Second Hand Effects: Exploring Spatial Influences on Temporal Judgments in Clocks

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Abstract

Humans use clocks to objectively measure their subjective temporal experiences. But can the spatial properties in a clock distort our experience of time ? This study examines how spatial boundaries in an analog clock influence prospective temporal judgements. We found that when the second hand crossed more boundaries, it distorted participants' spatial memories, causing them to overestimate the arc traced by the second hand. However, this distortion in spatial memory did not significantly influence participants' temporal judgments. Besides boundary crossing, our study examined and replicated the influence of speed on temporal judgment, with faster speeds of the second hand being associated with a dilated temporal experience.

Keywords: time perception; spatial cognition; representational momentum; concepts and categories

Introduction

Human experience of time is subjective, and its perception varies depending upon the event we are experiencing. A meeting with a dear friend might feel a minute long, whereas a boring lecture for the same duration could seem to last ages. Previous research (Droit-Volet, 2008; Wearden, et al., 2007) has shown that filled duration intervals are judged by participants to last longer than empty intervals. This illusion of filled duration has been demonstrated across a variety of non-temporal stimuli such as tone bursts (Adams, 1977), light flashes (Buffardi, 1971), and word lists (Poynter, 1979). Studies have shown that the memory for overall amount of contextual change experienced during a period is positively correlated with temporal judgment (Poynter & Homa, 1983; Block & Reed, 1978).

Modern clocks lend objectivity to our subjective temporal experiences by dissociating time from human events. While digital clocks discretize time through numeric symbols, analog clocks represent time spatially through the use of moving hands. But can the representational properties of a clock distort human temporal judgments? Recently, Donnelly et al. (2022) found that participants estimated time periods to feel longer when they spanned more categorical boundaries. Periods like 1:45pm–3:15pm felt longer than 1:15pm–2:45pm since the former spanned the categorical boundary of 2pm. This effect was consistent across presentation formats, including numberless analog clocks (Donnelly et al., 2022, p.826). The behavioral measure used in these experiments required participants to predict the number of tasks they could complete in the presented time period. When a presented period spanned more boundaries, participants estimated they could do more tasks, which was used to infer that the slot encompassed more subjective time. However, this effect was limited to participants' estimates of task completion, and not the subjective experience of duration itself.

Thones et al. (2018) reviewed studies in which a participant's subjective perception of time was altered by rigging external clock speeds. Four studies (London & Monello, 1974; Rotter, 1969; Craik & Sarbin, 1963; Park et al., 2016) in this review, which probed participants' duration judgments, found that faster/slower clocks systematically accelerated/decelerated participants' passage of time. In this study, we investigate how certain spatial properties of analog clocks (like the presence of ticks marking 5 second intervals), which are fundamental to its design, distort participants' judgments of time. We expect biases in participants' spatial memories of change to have a significant effect on participants' temporal judgments.

Biases in Spatial Memory

A key question in the spatial cognition literature explores how we encode information in space. Huttenlocher et al. (1991) argued that information about spatial location is encoded at two levels, a fine-grained level and a categorical level. Reproducing this location from memory involves a weighted combination of information at both these levels. This argument arose from experiments aimed at reproducing the location of dots in a circle (Huttenlocher et al., 1991). Participants were shown dots whose location varied on radial and angular dimensions. In a subsequent trial, participants had to reproduce the dot's location on the circle. The authors found that participants' angular estimates were distorted away from a quadrant boundary and towards the quadrant prototype. These findings were formalized through the Category Adjustment Model (Huttenlocher et al., 2000) and later tested on naturalistic stimuli (Holden et al., 2013).

Alongside prototypes, landmarks have also been shown to distort location estimates in space (Bryant and Subbiah, 1994). To understand the combined influence of prototypes and landmarks, Verbeek and Spetch (2008) presented participants with dots in a circular space alongside visible landmarks. These landmarks were in the form of sectioning lines. They found that when the lines were present during response, participants' reproductions were distorted towards the visible landmarks. However, in the absence of lines, the reproductions were distorted towards the categorical

In D. Barner, N.R. Bramley, A. Ruggeri and C.M. Walker (Eds.), *Proceedings of the 47th Annual Conference of the Cognitive Science Society*

prototypes. Overall, these findings conclude that spatial memory is distorted due to prototypes and landmarks.

Our stimulus consists of an analog clock with landmarks in the form of ticks. An imaginary categorical prototype can be projected between any two ticks. However, what participants might remember after they have been exposed to a functioning clock isn't just static locations, but memory of the second hand's motion in space. As soon as motion is introduced, other effects start influencing memory representations. Representational momentum is one such effect, which is the finding that our memory for the final position of an object moving in space is displaced in the direction of motion (Freyd & Finke, 1984). Representational momentum varies depending upon the characteristics of target, display and participant (see Hubbard, 2018 for a comprehensive review). The presence of landmarks has also been shown to have an attraction effect in the representational momentum literature (see Hubbard & Ruppel, 1999). While representational momentum is usually associated with the final position of a moving object, researchers have also observed displacements for the starting point. Hubbard & Motes (2002) asked participants to indicate either the initial or the final position of a moving object. They found that judgments of initial position were backward and final position were forward. While the forward displacement aligns with the representational momentum effect, backward displacement of initial position has been documented as the onset repulsion effect (Thorton, 2002) in the literature. Overall, if a participant were to remember the trajectory the second hand's trajectory on a fine-grained level, landmarks, prototypes, representational momentum and onset repulsion would collectively influence a participants' memory representation. At a categorical level however, a participant might just keep track of the ticks that the second hand crossed.

The Present Study

The present study was aimed at understanding how boundary crossings on an analog clock influence participants' prospective temporal judgments. To ensure a direct psychophysical measure of time, we chose duration reproduction as our research method (Rammsayer & Verner, 2014). Experiment 1 had two key goals: (1) to investigate whether differences in boundary crossings influenced temporal judgments; and (2) to study the effect of stimulus duration and speed (as measured by the rate at which the second hand moved) on temporal judgments. We expected more boundary crossings to have a similar effect as Donnelly et al. (2022), leading to higher reproductions. However, if participants' judgments relied upon fine-grained trajectory encodings, reproduced durations would be proportional to the remembered spatial locations of the moving clock hand. Specifically, arc contractions would result in lower judgments whereas expansions would lead to higher judgments. In line with previous findings (Makin et al., 2012; Yamamoto & Miura, 2012), we expected speed to have a positive effect on temporal judgments. Experiment 2 also had two major goals: (1) to replicate the findings of Experiment 1; and (2) to study the relationship between arc reproductions and temporal judgments. The second experiment had an additional task where participants had to reproduce the arc traced by the second hand. Overall, both these experiments manipulate spatial features fundamental to analog clocks and investigate how biases in spatial memory can lead to biases in our subjective experience of time.

Experiment 1

Methods

All the materials are publicly available [here](). The present study was exploratory and was not preregistered. It was conducted online using jsPsych (de Leeuw et al., 2023).

Participants

Undergraduate psychology students (n = 136) from a large public university in the midwestern US participated in this experiment in exchange for partial course credit. All participants completed a single online experimental session and provided consent to participate.

Materials and Design

A clock stimulus was present in each trial with 12 boundaries (Figure 1). These boundaries were not labelled with Arabic numerals, limiting the possibility that participants would reason arithmetically about the task. Similarly, to prevent participants from counting, the second hand followed a continuous sweeping motion instead of a stepping motion. To mark the onset of a trial's duration estimate, a red ring appeared along the border of the clock. To ensure that the clock appeared functional and ecologically valid, it displayed the participant's accurate local time on each trial.

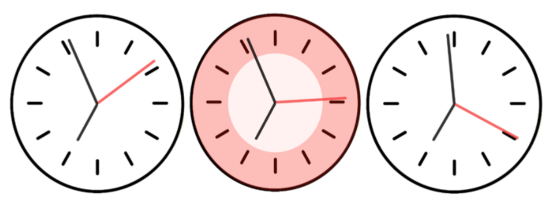

Figure 1: Snapshot of a stimulus experienced by the participant at different time points. Participants are instructed to keep track of time when the red ring is visible.

Our experiment followed a 3x3 within-subjects repeated measures design with duration and speed as the two factors. The duration factor had three levels, namely 4000ms, 7000ms and 10000ms, corresponding to the duration for which the red ring would be visible on the clock. Participants were expected to reproduce these durations once the stimulus disappeared. The speed factor also had three levels, namely Slow, Regular and Fast; corresponding to the second hand's speed, with Regular being equal to the speed of a regular clock (i.e. an angular speed of 6 degrees/second). The Slow level had half the speed of Regular (i.e. 3 degrees/second) while the Fast level had twice the speed of Regular (i.e. 12 degrees/second). Both these factors were introduced to add variability in the task. Each block had 3x3 = 9 unique trials and every participant was exposed to 7 blocks of trials. The order of trials was randomized within a block. In total, a participant was exposed to 63 trials of varying durations and speeds. Varying duration and speed also led to a variation in the number of boundaries (i.e., tick marks) crossed by the second hand. This was an additional derived factor that varied randomly with each duration and speed combination. For example, a 4000ms-Slow condition covered 2 seconds on the clock, which meant that it could either cross zero boundaries or one boundary on the clock.

Finally, participants answered demographic questions about their age, gender and ethnicity. They also reported their duration reproduction strategy. The entire experiment lasted 30 minutes.

Procedure

Once the participants provided consent, they were shown instructions for the task. Every trial had a stimulus exposure phase followed by the duration reproduction phase. During exposure, participants saw the clock stimulus for a particular value of duration and speed. The red ring appeared for that duration and participants were instructed to remember the amount of time when the ring was visible (middle clock in Figure 1). The clock was visible to the participants 3000ms before the stimulus duration and 3000ms after. For these portions, there was no red ring on the clock. Next, participants reproduced the stimulus duration by pressing the spacebar for the duration they thought the red ring was visible. If the reproduced duration was less than half of the stimulus duration, they were given a ten second penalty. They could proceed to the next trial only after the penalty duration was over. Finally, participants answered the questionnaire which marked the end of the experiment.

Data Processing and Analysis

Along with reproduced duration, the exact angle covered by the second hand in each trial was recorded, so that the number of boundaries crossed in a trial could be calculated. A categorical variable of Few and Many was created for classifying the number of boundary crossings in each duration-speed combination,allowing comparison across different durations and speeds. Reproduction error was calculated by subtracting stimulus duration from the reproduced duration, and this error was treated as the dependent variable for analysis. Positive values indicate overestimation and negative values indicate underestimation in reproduction.

Penalty trials as well as trials in which the reproduced duration was five seconds more than the stimulus duration were excluded from analysis. We arrived at this outlier threshold through a visual inspection of the distribution of reproduced durations. Penalty and outlier trials accounted for 6.6% of the entire data.

The influence of boundary crossing was not analyzed for 10000ms duration, since most of the trials in this duration necessarily covered the same number of boundaries (10000-Slow trials crossed 1; 10000-Regular trials crossed 2; 10000-Fast trials crossed 4).

For each participant, all the trials within a condition were grouped so that analysis could be done at a participant level. A linear mixed model was used for analysis, with participants as a random intercept. The analysis was performed in R (version 4.2.1) by using the lme4 package (Bates et al., 2015).

Results

Participants' reproductions were overestimated in the 4000ms condition (M = 363.46ms, SD = 1043.37ms) and underestimated in 7000ms (M = -297.63, SD = 936.73) and 10000ms (M = -1035.54ms, SD = 942.74ms) conditions (Figure 2A). Pairwise comparison of reproduction error across all three durations was statistically significant ($p < 0.0001$). When averaged across all durations, higher speeds led to lower underestimations (Figure 2B).The mean reproduction error in the Fast speed condition was significantly different from the Slow speed reference condition (B = 96.58, SE = 39.93, p = 0.01). However, the difference between the Regular speed and Slow speed condition (B = 51.52, SE = 39.95, p = 0.19) and Fast speed condition (B = 45.06, SE = 39.94, p = 0.25) was not statistically significant.

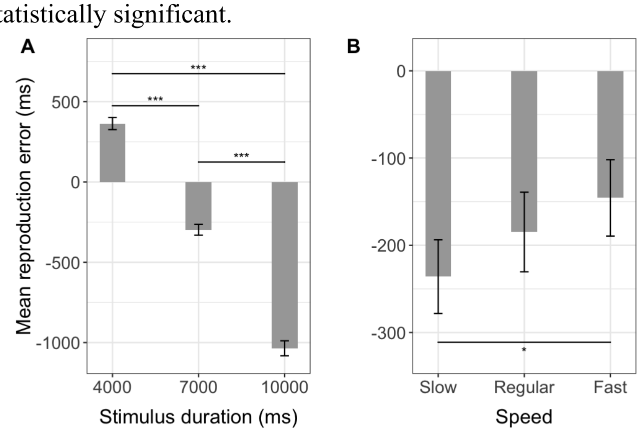

Figure 2: Mean reproduction error for different stimulus durations(A) and speeds (B). Error bars represent SEM.

To analyze the influence of boundary crossing, we added boundary crossing as a fixed effect to the existing model: reproduction_error ~ duration + speed + boundary_crossing + (1 | subject_id). We found no overall effect of crossing more boundaries on the mean reproduction error (B = -9.95, SE = 35.02, p = 0.77). To study the influence of boundary crossing on certain durations and speeds, we ran a model which incorporated interaction effects. For the 4000ms-Slow condition, crossing Many boundaries had a significantly lower reproduction error than crossing Few boundaries (B = -173.00, SE = 85.23, p = 0.042). There wasn't a significant difference between Few and Many boundary crossing for any other duration-speed combination. For 4000ms duration however, we observed a significant two-way interaction between speed and boundary crossing. Specifically, when the speed changed from Slow to Fast, crossing Many boundaries compared to Few led to a significantly higher reproduction error (B = 295.74, SE = 119.89, p = 0.013).

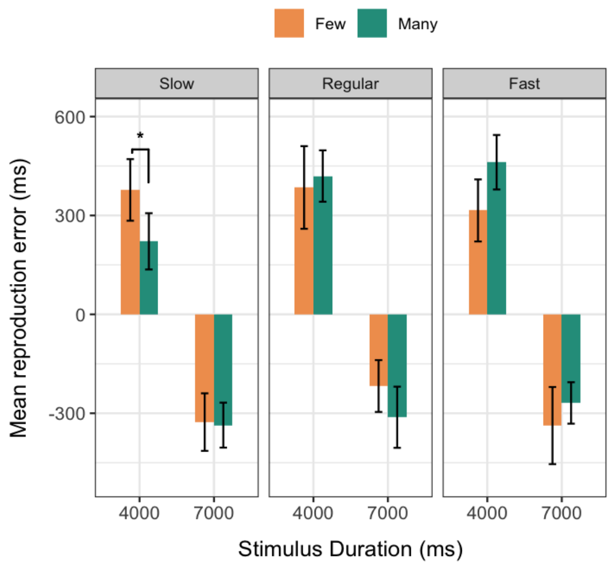

Figure 3: Mean reproduction error for different number of boundaries crossed across all combinations of stimulus duration and speed. Error bars represent SEM.

Discussion

In Experiment 1, we found a meaningful influence of all three factors – duration, speed and boundary crossing – on participants' prospective temporal judgments. First, we found that participants significantly overestimated the shortest duration and underestimated the longer two durations. This was a replication of the Vierordt effect, according to which estimation of duration is influenced by memory of previously perceived durations (Vierordt, 1868; Jazayeri & Shadlen, 2010).

Second, speed also significantly influenced temporal judgments, with the Fast speed condition leading to a dilation in the perceived duration compared to the Slow speed condition. This was again a replication of previous findings (Makin et al., 2012; Yamamoto & Miura, 2012).

Third, crossing more boundaries led to two significant findings. First, there was a significant contraction of perceived time in 4000ms-Slow condition. This was contrary to our categorical encoding hypothesis, which had predicted that crossing more boundaries should lead to a higher reproduced duration. A possible explanation for the contraction could be found in the fine-grained encoding of the arc trajectory. It is possible that the arc traced by the second hand in the 4000ms-Slow-Many condition was contracted due to an attraction towards the landmark it crossed (Figure 4B). Due to this contraction, participants' memory of change was distorted, leading to a perception that less time has passed. In the 4000ms-Slow-Few (Figure 4 A) however, the landmarks were present outside the arc traced by the second hand. Any attraction towards them would result in an expansion, rather than contraction.

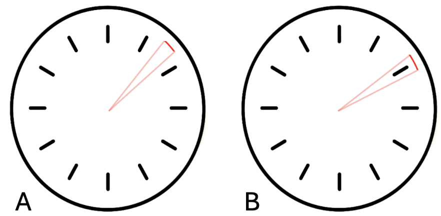

Figure 4: Arc traced by the second hand for different boundary crossings. A) 4000ms-Slow-Few condition. No boundary is crossed. B) 4000ms-Slow-Many condition. One boundary is crossed.

Second, there was a significant two-way interaction between boundary crossing and speed for the 4000ms duration. While crossing more boundaries led to a contraction at slower speeds, crossing more boundaries seemingly led to an expansion at higher speeds. It is possible that at higher speeds, since a large amount of change occurred speedily, participants relied more upon the categorical encoding. This meant that crossing more boundaries was consistent with more change and therefore led to an expansion in temporal judgment.

To replicate our findings and test these hypotheses, we conducted Experiment 2 and introduced an additional arc reproduction task. This task was meant to measure participants' fine-grained encoding of the second hand's trajectory. Three additional changes were made to the existing design. First, since the influence of speed was only found between Slow and Fast conditions, the Regular speed level was removed. Second, since 10000ms duration condition did not lead to a meaningful difference in boundary crossings, it was removed. Third, to ensure a relatively balanced distribution of trials in the boundary crossing factor, we replaced 7000ms duration condition with a 6000ms duration.[1]

Experiment 2

Methods

Preregistration as well as all the materials are publicly available here. We used the software program G*Power to conduct a power analysis using our findings from Experiment 1. Our goal was to obtain .80 power to detect an effect size of .208 at the standard .05 alpha error probability. The target sample size for achieving this goal was atleast 150 participants.

[1]The 7000ms duration had a 30/70 and 20/80 split between Few/Many trials for Slow and Fast durations. In comparison, the 6000ms duration would have a 40/60 and 60/40 split for the same conditions.

Participants

Undergraduate psychology students (n = 202) from the same university participated in this experiment in exchange for partial course credit. All participants completed an online experimental session and provided consent to participate.

Materials and Design

Experiment 2 was similar to Experiment 1 but with an additional arc reproduction task. Similar to the previous experiment, participants were shown a clock stimulus and they had to reproduce this stimulus duration. This experiment followed a 2x2 within subjects repeated measures design with duration and speed as two explicit factors. The duration factor had two levels, namely 4000ms and 6000ms. The speed factor also had two levels, namely Slow and Fast. Each block had 2x2 = 4 unique trials, performed twice for 8 trials in total. Every participant was exposed to 9 blocks of randomized duration reproduction trials. Similar to Experiment 1, varying duration and speed also led to a variation in the number of boundaries crossed , which was an additional derived factor in our experiment. After 9 blocks of duration reproduction trials, Experiment 2 had 3 additional blocks of arc reproduction (with 8 trials each) trials. During these trials, participants were exposed to the same duration-speed combinations of the clock stimulus. But rather than reproducing its duration, participants were instructed to reproduce the arc traced by the second hand using their memory.. To prevent participants from using their cursor as a visual reference point, its visibility was hidden when the stimulus was presented.

Finally, participants answered demographic questions, reported their duration/arc reproduction strategies, and answered if the clock had any influence on their reproduced duration. The entire experiment lasted 30 minutes.

Procedure

The procedure for the duration reproduction trials was exactly the same as Experiment 1. For the arc reproduction task, participants were shown the same clock without the ticks during reproduction. A red circle was present along the border of the clock. Participants could click anywhere on this circle and an arc would automatically be generated with the initial click position as its starting point (Figure 5).

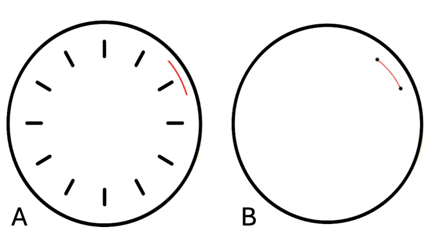

Figure 5: A typical arc reproduction trial. A) Arc traced by the second hand for a particular stimulus duration. B) Arc reproduced for that trial.

A second click would make that point the endpoint of the arc. This arc's length could be adjusted multiple times by clicking the endpoints and dragging them. If the average angle traced by the reproduced arc deviated by more than 45 degrees from the stimulus arc, participants were prompted to try again, and their attempts were recorded. Experiment 2 ended with a questionnaire similar to Experiment 1.

Data Processing and Analysis

For the duration reproduction dataset, the same procedure was followed for detecting outliers as in Experiment 1. Removing outlier and penalty trials led to a 5.2% reduction in trials. For the arc reproduction task, 21 participants, who mentioned the use of their fingers as a reference point were excluded from the analyses. For the remaining participants (n = 181), two types of arc reproduction trials were removed. First, trials in which participants took more than one attempt. Second, trials in which arc reproduction error exceeded 50 degrees. This outlier criteria was decided through a visual inspection of the distribution. Removal of these trials led to a 7.1 % reduction in data..

For the arc reproduction task, error was calculated by subtracting the stimulus arc length from the reproduced arc length. Arc length was measured as the angle subtended by the arc at the center of the clock. For example, for a 4000ms-Slow condition, the duration on the clock was 2 seconds, and therefore the arc length was 2x6 = 12 degrees. This is because each second covers a 6-degree angle on the clock. This error was treated as the dependent variable. Along with the error in length, start and end points of both the reproduced arc and the stimulus arc were analyzed for their respective displacements. Similar to Experiment 1, all the trials within a condition were grouped so that analysis could be performed at a participant level.

Results

Duration Reproduction

Similar to Experiment 1, participants' reproductions were overestimated in the 4000ms condition (M = 169.61ms, SD = 708.71ms) and underestimated in 6000ms (M = -529.15, SD = 702.59) condition. When averaged across both durations, higher speed in Fast condition led to a higher reproduction. To test the statistical significance of duration and speed factors, a linear mixed model was applied, with duration, speed and boundary crossing as fixed effects and participant as a random effect. We found that the mean reproduction error in 6000ms duration was significantly different from the reference level of 4000ms (B = -690.23, SE = -19.49, $p < 0.0001$). With Slow speed as the reference level, we found that the mean reproduction error in Fast speed condition was significantly different from the former (B = 53.25, SE = 19.49, p = 0.006).

We found no overall effect of crossing more boundaries on the mean reproduction error (B = 9.30, SE = 19.61, p = 0.63). To study if the influence of boundary crossing persisted for a particular duration or speed, we ran a model which incorporated interaction effects. Contrary to Experiment 1, we found no effect of boundary crossing on duration reproductions for the 4000ms-Slow condition (B = 6.17, SE = 39.96, p =0.87). We also didn't find a significant interaction between speed and boundary crossing for the 4000ms duration (B = -10.64, SE = 56.52, p = 0.85).

Arc Reproduction

Participants' arc reproductions were overestimated for smaller stimulus lengths of 4000ms-Slow (M = 13.22, SD =10.29) and 6000ms-Slow (M = 12.75, SD =10.72). The reproduced arcs were much closer to the original stimulus lengths for 4000ms-Fast (M = 3.31, SD =9.96) and 6000ms-Fast (M = -1.87, SD =12.83) conditions. Overall, boundary crossing led to an increase in overestimation across all conditions (Figure 6). To test the statistical significance of boundary crossing factor, we applied a linear mixed model with duration, speed and boundary crossing as fixed effects and participant as a random effect. We found that overall, mean arc reproduction error was significantly higher when it crossed Many boundaries than when it crossed Few boundaries (B = 1.17, SE = 0.44, p = 0.009)

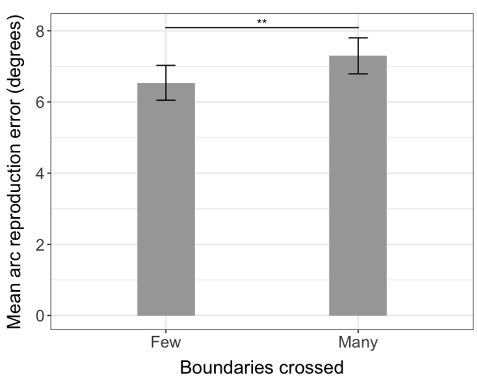

Figure 6: Mean arc reproduction error for boundary crossings across all conditions. Error bars represent SEM.

Next, we analyzed the displacement of start and end points to study their relative contribution in the overestimated arc reproductions. When averaged across all conditions, mean displacement of the start point was in the backward direction (M = -3.66, SD = 9.94) while mean displacement of the end point was in the forward direction (M = 3.25, SD = 10.71). This meant that the overestimations resulted from a displacement of start and end points in the opposite directions.

Discussion

Experiment 2 had two main goals. First, to replicate findings from Experiment 1 and second, to test a possible explanation of those findings through the arc reproduction task. We were able to replicate the influence of stimulus duration and speed on reproduced duration. However, unlike Experiment 1, crossing more boundaries had no significant influence on participants' temporal judgments.

The arc reproduction task also led to some interesting findings. We found that participants' arc reproductions were largely overestimated, especially at lower speeds. This overestimation resulted from a displacement of the start point in the backward and end point in the forward direction. These findings were a direct replication of Hubbard & Motes (2002), who found the same result in their experiments. Interestingly, crossing a boundary led to a significantly larger expansion in the reproduced arc. For slower speed conditions, this was equivalent to crossing one tick on the clock (Figure 4B). This meant that the tick, when crossed, repelled the arc in both directions, resulting in an even larger expansion. It is possible that this repulsion was actually an attraction towards an imagined category prototype, which could be projected at the midpoint of both the landmarks.

General Discussion

The current study was aimed at examining the influence of spatial memory biases on prospective temporal judgments. We examined this influence using a naturalistic stimulus: an analog clock. Across both experiments, we found a significant influence of stimulus duration and speed on temporal judgments. While boundary crossing significantly influenced temporal judgments in one condition in Experiment 1, we failed to replicate this finding in the subsequent experiment. However, Experiment 2 found a significant influence of boundary crossing on spatial memory, with more boundary crossing associated with larger arc reproductions. We infer that the effect of boundary crossings observed in Experiment 1 was spurious.

It was interesting to observe that even though boundary crossing influenced participants' spatial memories, it did not reliably influence their temporal judgments. It is possible that participants did not attend to boundary crossing during the duration reproduction task. Even though the red ring forced them to observe the motion of the second hand, it did not necessitate focus on the boundary crossings. Participants' verbal reports suggest that most resorted to counting or a rhythmic activity (like tapping their foot) to keep track of time. While a faster motion of the moving hand might have sped up this count, boundary crossing does not seem to have influenced it. Future studies might incorporate methods which suppress participants' counting during temporal judgment tasks (Rattat & Droit, 2012).

On the other hand, using novel stimuli and methods, the current study replicates past findings in temporal judgment and spatial cognition literature. For the former, our study replicates the Vierordt effect as well as the influence of speed on temporal judgments. For the latter, we successfully replicate the effects of representation momentum and onset repulsion in naturalistic stimuli.

From fixing appointments to planning dates to structuring our everyday life, modern societies rely heavily on clocks. While the spatial features of a clock might influence our subjective feelings of duration, and even significantly influence our day to day decisions (Donnelly et al., 2022), our study shows that these features do not exert a reliable influence on our experience of time.

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