did not affect the experience of how fast time seems to pass by. On the basis of the present data we can only speculate why this is the case. One possibility would be the influence of number of stimuli on attention allocation is more relative and depends more on comparison, whereas the influence of presentation regularity of stimuli on attention allocation is more absolute and depends less on comparison. However, future research needs to be conducted to test this speculation.

3.5 General Discussion

The present research aimed to disentangle the roles of presentation speed or frequency of stimuli and comparison frame from the role of attention in the processes of judging the speed of time passage. Specifically, two questions were brought to our interest. One question was that in Li et al's research (under review), time was judged as passing faster when more stimuli were presented; however, as the stimuli were presented regularly in this research, when more stimuli were presented, they were also presented faster. Does the presentation speed of stimuli thus also play a role in judging the speed of time? The other question was that if people could still make judgments about the speed of time passage based on attentional processes when doing so in a rather absolute manner (i.e., without a reference frame as provided in a within participants design).

To answer the first question, we manipulated the presentation frequency of stimuli in the first two experiments. In Experiment 1, we found the number effect to prevail over the manipulation of presentation frequency. In fact, we found both presentation frequency and number of stimuli to independently affect the judgments of the speed of time passage. The same holds true for the different (and cleaner) setup we used in Experiment 2: Even if the only difference between conditions was the either frequency or number did we find two independent effects.

Taken together, these results do not only strengthen the argument we brought forth earlier, but do they also generalize our reasoning: Whatever it may be that attracts attention, the sheer number of information or the frequency at which the information is being presented, it may help people to judge how fast time is passing by. Moreover, if there is more detailed information in a cue, like for instance presentation frequency being also a direct cue to speed, people will also use this information in their judgments.

In a comparable manner, we also found the regularity of presentation to affect the judgment of time passage. Irregular stimuli that are presumably more attention grabbing made time seem to pass by faster, even in a between participants design. The latter was used in Experiment 3, originally in order to see how important a reference point is to what we have found. As results of Experiment 3 show, such a reference point seems to be extremely important, as we see our typical results disappear with the comparison frame disappearing.

At first sight, this seems to be a big problem, not only towards the results of the present study but also to the generalizability of our previous experiments: Are our findings nothing more than an artifact of the design we implemented? We do not think so but rather see this fact as an important (natural) moderator: Time passage is a relative judgment by nature! Whenever we judge how fast an event is passing by, we do so in comparison to the same event a couple of days earlier or something alike. What we then do is looking for potential differences that helped us decide which of the two events passed by faster. Stated differently, we would even go thus far as to state that over and above replicating our previous findings, our present findings provide initial support for the notion that judgments of the speed of time passage are relative by nature. That is, people need to have a standard of comparison in order to judge the speed of time in a meaningful way.

Chapter 4

Unpredictability gives time wings

Abstract

Two experiments are reported examining the influence of the unpredictability of events occurring within a time frame. We predicted and found that if the occurrence of an event is unpredictable then time will be judged to be passing faster compared to the same events that are in predictable temporal intervals during the same time interval. In the second experiment, we examined the effect of event sequences whereby the content of an event was manipulated. Again, we predicted and found that when the content of an event changes from event occurrence to event occurrence then time will be judged to be passing faster. The implications of these findings are discussed.

4.1 Introduction

The subjectively experienced speed of time passage has not been much researched. Some early studies (e.g., Janet, 1877, Benford, 1944) have addressed the speed of time passage as a function of age, suggesting that time is perceived to pass faster with age (e.g., Fraisse, 1963, Gallant, Fidler, & Dawson, 1991; Lemlich, 1975), a point asserted by William James (1890) for whom time stood central for psychology. Indeed, it has been suggested that time is perceived to pass faster when we are in a happy state or anticipating an impending negative event (e.g., Reichenbach & Mathers, 1959). Other research by Feifel (1957) and Surwillo (1964) revealed that how time is filled influences the rate at which time is perceived to pass. More recently, Makin and colleagues (2012) demonstrated that auditory click trains increased velocity estimates. Our experience of time and the speed with which we experience the passage of time is strongly shaped by the events that take place during a time frame. Indeed, the more events that take place within a fixed time frame the faster we perceive time passing (Li, Häfner, Garrido, Gallucci, & Semin, under review; Li, Häfner, & Semin, manuscript). As we have argued (Li et al., under review), events taking place within a time frame distract from the monotony of uneventful time frame and an increase in the number of events within any given time interval leads us to perceive time as passing faster. If it is the case that the occurrence of events within a given time frame leads us to a perceive time as passing faster, then other features of such events occurring within a time frame could also contribute to this phenomenon. On the other hand, there are arguments (e.g., Arstila, 2012) that time is perceived to slow down during accidents, although the evidence seems to be primarily anecdotal.

The feature we investigated in the two studies reported here were the unpredictability events occurring within a time frame and their contribution to the perceived speed of time passage. Unpredictability of an event can take two forms, namely, the ‘when’ and ‘what’ of an event. The former, to which we refer as temporal unpredictability, is when some events occur at unexpected points of time. The latter, to which we refer to as content unpredictability, is the occurrence of events that are unexpected. The two studies reported here investigate the effects of these two types of unpredictability upon the perceived speed of time passage. These particular features of events that occur during a time frame have, to our knowledge, not been investigated in the literature on the perceived speed with which time passes. The current contribution consists of two experiments that separately investigate the influence of temporal unpredictability (Experiment 1) and unpredictability (Experiment 2) on people’s perception of the speed of time passage.

Perception of the speed of time passage is a subjective feeling about how fast time is passing. Previous research has shown that it can be systematically influenced by factors such as the amount of information during a fixed interval or how fast the information is presented. Time was shown to be judged as passing faster if more information is presented within a fixed time frame or when the information is presented faster (Li et al., under review; Li et al., manuscript). An attentional model on judgments of the speed of time passage has been proposed to explain the underlying processes of perceiving the speed of time passage. According to this model, people’s attention is divided between *non-temporal information* (i.e., time-unrelated tasks) and *temporal information*. Judgments of the speed of time passage depend on how much attention is paid to temporal information: the less attention is paid to temporal information, the faster time is perceived as passing. The allocation of attention to temporal information varies with the allocation of attention to non-temporal information. The more attention is given to non-temporal information, the less attention is allocated to the temporal information. Accordingly, in the present research, we examined the hypothesis that when events become unpredictable, then they are expected to absorb attentional resources by detracting from the normal flow of time. Unpredictable events absorb attentional resources and thus detract from temporal information. This leads participants to judge time as passing faster during time frame frames, which contain unpredictable events.

In addition to judgments of the speed of time passage, we also examined how unpredictability affects duration judgments (i.e., judgments about how long time lasted). Subjective judgments of duration have long been a central variable in research on the subjective perception of time (see Allman, Teki, Griffiths, & Meck, 2014). Similarly to the research on the judgments of the speed of time passage, attention has also been argued to play an important role in judging duration. Time has been shown to be judged as lasting longer when more attention is paid to temporal information. This argument has been supported by research on duration judgments (Block & Zakay, 1996; Brown, 1997; Frankenhauser, 1959; Macar, 1994; Priestly, 1968; Zakay, Nitzan, & Glicksohn, 1983). This set of findings would support the hypothesis that duration of a temporal event would be judged as shorter in an unpredictable situation – since unpredictability would be expected to detract from the flow of time. Nevertheless, previous research has shown that people judge the duration of an event as loner when an oddball longer occurs than repeated stimuli (Avni-Babad, & Ritov, 2003; Pariyadath & Eagleman, 2007; Schindel, Rowlands, & Arnold, 2011; Tse, Intriligator, Rivest, & Cavanagh, 2004; Ulrich, Nitschke, & Rammsayer, 2006). These findings would suggest that unpredictable stimuli are judged as longer than predictable stimuli. In the two studies reported below we examine the influence of unpredicted events on duration judgments.

4.2 Experiment 1: The influence of temporal unpredictability on judgments of the speed of time passage

The first experiment controlled for the temporal predictability of events by presenting the same stimuli at regular and irregular intervals within a time frame. In the control condition, the stimuli (events) were predictable. In other words, they were presented at fixed temporal intervals. In contrast, in the unpredictable condition, the same stimuli were presented at irregular intervals making it impossible to predict when an event would occur. We expected that time would be judged as passing faster when the same stimuli were presented at irregular intervals. Additionally, we also controlled for the number of stimuli in order to have a more generalized observation of the effect of temporal unpredictability on judgments of the speed of time passage. Previous research has found that time is judged as passing faster when more stimuli are presented (Li et al., under review; Li et al., manuscript). We expected the same effect in this experiment. The resulting design was a 2 (temporal predictability: predictable vs. unpredictable) * 2 (number of stimuli: few vs. many) within-subjects design.

4.2.1 Method

Participants. 85 participants were recruited at Utrecht University. If participants missed two or more duration judgments then they were considered as inattentive and eliminated from the data analyses. Two participants were excluded from the data analyses. The analyses were based on the data from the remaining 83 participants (age M = 21.90, SD = 3.74; 35 males).

Procedure. Stimulus presentation: 30 or 60 stimuli were presented at regular (predictable) or irregular intervals (unpredictable) in a fixed duration of 51 s. The stimuli consisted of synchronized beeps delivered by headphones and circles in the center of the computer screen. The duration of each stimulus was 100 ms.. Two trials were presented for each of the conditions condition resulting in 8 experimental trials. The predictable trials and unpredictable trials were divided into two blocks, and the sequence of the blocks were counterbalanced between subjects — half of the participants had the predictable trials first and the other half of the participants had unpredictable trials first. The trials in each block were randomly presented. The main part of the experiment was preceded by two trials of 30 s with 30 stimuli each. These constituted the practice trials. The stimuli in the practice trials were identical to those presented in the experimental trials. In one trial they were presented at regular intervals and at irregular intervals in the other.

Participants were told the goal of the study was to investigate attention processes. They were informed that they would hear beeps from headphones and watch circles in the center of computer screen simultaneously. Participants pressed the space bar to start each trial. To prevent participants from simply using a counting strategy to estimate a trial's duration, they were also visually presented with two three-digit numerals at random temporal intervals at the bottom of the screen. Participants were asked to read these numerals out loud immediately after they appeared on the screen. Each trial ended with a sound, which was a markedly distinctive one from the stimulus beeps.

After each trial, participants were asked to give their judgments on the speed of time passage (*How fast did time pass when you were doing this trial?*) and on duration (*How long do you think this trial lasted?*). The judgments of the speed of time were given on a 9-point scale (from *1-very slowly* to *9-very fast*), and duration judgments were given by writing down the number of seconds as accurately as possible.

4.2.2 Results

Repeated measures analyses of variance were conducted for each DV (i.e., judgments of the speed of time passage and duration judgments) with temporal predictability and number of stimuli as the two within-subject factors.

Judgments of the speed of time passage

A main effect of temporal predictability was found on judgments of the speed of time passage, F (1, 82) = 4.96, p = .030, η_p^2 = .057, 95% CI [-.60, -.03], showing that time was judged as passing faster in the unpredictable presentation of stimuli condition ($M_{\text{unpredictable}}$ =4.49, SD = .16) than the predictable condition ($M_{\text{predictable}}$ = 4.17, SD = .16;). The effect of number of stimuli was also found significant on judgments of the speed of time passage, F (1, 82) = 34.50, p < .001, η_p^2 = .30, 95% CI [-.97, -.48], showing that time was judged as passing faster when more stimuli were presented (M_{30} = 3.96, SD = .15; M_{60} =4.69, SD = .16). In addition, a significant interaction between temporal predictability and number of stimuli was found, F (1, 82)= 16.93, p < .001, η_p^2= .17. Simple analysis showed that time was judged as passing faster in the unpredictable condition when there were only 30 stimuli (mean difference $_{\text{(regular-irregular)}}$ = -.72, p < .001) but not in the 60 stimuli condition (mean difference $_{\text{(regular-irregular)}}$ = .090, p > .10).

Duration judgments

No main effects of temporal predictability or number of stimuli were found for duration judgments. Whereas the interaction between temporal predictability and number of stimuli was significant, F (1, 82) = 4.29, p = .042, η_p^2 = .050, simple analyses did not reveal any significant effects.

4.2.3 Discussion

Our first study revealed that participants judged time as passing faster when the events occurred in a temporally unpredictable sequence. This finding confirmed our hypothesis that time is judged as passing faster with the experience of unpredictability, and supported the attentional model on judgments of the speed of time passage. Compared to predictable sequences of stimulus presentation, unpredictable presentations of stimuli are assumed to attract more attention, depleting the attention paid to temporal information. Thus, time was judged as passing faster. Aside from that, we also found an effect of number of stimuli on judgments of the speed with which time is perceived to pass. When more stimuli were presented then time was judged as passing faster. This result is consistent with previous findings (Li et al., under review; Li et al., manuscript) supporting the attentional model on judgments of the speed of time passage. Increased number of stimuli attracts more attention depleting the attention paid to temporal information. Thus, time was judged as passing faster.

Interestingly, the effect of temporal predictability was only observed when there were few stimuli in the presentations. It is likely that with few stimuli in a presentation, irregularity becomes more pronounced and more distracting, whereas a high number of stimuli in the same fixed temporal interval take away the irregularity or unpredictability of the stimuli.

Surprisingly, we did not find any effects of temporal unpredictability on duration judgments. Although earlier research has shown that unpredictability leads to longer duration judgments (Ornstein, 1969; Thomas & Brown, 1974) the results of the present experiment did not show any indication of such an effect. This is inconsistent with the finding that the oddball stimulus is judged as lasting longer than repeated stimuli or the attentional model on duration judgments. It is possible that when participants are presented with a series of temporally unpredictable stimuli instead of a single unpredictable stimulus, then their attention stays focused on the single unpredicted event for a longer time and consequently they judge the duration overall as longer. This reasoning converges with the argument (e.g., Arstila, 2012) that time is perceived to slow down during accidents – a typical oddball stimulus condition.

4.3 Experiment 2: How content unpredictability influences judgments of the speed of time passage

The second experiment addressed the question of how the speed of time passage is judged as a function of content unpredictability, namely the occurrence of events in a specific temporal frame that are unexpected. Similar to temporal unpredictability, we hypothesized that people would perceive time as passing faster with content unpredictability than content predictability. We manipulated content predictability by sequentially presenting either the same stimuli or different stimuli. When the same stimuli were presented, participants always knew what next stimulus would be (i.e., predictable content). In contrast, when different stimuli were presented, participants did not know what next stimulus would be (i.e., unpredictable content). Additionally, we also manipulated the number of stimuli. Although we found that the number of stimuli moderated the effect of temporal unpredictability on judgments of the speed of time passage, we reasoned that the number of stimuli would not influence the effect of content unpredictability on judgments of the speed of time passage. This is because even when many stimuli are presented, unpredictable stimulus content sequences present more salient differences compared to temporal unpredictability of the same stimulus sequences. Indeed, the higher the number of temporally unpredictable events that occur within the same temporal interval the less the unpredictability becomes salient. This however does not apply in the case of stimuli, which differ from one moment in time to another. This is expected to attract more attention and thus predicted to lead to a perceived increase in the speed of time passage. The resulting experiment consisted of a 2 (content predictability: predictable vs. unpredictable) * 2 (number of stimuli: 30 vs. 60) within-subjects design.

4.3.1 Methods

Participants. 56 participants (age *M*= 20.73, *SD* = 2.53; 15 males) were recruited from Utrecht University. They participated for course credit or a monetary reward.

Procedure. Synchronized beeps via headphone and circles in the center of the monitor were used as stimuli; the duration of each stimulus was 100 ms.; 30 or 60 stimuli were presented to participants for 51 s at regular intervals; the pitch of beeps and color of circles stayed the same in the predictable condition and changed in random patterns in the unpredictable condition. The trial of each condition was presented twice and distributed across two blocks. In total, participants were presented 8 experimental trials. In each block, trials were randomly presented. Two practice trials preceded the main experimental session and were of 30 s duration. The stimuli in the practice trials were of the same types as those in experimental trials – one was with the same stimuli, and the other was with different stimuli.

The same procedure as Experiment 1 was used in Experiment 2. After each trial, participants were asked to answer the same questions regarding the speed of time passage and duration as in Experiment 1.

4.3.2 Results

Repeated measures analyses of variance were conducted for each DV (i.e., judgments of the speed of time passage and duration judgments) with content predictability and number of stimuli as two within-subject factors.

Judgments of the speed of time passage

The main effect of content predictability on judgments of the speed of time passage was found significant, F (1, 55) = 4.81, p = .033, η_p^2 = .080, 95% CI [.025, .547], showing that time was judged as passing faster with unpredictable stimuli ($M_{\text{predictable}}$ = 4.84, *SD* = .18; $M_{\text{unpredictable}}$ = 5.13, *SD* = .19). The main effect of number of stimuli was also found significant, F (1, 55) = 74.08, p < .001, η_p^2 = .57, 95% CI [1.178, 1.893], showing that time was judged as passing faster when more stimuli were presented (M_{30} = 4.22, *SD* = .20; M_{60} =5.75, *SD* = .19). No interaction was found between content predictability and number of stimuli on judgments of the speed of time passage, F < 1.

Duration judgments

Neither the main effect of content predictability, the main effect for the number of stimuli, nor the interaction between them was found to be significant on duration judgments, *p*s > .10. It was the same pattern of results as in Experiment 1.

4.3.3 Discussion

As in Experiment 1, we found both the effects of unpredictability and number of stimuli on judgments of the speed of time passage. When participants experienced unpredictable stimuli, they perceived time as passing faster. This is consistent with our hypothesis that time is perceived to be faster with unpredictability, and is also congruent with the attention model on judgments of the speed of time passing — when different stimuli were presented, more attention was attracted to the changing of stimuli and less attention was paid to time passage. Therefore, time was judged to be passing faster. In addition, as we expected, this effect was not moderated by the number of stimuli, which supported our hypothesis that different from temporal unpredictability, the effect of content unpredictability on judgments of the speed of time passage was not affected by the number of stimuli.

4.4 General discussion

The present line of research was designed to investigate how unpredictability would influence the people's judgments of the speed of time passage. We hypothesized that time would be judged as passing faster when people experienced unpredictability. We investigated two types of unpredictability, namely temporal unpredictability and content unpredictability on judgments of the speed of time passage, respectively in Experiment 1 and Experiment 2. In Experiment 1, we manipulated temporal predictability by presenting stimuli at regular and irregular intervals. In Experiment 2, we manipulated content predictability by varying the type of stimuli sequentially. In both experiments, we found that time was judged as passing faster in the unpredictable conditions. Particularly, in Experiment 1, we also found this effect was moderated by the number of stimuli — it only appeared when there were few stimuli.

The present findings provide new evidence on a factor that has a major contributory role to play in shaping judgments of the passage of time. Unpredictable features in a person's ecology are very likely to play an important role in their perception of how fast time passes, and this finding can find a wide range of applications in a marketing world, such as advertising for cars where speed is often regarded as an important factor in buying decisions, particularly by male consumers.

Another interesting finding of this research is that temporal unpredictability and content unpredictability showed different effects on judgments of the speed of time passage by the influence of the number of stimuli. In Experiment 1, we found that only when there were few stimuli was time was judged as passing faster in the temporally unpredictable condition. When there were many stimuli, there was no difference on judgments of the speed of time passage between temporally predictable condition and temporally unpredictable condition. In contrast, in Experiment 2, we found that time was judged as passing faster in the unpredictable content condition regardless of the number of stimuli. We argued that is likely that with few stimuli in a presentation, irregularity becomes more pronounced and more distracting when the unpredictable stimuli are the same, whereas a high number of stimuli in the same fixed temporal interval take away the irregularity or unpredictability of the stimuli. In contrast, with content unpredictability, the nature of the stimuli changes on each and every occasion irrespective of whether there are few or many stimuli within the same temporal interval. It is the continuous change or unpredictability both in terms of temporal intervals and the feature sof a stimulus that distracts by being attractive for the senses and makes people loose a sense of time and perceive time as passing fast.

To conclude with a general observation: As the physicist E. Mach (1977) has noted: “it is utterly beyond our power to measure the changes of things by time. Quite the contrary, time is an abstraction, at which we arrive by means of the change of things”. The change can be in any form. For example, it can be external (e.g., seasonal cycle) or internal (e.g., breathing); it can be in long term (e.g., global warming) or in short term (e.g., boil water). These changes are reflections of time, and consist of our perception of the passing of time. In this research, we found that time was judged as passing faster when people experienced changes on both temporal intervals (Experiment 1) and stimuli themselves (Experiment2). These findings further strengthen the relation between the experience of change and time perception.

In conclusion, life is full of unpredictability; compared to predictability, the experience of unpredictability leads people to different reactions, including people’s perception of the speed of time passage — time is perceived as passing faster when you don’t know the timing (when to happen) and the content (what to happen) of the next event. Basically, this faster perception of the passing of time results from the experience of change. It therefore also demonstrates that the experience of change is not only essential for people to perceive time, but also could influence people’s experience of the passing of time.

Chapter 5

Left-To-Right Movements

Accelerate Speed Of Time Passage

Abstract

We examined the perceived speed of time passage as a function of horizontal movements (left-to-right vs. right-to-left). The hypothesis that movements from left to right within the same temporal duration of an event would lead to time being perceived as faster than right-to-left was confirmed in three experiments. This pattern was found to be a reliable but small effect in a meta-analysis. Experiments 2 and 3 were conducted to examine whether writing direction drove this phenomenon. The results obtained from Farsi writers in the Netherlands who were born in Iran (right-to-left) (Exp. 2) and priming participants with a mirror image reading procedure (Exp. 3) proved inconclusive. The possible reasons for the failure to find a reversal of the time-line driven perceived speed of time passage effect are discussed.

5.1 Introduction

The concept of time eludes sensory experience even though we cannot touch, smell, or see it. This invites the question of how we represent time. Interestingly, looking at conceptions of time is examined across cultures reveals a consistent use of spatial representations to ground time. State differently, our language utilizes spatial terms when we refer to time related features, such as a meeting was too long, that New Year is around the corner, that the film had a short break, and so on. Indeed, our gestural references when talking about time are consistent with such a spatial representation. Hence, There seems to be a close relationship between time and space (Majid, Borooditsky, & Gaby, 2014). The question we addressed in the studies reported here was whether features of this close connection between space and time can affect our judgments of the speed of time passage.

In fact, there is research showing that spatial information influences time perception with particular reference to duration judgments, namely judgments about how long an event lasted (e.g., Bottini & Casasanto, 2013; Casasanto & Boroditsky, 2008; Casasanto, Fotakopoulou, & Boroditsky, 2010). For instance, Casasanto and Boroditsky (2008) asked participants to judge the presentation duration of lines of various spatial lengths on the computer screen, and found that participants judged lines with longer length as lasting for longer.

The connection with spatial gestures or gestures referring to space and their influence on time perception is another domain demonstrating the interface between time and space. For instance, Casasanto and Boroditsky (2008) presented participants with growing lines and moving dots, and found that a longer moving distance of growing lines and moving dots was judged as lasting for a longer duration even when the duration of the movements was the same. Another study by Blom and Semin (2013) showed that priming participants with hand arm movements (HAMs) led them to report a distant event they recalled as closer in time if the HAMs were from the left to the right and more distant when the HAMs were from the right to the left. However, these two studies, to our knowledge, constitute exceptions, because there is not any other research on spatial movements and time perception. Although the spatial grounding of time (Lakoff & Johnson, 1999) can be noted in the everyday language we use when talking about time (Boroditsky, 2000; Boroditsky & Gaby, 2010; Boroditsky & Ramscar, 2002; Casasanto & Boroditsky, 2008; Matlock, Ramscar, & Boroditsky, 2005), its directionality seems to be influenced by writing direction (e.g., Boroditsky, 2001, 2011; Boroditsky, Fuhrman, & McCormick, 2010; Chan & Bergen, 2005). English speakers were faster in classifying events as having occurred “earlier” when they pressed a left compared to a right response key, Hebrew speakers, who write from right to left, were predicted and found to be faster in classifying earlier events with a right compared to a left response key (Fuhrman & Boroditsky, 2010). In line with these findings, a study on the relation between writing direction and classifying auditory presented time-related words found that responses of Spanish and English participants (left-to-right writing cultures) were faster to past (future) words with the left (right) hand, whereas the opposite held for Hebrew participants (Ouellet, Santiago, Israeli, & Gabay, 2010). Moreover, categorization of past and future words is faster when the key to be pressed and the position of the words on the screen are congruent with the left-to-right timeline (Santiago, Lupianez, Perez, & Funes, 2007). For instance, activating past or future words primes attention and motor responses to the left and right (Ouellet, Santiago, Funes, & Lupianez, 2010). In general, a spatial left-to-right mental timeline is thus commonly used in the West (Ouellet, et al., 2010; Weger & Pratt, 2008), where “the left” is associated with earlier times and “the right” with later times.

This dovetails with research on how we process spatial movements and their influence on our judgments. A typical finding is that people show a left-to-right bias at cognitive, social and neural levels. For example, research on representation momentum suggests that people remember the moving distance of objects as further in their path of motion than the actual case (Freyd & Finke, 1984; Hubbard, 2005), and this effect was found was to be stronger if the motion was from left to right (Halpern & Kelly, 1993). Maass and colleges found that people rated left-to-right actions as faster, more powerful and more beautiful than right-to-left actions (Maass, Pagani, & Berta, 2007). In the domain of time perception, it was found that people tended to project the past on the left and the future on the right (Santiago, Pérez, Lupiáñez, Funes, 2007), which suggests a flow of time from left to right.

Extrapolating from these research areas and by combining it with the work on the spatial agency bias we developed specific hypotheses about the perceived speed of time passage. Spatial Agency Bias describes the tendency to associate targets … to specific spatial features in a visual representation according to the agency they express. Agency is defined from a cognitive point of view as the role of being the agent of an action and from a social point of view as the potential to act socially, often measured in terms of power or social status." (Suitner and McManus, 2011, p. 280, in Schubert and Maass, 2011). This bias is assumed to be driven by reading and writing experiences and these experiences are also regarded as the source of a left-to-right bias in cognition (Chatterjee, 2011; Maass & Russo, 2003; Maass et al., 2007; Spalek & Hammad, 2005; Tversky, Kugelmass, & Winter, 1991). The evidence in favor of this (also cultural) bias comes mainly from cross-cultural research, which shows a reversed bias (right-to-left bias) in cultures where languages are written from right to left (e.g., Arabic, Hebrew). For example, Maass et al. (2007) found that with Arabic speakers' right-to-left actions were judged as faster, more powerful and more beautiful. It was also found events that follow a temporal sequence (e.g., breakfast, lunch and dinner) were ordered in a rightward horizontal line by English speakers, but in a leftward horizontal line by Arabic speakers (Tversky et al., 1991). These findings suggest that people writing from the left to the right are more likely to perceive time as passing faster when perceiving left-to-right movements than right-to-left movements, The reverse would be expected from people having a right to left writing culture. They would perceive time as passing faster with right-to-left movements than left-to-right movements.

The current research was driven by these considerations and examined the following hypothesis. If participants are exposed to a left-to-right movement during a fixed temporal duration then they will perceive time as passing faster as compared to a no movement condition or, for that matter, a right to left movement during the same objective duration. In short, we hypothesized that people would judge time as passing faster when they experienced left-to-right movements than right-to-left movements.

5.2 Experiment 1

In the first experiment, we manipulated the direction in which a circle on the computer screen moved (left-to-right vs. right-to-left). We expected that time would be judged as passing faster if the circle moved from the left-to- the right rather than right-to-left movements. In addition, a static circle in the center of the computer screen was included as a baseline condition. We hypothesized that time would be judged as passing slower for the static circle than the moving circles. This hypothesis was derived from the attentional model on judgments of the speed of time passage (Li, Häfner, Garrido, Gallucci, & Semin, manuscript submitted for publication). According to this model, time is judged as passing faster when less attention is paid to temporal information. Aside from manipulating the direction of movements, we also manipulated the duration of movements (10 s, 15s, 20 s) to be able to generalize the possible effect of direction of movement on judgments of the speed of time passage.

5.2.1 Method

Participants. 31 participants (M_{age} = 22.32, SD = 4.25; 22 females) were recruited from Utrecht University in exchange for course credit or monetary rewards.

Procedure. A 3 (direction of movements: left-to-right vs. right-to-left vs. static) * 3 (duration of movements: 10 s, 15 s, 20 s) within-subjects design was utilized. In total, 9 experimental trials were presented to participants. In each trial, a circle was either moving from left to right or from right to left at a constant speed in a horizontal line across the center of the computer screen, or being static in the center of the computer screen; the movement or the static circle lasted for 10 s, 15 s or 20 s on the computer screen. To create variety of movements, another two directions of movement: up-to-down and down-to-up were included as filler conditions. In each trial, a circle was moving at a constant speed in a vertical line across the center of the computer screen for 10 s, 15 s or 20 s. In total, 6 filler trials were presented. The filler trials were randomized with the 9 experimental trials during the presentation. In addition, to familiarize the participants with the task, five practice trials preceded the main trials. The circles in the five trials were presented in the five direction with different duration: from left to right, from right to left, from up to down, from down to up, and static for 10 s, 20 s, 15 s, 20 s and 20 s, respectively. After each trial, participants were asked to indicate how fast they thought time was passing during the trial by answering the question: *How fast do you think time was passing during this trial?* Participants could indicate their answers on a 9-point scale (from 1-*very slowly* to 9-*very fast*).

5.2.2 Results

Repeated measures analyses of variance were conducted for judgments of the speed of time passage with direction of movements and duration of movements as two independent variables.

The effect of direction of movements on judgments of the speed of time passage was found to be significant, F (2, 60) = 10.57, p < .001, η_p^2 = .26, showing that time was judged as passing faster for the moving circles than for the static circles, and more importantly, time was judged as passing faster for the left-to-right movements than the right-to-left movements ($M_{\text{left-to-right}}$ = 5.13, SD = .20; $M_{\text{right-to-left}}$ = 4.71, SD = .21; M_{static} =3.93, SD = .28). The main effect of duration of movements was also found to be significant for judgments of the speed of time passage, F (2, 60) = 90.69, p < .001, η_p^2 = .75, showing that time was judged as passing faster for shorter duration ($M_{10\text{ s}}$ = 5.62, SD = .21; $M_{15\text{ s}}$ = 4.53, SD = .19; $M_{20\text{ s}}$ = 3.61, SD = .17). The interaction between direction of movements and duration of movements was also found significant, F (4, 120) = 3.67, p = .007, η_p^2 = .11. Simple analyses revealed that when the duration of movements was 10 s, time was judged as passing faster for the moving circles than the static circles, and time was judged as passing faster for the left-to-right movements than the right-to-left movements ($M_{\text{left-to-right}}$ = 6.32, SD = .26; $M_{\text{right-to-left}}$ = 5.90, SD = .25; M_{static} = 4.65, SD = .38); when the duration of movements was 15 s, time was judged as passing faster for the moving circles than the static circles, but no difference of judgments of the speed of time passage was found between the moving circles ($M_{\text{left-to-right}}$ = 5.10, SD = .22; $M_{\text{right-to-left}}$ = 4.65, SD = .24; M_{static} =3.84, SD = .29); when the duration of movements was 20 s, time was judged as passing faster for the left-to-right movements than the right-to-left movements and static circles; no other difference on judgments of the speed of time passage was found ($M_{\text{left-to-right}}$ = 3.97, SD = .20; $M_{\text{right-to-left}}$ = 3.58, SD = .23; M_{static} =3.29, SD = .27).

5.2.3 Discussion

As expected, we found that time was judged as passing faster with left-to-right movements than right-to-left movements. This finding supported our hypothesis that although spatial movements seemed to have no influence on duration judgments[1], they could influence people's judgments of the speed of time passage. These findings support the idea that if the movement of an object (e.g., a circle in this case) is congruent with the cultural direction in which the spatial agency bias is anchored, then it is perceived as moving faster (which we did not measure, but assumed) thus influencing judgments of the speed of time passage. In the following two experiments, we investigated the possible causes of this effect.

5.3 Experiment 2

In this experiment, we examined the possible role of reading and writing experiences in the effect that we found in Experiment 1. Previous research has attributed the left-to-right bias to reading and writing experiences, and showed that the left-to-right bias can be reversed with participants who read and write from right to left (Chatterjee, 2011; Maass & Russo, 2003; Maass et al., 2007; Spalek & Hammad, 2004; Tversky et al., 1991). Here, we examined if the left-to-right bias on judgments of the speed of time passage would be influenced in participants who had right-to-left reading/writing experiences. Specifically, two manipulations were included. In one condition, similar to previous research, we recruited participants from the culture where people read and write from right to left (i.e., Persian speakers); in the other condition, we introduced the manipulation: mirror reading to induce right-to-left reading experiences to Dutch participants. This manipulation has been used by Casasanto and Bottini (2014) and found to be effective in reversing people's mental timelines.

5.3.1 Method

[1] We also conducted the same experiment with duration judgments as dependent variables. No effect of direction of movements was found on it.

Participants. 97 participants (M_{age} = 24.34, SD = 5.64; 43 females) were recruited from Utrecht University in exchange for course credit or monetary rewards, among which 66 participants were native Dutch speakers, and 31 participants were Farsi speakers in the Netherlands who were born in Iran. Half of the Dutch participants (33) were in the standard condition where they had to read a text from left to right. The other half of Dutch participants were in the mirror reading condition where they had to read from right to left with mirror-reversed letters.

Procedure. A 3 (direction of movements: left-to-right vs. right-to-left vs. static) * 3 (duration of movements: 10 s, 15 s, 20 s) * 3 (reading type: Dutch normal reading, Farsi reading, Dutch mirror reading) mixed design was used, with direction of movements and duration of movements as two within-subject factors and reading type as a between-subject factor. Three groups of participants were recruited. Each group of participants had to complete two tasks: the reading task and the time judgments task. In the reading task, participants were asked to read two texts that were selected in advance. The criteria for the selection of the texts were that their content was neutral as possible. One text was about safety practices during storms, and the other was about how to get a good sleep (see additional materials). In the Dutch, normal reading condition, and Farsi reading condition, the texts were presented in Dutch and Farsi, respectively; in the Dutch mirror reading condition, the texts were presented in Dutch but in a mirror-reversed manner, therefore participants needed to read from right to left with mirror-reserved letters. After each text, participants were asked to recall what they had read and write them down on papers in the Dutch normal reading condition and Farsi reading condition. It was unreasonable to expect participants in the Dutch mirror reading condition to write in mirror-reversed manner. Instead they were asked to indicate if two statements about the text were true or false.

After the reading task, participants were asked to finish the same time judgments task as that in Experiment 1.

5.3.2 Results

Repeated measures analyses of variance were conducted for judgments of the speed of time passage with direction of movements and duration of movements as two within-subject variables and reading type as a between-subject variable.

Main effects

The effect of direction of movements was found significant on judgments of the speed of time passage, F (2, 188) = 38.56, $p < .001$, $\eta_p^2 = .29$, showing that time was judged as passing faster for the moving circles than the static circles; moreover, time was judged as passing faster for the left-to-right movements than the right-to-left movements ($M_{\text{left-to-right}} = 4.55$, $SD = .13$; $M_{\text{right-to-left}} = 4.38$, $SD = .14$; $M_{\text{static}} = 3.20$, $SD = .19$). The main effect of duration of movements on judgments of the speed of time passage was also found significant, F (2, 188) =194.44, $p < .001$, $\eta_p^2 = .67$, showing that time was judged as passing faster for shorter duration than longer duration ($M_{10\text{ s}} = 5.11$, $SD = .16$; $M_{15\text{ s}} = 4.03$, $SD = .13$; $M_{20\text{ s}} = 3.00$, $SD = .12$).

Two-way interaction

The interaction between direction of movement and reading type was found to be significant, F (4, 188) = 2.75, p = .030, $\eta_p^2 = .055$. Simple analysis showed that in the Dutch normal reading condition, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 4.73$, $SD = .23$; $M_{\text{right-to-left}} = 4.59$, $SD = .24$; $M_{\text{static}} = 3.84$, $SD = .32$); in the Farsi reading condition, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}}$ = 4.60, SD = .24; $M_{\text{right-to-left}}$ = 4.54, SD = .24; M_{static} = 2.65, SD = .33); in the Dutch mirror reading condition, time was judged as passing faster for the moving circles than the static circles, and moreover, time was judged as passing faster for the left-to-right movements than the right-to-left movements ($M_{\text{left-to-right}}$ = 4.31, SD = .23; $M_{\text{right-to-left}}$ = 4.02, SD = .24; M_{static} = 3.12, SD = .32).

The interaction between direction of movement and duration of movement was also found significant, F (4, 376) = 13.84, $p < .001$, $\eta_p^2 = .13$. Simple analysis revealed that when the duration of movements was 10 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found significant on judgments of the passing speed of time ($M_{\text{left-to-right}}$ = 5.80, SD = .17; $M_{\text{right-to-left}}$ = 5.65, SD = .18; M_{static} = 3.87, SD = .25); when the duration of movements was 15 s, time was judged as passing faster for the moving circles than the static circles, and moreover, time was judged as passing faster for the left-to-right movements than the right-to-left movements ($M_{\text{left-to-right}}$ = 4.55, SD = .16; $M_{\text{right-to-left}}$ = 4.31, SD = .15; M_{static} = 3.23, SD = .21); when the duration of movement was 20 s, time was judged as passing faster for the moving circles than the static circles, and no other difference on judgments of the passing speed of time was found ($M_{\text{left-to-right}}$ = 3.30, SD = .15; $M_{\text{right-to-left}}$ = 3.19, SD = .14; M_{static} = 2.51, SD = .16).

Three-way interaction

The three-way interaction between direction of movements, duration of movements and reading type was found to be significant, F (8, 376) = 3.37, p = .001, $\eta_p^2 = .067$. Simple analysis showed that in the Dutch normal reading condition, when the duration of movements was 10 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}}$ = 5.76, SD = .28; $M_{\text{right-to-left}}$ = 5.58, SD = .30; M_{static} = 4.70, SD = .43); when the duration of movements was 15 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 4.76$, $SD = .27$; $M_{\text{right-to-left}} = 4.76$, $SD = .26$; $M_{\text{static}} = 3.61$, $SD = .36$); when the duration of movements was 20 s, no difference was found on judgments of the speed of time passage between any conditions ($M_{\text{left-to-right}} = 3.67$, $SD = .26$; $M_{\text{right-to-left}} = 3.42$, $SD = .24$; $M_{\text{static}} = 3.21$, $SD = .28$). For the Farsi reading condition, when the duration was 10 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 6.07$, $SD = .29$; $M_{\text{right-to-left}} = 6.03$, $SD = .31$; $M_{\text{static}} = 3.07$, $SD = .44$); when the duration was 15 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 4.61$, $SD = .27$; $M_{\text{right-to-left}} = 4.32$, $SD = .27$; $M_{\text{static}} = 2.74$, $SD = .37$); when the duration was 20 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 3.13$, $SD = .27$; $M_{\text{right-to-left}} = 3.26$, $SD = .25$; $M_{\text{static}} = 2.13$, $SD = .29$). For the Dutch mirror reading condition, when the duration of movements was 10 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 5.58$, $SD = .28$; $M_{\text{right-to-left}} = 5.33$, $SD = .30$; $M_{\text{static}} = 3.85$, $SD = .43$); when the duration of movements was 15 s, time was judged as passing faster for the left-to-right movements than the right-to-left movements and static circles, and no other difference was found ($M_{\text{left-to-right}} = 4.27$, $SD = .27$; $M_{\text{right-to-left}} = 3.85$, $SD = .26$; $M_{\text{static}} = 3.33$, $SD = .36$); when the duration of movements was 20 s, time was judged as passing faster for the moving circles than the static circles, and no other difference was found ($M_{\text{left-to-right}} = 3.09$, $SD = .26$; $M_{\text{right-to-left}} = 2.88$, $SD = .24$; $M_{\text{static}} = 2.18$, $SD = .28$).

5.3.3 Discussion

In this experiment, we aimed to examine if the left-to-right bias on judgments of the speed of time passage was influenced by reading and writing experiences. Participants read either from left to right (Dutch normal reading) or from right to left (Farsi reading, Dutch mirror reading) in the experiment. It was found that Farsi speakers showed no bias when they judged the speed of time passage between left-to-right movements and right-to-left movements. This result was inconsistent with previous findings that the left-to-right bias is reversed in the culture where people read and write from right to left. It suggests that the observed left-to-right bias on judgments of the speed of time passage might be different from other left-to-right biases that have been shown by earlier research. Another explanation for this result would be that as we recruited Farsi speakers in the Netherlands who are experienced left-to-right readers and writers. It is therefore likely that the right-to-left bias induced by Farsi reading/writing and the left-to-right bias from English/Dutch reading/writing balanced each other out. Recruiting native Farsi speakers who have no experience with left-to-right reading and writing could test this possibility.

Interestingly, it was found that Dutch speakers also showed the left-to-right bias even when they were in the mirror reading condition, which suggests that right-to-left reading experience didn't influence their judgments of the speed of time passage. Taken together the results from Farsi reading condition and Dutch mirror reading condition suggests that reading and writing experiences didn't play a significant role in the observed left-to-right bias on judgments of the speed of time passage.

5.4 **Experiment 3**

In this experiment, we intended to further examine the role of mental timeline in the observed effect of spatial direction of movements on judgments of the speed of time passage. People's mental timeline has been suggested by previous research to flow from left to right (Casasanto & Jasmin, 2012; Cienki, 1998; Santiago et al., 2007; Tversky et al, 1991). If people's mental timeline can be reversed that an opposite effect could be observed. Thus, if people were to represent the past on the right and the future on the left with a more powerful manipulation than mirror writing as in the previous experiment (Casasanto & Bottini, 2014) then could the perceived difference in the perceived speed with which time passes be reversed?

To this end, we primed participants with a categorization task where they were to categorize past-related words (e.g., yesterday) with the right response key and future related words (e.g., tomorrow) with a left response key. This manipulation was expected to reverse the mental timeline and thus reverse the findings we found in the first experiment. Movements of a circle from the right to the left instead of left to right were expected to lead to participants judging time in the former event as passing faster than the reverse.

5.4.1 Method

Participants. 149 participants (M_{age} = 20.67, SD = 5.67; 64 males) were recruited from Utrecht University in exchange for course credit or monetary rewards, among which 50 participants were in the no priming condition, 49 participants were in the *left-past* priming condition, and 50 participants were in the *right-past* priming condition.

Procedure. A 3 (direction of movements: left-to-right vs. right-to-left vs. static) * 3 (duration of movements: 10 s, 15 s, 20 s) * 3 (priming: no priming, left-past priming, right-past priming) mixed design was used, with direction of movements and duration of movements as two within-subject factors and priming as a between-subject factor. Participants were assigned to different priming conditions with a counterbalanced order. In the no priming condition, participants only finished the time judgments task; in the priming conditions, before the time judgments task, participants were asked to finish a lexical categorization task. In the lexical categorization task, 15 past-related words and 15 future-related words (see additional materials) were presented to participants one by one. Each word was presented twice. The order of the presentation of words was randomized.

In the control condition, left key press was used for classifying past words and right key press for future words. In the *left-past* priming condition, participants were asked to press the left key (key Z in the keyboard) in response to the past-related words and the right key (key M in the keyboard) in response to the future-related words. In the *right-past* priming condition, participants had to press the right key in response to the past-related words and the left key in response to the future-related words. In the right-past priming condition the reverse was the case. 12 additional words (6 past-related words and 6 future-related words) were presented as practice trials for participants.

After the lexical categorization task, participants were asked to finish the time judgments task. In the time judgments task, the same 9 experimental trials as those in Experiment 1 were randomly presented to participants. After each trial, participants were asked to judge how fast they thought time was passing during the trial by answering the question: *How fast do you think time was passing during this trial?* Participants indicated their answers on a 9-point scale (from 1-*very slowly* to 9-*very fast).*

5.4.2 Results

Repeated measures analysis of variance was conducted for judgments of the speed of time passage with direction of movements and duration of movements as two within-subject variables and priming as a between-subject variable.

The effect of direction of movements was found marginally significant on judgments of the speed of time passage, F (2, 292) = 2.55, p = .080, η_p^2 = .017, showing that time was judged as passing faster for the left-to-right movements ($M_{\text{left-to-right}} = 3.92$, $SD = .11$) than the right-to-left movements ($M_{\text{right-to-left}} = 3.80$, $SD = .11$) and static circles ($M_{\text{static}} = 3.63$, $SD = .14$); no other difference was found. The main effect of duration of movements was also found significant on judgments of the speed of time passage, $F\ (2, 292) = 268.67$, $p < .001$, $\eta_p^2 = .65$, showing that time was judged as passing faster for shorter duration than longer duration ($M_{10\text{ s}} = 4.77$, $SD = .10$; $M_{15\text{ s}} = 3.75$, $SD = .11$; $M_{20\text{ s}} = 2.83$, $SD = .11$). Besides, the interaction between direction of movements and duration of movements was found significant, $F\ (4, 584) = 6.92$, $p < .001$, $\eta_p^2 = .045$. Simple analyses revealed that when the duration of movements was 10 s, time was judged as passing faster for the moving circles than the static circles, but no difference was found between the left-to-right movements and the right-to-left movements ($M_{\text{left-to-right}} = 4.93$, $SD = .12$; $M_{\text{right-to-left}} = 4.98$, $SD = .13$; $M_{\text{static}} = 4.40$, $SD = .18$); when the duration of movements was 15 s, time was judged as passing for the left-to-right movements than the right-to-left movements and static circles, but no difference was found between right-to-left movements and the static circles ($M_{\text{left-to-right}} = 4.01$, $SD = .13$; $M_{\text{right-to-left}} = 3.65$, $SD = .13$; $M_{\text{static}} = 3.58$, $SD = .16$); when the duration of movements was 20 s, no difference of judgments of the speed of time was found between the three conditions ($M_{\text{left-to-right}} = 2.81$, $SD = .12$; $M_{\text{right-to-left}} = 2.78$, $SD = .13$; $M_{\text{static}} = 2.90$, $SD = .15$). No other effects were found significant.

Additionally, a planned comparison was performed for the right-past priming condition with direction of movements and duration of movements as two independent variables. The effect of direction of movement on judgments of the speed of time passage was not significant, $F < 1$. The effect of duration of movements on judgments of the speed of time passage was found significant, $F\ (2, 98) = 142.86$, $p < .001$, $\eta_p^2 = .75$. Furthermore, the interaction between direction of movements and duration of movements was also found significant, $F\ (4, 196) = 2.57$, $p = .039$, $\eta_p^2 = .050$. Simple analysis revealed that when the duration was 15 s, time was judged as passing faster for the left-to-right movements than the right-to-left movements ($M_{\text{left-to-right}}$ = 3.86, *SD* = .19; $M_{\text{right-to-left}}$ = 3.40, *SD* = .23), and the judgments for the left-to-right movements were slightly higher (marginally significant) than the static circles (M_{static} =3.36, *SD* = .24). No other difference was found.

5.4.3 Discussion

In this experiment, we aimed to examine if the direction of people's mental timelines influenced the observed left-to-right bias on judgments of the speed of time passage. Across three priming conditions, we again found that time was judged as passing faster when there was a left-to-right movement than a right-to-left movement Furthermore; the priming manipulations did not have any effect. The planned comparison revealed that even when the past (future) was manipulated to map to the right (left) explicitly, time was still judged as passing faster with the left-to-right movements than the right-to-left movements (in the 15 s duration condition). This result suggests that the manipulated directions of mental timelines had no influence on the left-to-right bias on judgments of the speed of time passage. The findings from this experiment also confirmed the result from Experiment 2 that the left-to-right bias on judgments of the speed of time passage were not influenced by mirror reading which could reverse people's metal timelines.

5.5 Meta-analysis

To examine the stability of the effect of spatial direction on judgments of the speed of time passage, we conducted another two replication studies with the same design as in Experiment 1. In one study, we again observed the left-to-right bias on judgments of the speed of time passage ($M_{\text{left-to-right}}$ = 4.72, *SD* = .26;

$M_{\text{right-to-left}} = 4.49$, $SD = .31$), $F(1, 34) = 3.86$, $p = .058$, $\eta_p^2 = .10$. In the further study, we found the pattern of the effect ($M_{\text{left-to-right}} = 4.72$, $SD = .25$; $M_{\text{right-to-left}} = 4.41$, $SD = .30$), but it was not significant, $F(1, 25) = 2.59$, $p = .12$, $\eta_p^2 = .094$. Similar results appeared in the normal reading condition in Experiment 2 and in the no priming condition in Experiment 3. To further verify the observed left-to-right bias on judgments of the speed of time passage, a meta-analysis was conducted with the results from these five experiments (see Table 1 for the overview of the raw effects).

Table 1 Overview of the raw effects

Experiment	Sample	Mean difference	Standard Error	*p*	Hedges's *g*
1a	31	0.419	0.152	0.010	0.481
2	50	0.113	0.089	0.212	0.176
3	33	0.141	0.116	0.232	0.207
R1	35	0.238	0.121	0.058	0.324
R2	26	0.308	0.191	0.120	0.306

Note. R1 represents the first replication study; R2 represents the second replication study. Mean difference = mean difference of judgments of the speed of time passage between left-to-right movements and right-to-left movements.

Calculation of effect sizes. Hedges's *g*, which is a variation of Cohen's *d*, was chosen as the effect size because it can correct the slight bias from small samples, and is therefore considered a more conservative effect size measure (Hedges, 1981; Hedges & Olkin, 1985). It can be computed from mean difference, standard error and sample size. The interpretation of Hedges's *g* can adopt Cohen's suggestions to Cohen's *d* (Cohen, 1988): an effect size of 0.2 to 0.3 is a small effect, around 0.5 a medium effect, and 0.8 to infinity a large effect. Effect size was computed for each comparison (see Table 1).

Meta-analytic computations. Two statistical models are available for meta-analysis, the *fixed-effect model* and the *random-effect model*. According to Hedges and Vevea (1998), the fixed-effect model is appropriate for the inferences that extend only to the studies included in the meta-analysis, whereas the random-effect model is appropriate for the inferences that generalize beyond the studies included in the meta-analysis. Because the current meta-analysis only intended to make inference of the effect-size parameters in the five experiments we have done, fixed-effect models were chosen for the overall analysis and subsequent analysis. All analyses were conducted using *Comprehensive Meta-Analysis 2.0* program.

Results. The mean effect size based on a fixed-effect model was found to be $g = .28$; the 95% confidence interval (95% CI) was .13 (lower) to .43 (upper), which had a significant associated z score ($z = 3.73$, $p < .001$). According to Cohen's criterion, this can be considered a small effect. A chi-square test of homogeneity of effect size was not significant, χ^2 (4) = 1.99, $p = .737$, which indicated that the studies can reasonably be described as sharing a common effect size (Hedges & Vevea, 1998). Overall, the meta-analysis results confirmed our finding that time is judged as passing faster with left-to-right movements than right-to-left movements; furthermore, it showed the effect of spatial direction on judgments of the speed of time passage as a weak effect. It could therefore explain the missing effects in some of our experiments.

5.6 General Discussion

The present research was set out to investigate the influence of spatial directions of movements on judgments of the speed of time passage. It was found that time was judged as passing faster with left-to-right movements than right-to-left movements. This effect was proved as a reliable small effect by the meta-analysis. This finding added new evidence to the well-demonstrated left-to-right bias that appears in human's cognitive, social and neural reactions; specifically, it suggests that people's left-to-right bias on time perception occurs not only on spatial configuration (left vs. right) but also on spatial movements (left-to-right vs. right-to-left). Moreover, it was found that this left-to-right bias on judgments of the speed of time passage was not influenced by either reading/writing experiences or the direction of mental timelines. These findings leave us to the question that what exactly causes the current finding of the left-to-right bias on judgments of the speed of time passage.

Reading and writing experiences have been argued to cause the left-to-right bias in cognition with evidence from various research (Chatterjee, 2011; Maass & Russo, 2003; Maass et al., 2007; Spalek & Hammad, 2004; Tversky et al., 1991). However, from the present research we found no evidence that writing and reading experiences influenced the left-to-right bias on judgments of the speed of time passage. Two possible arguments could be formed from these findings. First, it suggests that the observed left-to-right bias on judgments of the speed of time passage did not result from people's reading and writing experiences, therefore when people experienced right-to-left reading (Farsi reading, Dutch mirror reading), they didn't show a right-to-left bias. However, as the Farsi speakers in the present research have also well experienced the left-to-right reading and writing (English and/or Dutch), it gives rise to the other possible argument: left-to-right reading and writing experiences caused the observed left-to-right bias on judgments of the speed of time passage; with the Farsi participants, however, the effects of left-to-right reading and writing experiences and right-to-left reading and writing experiences might have balanced out, which resulted in none effect on judgments of the speed of time passage. Previous research has showed similar results (Maass & Russo, 2003; Morikawa & Mcbeath, 1992). For example, Maass and Russo (2003) found that Arabic participants who lived in Italy showed no bias when they drew agents and recipients on the left or right, whereas Italian participants showed left-agents/right-recipients preference and Arabic participants who lived in Arab showed right-agents/left-recipients preference. This possibility could be examined by recruiting Farsi speakers who have no experience with left-to-right reading and writing. Overall, it is not conclusive about what roles of reading and writing experiences are playing in the observed left-to-right bias on judgments of the speed of time passage with the present findings. Future research needs to test this question more carefully.

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Nederlandse Samenvatting

In ons dagelijkse leven voelt het vaak alsof de ene dag snel verstrijkt, terwijl de andere dag juist heel lang lijkt te duren. Hoe komt het dat mensen soms voelen alsof de tijd sneller gaat in sommige situatie en langzamer in andere situaties, zelfs wanneer de werkelijke tijdsduur hetzelfde is? Welke factoren beïnvloeden de perceptie van de snelheid van tijd? Het onderzoek in deze PhD thesis had als doel om deze vragen te beantwoorden. Voor alle experimenten werd gevonden dat aandacht een belangrijke rol speelt bij het beoordelen van de snelheid van tijd. Wanneer externe stimuli meer aandacht trekken geeft men aan dat de tijd sneller verstrijkt. Bovendien werd het gevonden dat de subjectieve perceptie van de snelheid van tijd systematisch beïnvloed kan worden door externe factoren, zoals de hoeveelheid informatie en de presentatiesnelheid van deze informatie. Deze resultaten suggereren dat, alhoewel de snelheid van tijd onderhevig is aan subjectieve perceptie, het mogelijk is om dit te manipuleren. Restaurants zouden bijvoorbeeld meer informatie kunnen presenteren aan mensen in de wachtrij om de tijd als sneller te laten ervaren.

Acknowledgements

Time goes fast. Even though I have spent four years investigating how people perceive the speed of the time passage, as what is presented in this book, I still can't help myself being impressed by how fast it can go. I can clearly remember every detail from the first day of my arrival in Utrecht, and now, a moment later my adventure in this foreign city is coming to an end. It has not been an easy journey. Therefore, I would like to take this opportunity to thank all those who have encouraged me, supported me and helped me while making my way through it.

First of all, my thanks go to my supervisor Gün Semin. Thank you for having me here and bringing me to the world of social psychology. It was an interesting experience to live in a different culture and embark on research in a new area. Thank you for giving me the opportunity to challenge my weaknesses and turn them into strengths. It was rough but I learned very much. I appreciate your contribution to my growth during these four years, and wish for the chance to learn more from you in the future.

I thank most my supervisor Michael Häfner. Without your help, I can't imagine that this book could be finished so smoothly. Although we have only worked together for two years, it was a great time. I enjoyed every meeting we had. It was always a combination of relief and inspiration. You have been very caring and supportive. I could not thank you enough for your help on finishing my PhD thesis. I look forward to continuing our friendship in the future.

I would like to thank my dear colleagues from SOP. Esther P, you are the first person that I can think of whenever I had met problems that I didn't know how to deal with. You have been so kind to give me helpful advice and encourage me to explore possibilities. Many thanks. Erik, you are an intelligent and fun friend. Thanks for your help on my work. I really appreciate it. Robert, although most of the time your words are mean, they don't conceal your kind heart. It was good to have you as a colleague. Henk, thank you for trying to help me out in the end. It was a great comfort and much appreciated. Esther K and Toon, thank you for your concern and kind offer of help when I was finishing my thesis. Madelijn, thanks for helping me out on my data analysis and commenting on my research proposal. It was really helpful. Hagar and Gerdientje, Anouk and Clare, Florien, Michelle and Chantal, it was very nice to meet you girls in the department. You have been very helpful and supportive during my stay, thank you. Hans, Peter, Mike, Jasper and Baran, it was fun to have you guys around and I appreciate your help with solving the questions that I encountered during my work. Thanks Gaby, Katharina, Kees, Larry, Myrthel, Ron, Tom D and Tom F for the fun times in the department. Special thanks to my friends Yuru and Qiao. Your presence in the department made it feel more like home.

Besides, I want to thank Daniel Casasanto, Vincent Buskens, Rense Corten and Keon Franken for their contribution to my research. Daniel Lakens, thank you for your help and care when I was in trouble. Hans Ijzerman and Sander Koole, it was good to have the chance to benefit from your experiences. I would like to also thank my reading committee: Prof. dr. Theo Wubbels, Prof. dr. Daniel Wigboldus, Prof. dr. Toon Taris, Prof. dr. Monique Smeets, Prof. dr. Kai J.Jonas and Prof. dr. Wilco van Dijk for your effort and helpful comments. Tineke, Janet, Karima, Amal and Karin also thank you for being the support team.

I want to thank all my dear friends. It was a great fortune for me to know you guys during my stay in Utrecht. Hande and Stephanie, I had so much fun with you in the past four years. Hande, you are such a generous, caring and fun person. You were always there when I needed help. Stephanie, you are so sweet and special. I can share a lot with you and always get inspired. I am so glad to know you girls here. Many thanks for your company in the past. I want to thank my friends Shiwei, Cui Can, Xueqing, Jinqiang, Wentao, Yihong, Huang Xu, Jianxi, Wenhao, Yafei, Li Shuai, Jin

Shuang, Shi Yang, Dali, Chen Bin, Zhang min, Li Xin, Qiushi and Hu Hong. I enjoyed all our dinner parties and outing. It is a great memory of my stay in Utrecht. I believe no matter where we will be in future, our friendship will continue. Thank you my dear roommates Ke Yi, Sijie, Yipu and Chaozhong for giving me a sweet home in this foreign city. I enjoyed our cooking and hanging out together very much. Yongking and Lijie, our time together was mixed with work and life. It was always helpful and fun, many thanks. Wanyi, Wencui and Huadong: our trip was a great experience and I miss those times very much. Dear Fangxia, Junhui, Yujie, your presence made me feel much less lonely in the KLI. Good luck with your future work. Li Qian, we knew each other before we came to the Netherlands and we have supported each other through the difficulties in the past four years, thank you. Thank Li Xiao and Teng Fei. It was very fun to ride horses with you girls. I want to thank Jingwei, Qingyun, Hidde, Fangfang, Akshay, Jinfeng, Yuting, Wangli, Junxiao, Qianfan, Yingying, Haoran, YangLi, Zenghui, Yang Tao, Wang Gang, Fu Ou and Solly. It was nice to know you from here. I wish our friendship to be continued in future. I want to thank all my friends in China and all over the world. Your support was very important to me. I appreciate it very much. For all others whose names might not be mentioned here, thank you all the same.

Finally, my biggest thanks go to my dear parents. Without your understanding and support, I could not go so far. 亲爱的爸爸妈妈，谢谢你们多年对我在外求学的理解与支持，对我生活和工作的关心，以及对我各种毛病的包容。谢谢你们对我每一个决定的支持，让我总能在最困难的时候感到家庭的温暖，有勇气面对新的挑战。不论我将来身在何方，有你们的支持我都会信心满满！

Xiaoqian Li

February, 2015

Curriculum Vitae

Xiaoqian Li was born on March 27th, 1985 in Yuanping, China. She grew up in northern China. After graduating from high school in 2003, she went down to the south, and spent four years in Guangzhou city. In 2007, she graduated (cum laude) from South China normal University with her Bachelor's degree on Applied psychology. At the same year, she started her graduate study in Peking University in Beijing. In 2010, she obtained her Master's degree on Cognitive Neuroscience. As of September 2010, she continued her adventure in the Netherlands and began her PhD project in Utrecht University (funded by the China Scholarship Council). In this project she examined people's subjective judgments of the speed of time passage.

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