Time Flew By: Reading about Movement of Different Speeds Distorts People's Perceptions of Time

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Abstract

How humans conceive of abstract domains such as time is a fundamental question in the cognitive sciences. Many theorists hold that we ground the abstract in the concrete, and understand time through the domain of space. Just as we can move through time quickly or slowly, we can move through space quickly or slowly: this study aims to examine to what extent our perception of time is dependent on space. Participants read a story that described slow movement (e.g., ***strolled***), fast movement (e.g., ***raced***) or movement without reference to speed (e.g., ***travelled***) and were asked to provide a prospective time estimation of how long they had spent reading. Estimated reading times for fast stories were significantly shorter than those for neutral and slow stories. This finding indicates that even low-level judgements of temporal duration depend on spatial mappings, and suggesting that people simulate the attentional allocation of the protagonist during language comprehension.

Introduction

"Not only do we measure time by movement, but movement by time, because they define each other" (Aristotle, ***Physics*** IV:12).

A major question that has interested thinkers and philosophers for millennia is how we as humans conceive of the abstract. How do we think about things as diverse and intangible as postmodernism, metaphor, and integral calculus? How do we even understand a fundamental abstract domain such as time? Many researchers have suggested that abstract domains are grounded to some extent in more familiar concrete domains that we develop through sensorimotor experience (e.g., Barsalou & Wiemer-Hastings, 2005; Clarke, 1973; Gibbs, 1994; Lakoff & Johnson, 1999). Time, for example, can be understood through the domain of space, as reflected in our use of language: speakers of English may talk of looking ***forward*** to a party for a ***long*** time, or of regrets ***after*** partying ***through*** the night.

Moving Through Time and Space

We can move through time as we move through space, and this ego-moving perspective is the default view of time for approximately half the population (Gentner & Imai, 1992; McGlone & Harding, 1998), with the other half adopting the time-moving perspective (where time flows past us while we stand still).

Such perspectives on time are not fixed, however. Consciously moving through physical space influences how people think about time. When asked the question "Next Wednesday's meeting has been moved forward two days. What day is the meeting now that it has been rescheduled?", there are two possible responses: the ego-moving perspective (where you and the meeting move through time to Friday) and the time-moving perspective (where time and the meeting moves towards you to Monday). In normal circumstances, these responses are split around 50:50 (Gentner & Imai, 1992; McGlone & Harding, 1998). Ask the same question of people starting or ending a train journey, or travelling through an airport, and more respondents tend to adopt the ego-moving "Friday" perspective (Boroditsky & Ramscar, 2002). Indeed, one's own physical movement is not necessary to alter views of time: Boroditsky and Ramscar also found that ego-moving responses increased when people were betting on horseraces and were therefore focussed on the horses' forward movement.

There is also evidence to suggest that the effect of spatial movement on time is not limited to real, physical movement but also extends to imagined movement. The "Wednesday's meeting" paradigm was also used by Matlock, Ramscar and Boroditsky (2005), who first asked participants to draw a picture of either a static spatial description (e.g., "The highway is next to the coast") or a fictive motion description of the same scene (e.g., "The highway runs along the coast"). Matlock et al. found that fictive motion, where verbs of motion are used but no movement actually takes place (i.e., the highway does not literally run), influenced people's view of time in the same way as actual physical movement. Most people adopted the ego-moving perspective of time after reading about ego-moving fictive motion: imagining a highway "running" through space made people more likely to think of themselves as moving through time. This finding is consistent with other work showing that people mentally simulate movement during language comprehension (Zwaan et al., 2004), and represent spatial information from the perspective of the protagonist (Bryant, Tversky & Franklin, 1992; Zwaan & Radvansky, 1998).

Prospective Time Estimation

The research discussed above shows that our abstract thinking about time leans on our thinking about space.

However, the task of rescheduling a future meeting is relatively high-level. It could be argued that a temporal judgement about the movement of hypothetical events is relatively dependent on mapping to concrete space and thus is quite susceptible to manipulations of spatial movement. Does the same dependency exist for lower-level temporal judgements?

One such low-level temporal judgement is prospective time estimation, where people are aware in advance that they must make explicit judgements as to how much time they believe has elapsed. These judgements are influenced by the attentional demands of the concurrent task: the more difficult the required task, the less attention is available to monitor temporal information and the shorter the perceived duration (see Block & Zakay, 1997, for review). For example, sorting a deck of cards according to three criteria (a difficult task) seemed to take less time than sorting the deck according to a single criterion (a simple task), even when participants were interrupted after the same length of time (Hicks, Miller & Kinsbourne, 1976). Similarly, interesting stories engage our attention, and time estimates for listening to interesting stories were correspondingly shorter than those for dull stories of equivalent length (Hawkins & Tedford, 1976).

The Current Study

If we move through time as we move through space, then is our perception of temporal progress dependent on our representation of spatial progress? Just as time can seem to pass quickly or slowly, we can cover spatial distance quickly or slowly. Our thinking about time and space are inextricably interlinked through our thinking about speed.

The study reported in this paper examines to what extent our perception of time is dependent on space. Will time estimation be influenced by reading about movement of different speeds? Such a finding would lend support to the idea that we think about time in terms of space even for low-level tasks such as time estimation, and that language comprehension involves simulating not only motion but also the attentional allocation of the protagonist.

Experiment

This experiment presented participants with three brief stories describing different scenarios: one describing slow movement, one describing neutral movement without particular indication of speed, and one describing fast movement. For example, the same movement in one base story was described by the verb "strolled" (slow), "travelled" (neutral) or "raced" (fast). Participants were asked to read each story at a normal pace and then estimate how long they thought they had spent reading (i.e., prospective time estimation).

Moving at different speeds across the same space involves encountering the same number of attentional markers (visual or other landmarks that capture our attention and act as reference points in mental representation of space: e.g., Sadalla, Burroughs & Staplin, 1980) with varying intervals: slow movement results in long intervals while fast movement results in short intervals. If readers adopt the perspective of the protagonist in a story and simulate the corresponding movement (Bryant et al., 1992; Matlock, 2004; Zwaan et al., 2004), then their mental representation of the story may also simulate the attentional allocation of the protagonist: reading about slow movement will seem to encounter long intervals between markers (making time pass more slowly) and reading about fast movement will seem to encounter short intervals between markers (making time pass more quickly). This would lead to the prediction that estimated reading times should decrease as story speed increases (i.e., slow > neutral > fast).

On the other hand, psychophysical studies of time estimation may lead to different predictions. When people are asked to estimate how long a dot has spent moving a fixed distance onscreen, they generally estimate longer durations for fast movement than for slow movement (Brown, 1995), arguably because faster speeds represent more perceived changes in a given interval than slower speeds (see also Poynter, 1989), although some studies have failed to find this effect (e.g., Casasanto & Boroditsky, 2003). If perceived onscreen movement corresponds to simulated described movement, then one would predict that estimated reading times should increase as story speed increases (i.e., slow < neutral < fast).

Regarding actual reading times, there is some evidence to suggest that speed of described movement may also affect the speed of language comprehension. Zwaan (1996) found that participants reading brief narratives took longer to process sentences that started "an hour later" than sentences starting with "a moment later", arguing that such time shifts took longer for people to integrate into their situation models of the text. Similarly, it is possible that stories about slow movement (where there are long intervals between attentional markers) will take people longer to process than stories about fast movement (where there are short intervals between attentional markers). This view would predict that actual reading times may decrease as story speed increases (i.e., slow > neutral > fast).

Finally, since people tend to underestimate duration in prospective time judgements, especially for longer durations (Block & Zakay, 1997), we would expect estimated reading times to be overall shorter than actual reading times across speed conditions.

Method

Materials. Nine stories were used in this experiment, consisting of a 3x3 cross of base and speed: three base stories were created, and each base story was then manipulated to give rise to three speed versions (slow, neutral, fast). Stories had an average length of 133 words (range 131-137), designed to represent a moderate duration for the time estimation task (defined by Block & Zakay, 1997, as a range of 15-60 seconds). Sample stories can be seen in Table 1.

The speed manipulation of each base story was carefully controlled to ensure equivalence in factors important to reading times. Every sentence in each base story had at least one word altered to imply different speeds of movement. An average of 21.7 words per base story was

Table 1: Slow, neutral and fast versions of a sample base story used in this experiment.

Speed	Story
Slow	It was a cold morning but the sun was shining. Tom was waiting for the next bus, as a man in a red hat strolled passed with his dog, and a weary cat went slouching by. Tom drifted off of the pavement and onto the bus. He looked out of the window as the bus trudged off and overtook the man in the hat sitting with his dog in the nearby park. Tom noticed a milk cart rambling across the road, and a walker following sluggishly behind. The ticket inspector was crawling up and down the bus, looking annoyed with his job. Tom realized the next stop was his, and edged towards the front of the bus very slowly. As he slumped off the bus, he accepted that today was going to be a fairly quiet day.
Neutral	It was a cold morning but the sun was shining. Tom was walking for the next bus, as a man in a red hat travelled passed with his dog, and a ginger cat went passing by. Tom stepped off of the pavement and onto the bus. He looked out of the window as the bus drove off and overtook the man in the hat wandering with his dog in the nearby park. Tom noticed a hire van moving across the road, and a jogger following casually behind. The ticket inspector was moving up and down the bus, looking annoyed with his job. Tom realized the next stop was his, and headed towards the front of the bus very easily. As he got off the bus, he accepted that today was going to be a fairly average day.
Fast	It was a cold morning but the sun was shining. Tom was running for the next bus, as a man in a red hat raced passed with his dog, and a lively cat went dashing by. Tom jumped off of the pavement and onto the bus. He looked out of the window as the bus zoomed off and overtook the man in the hat sprinting with his dog in the nearby park. Tom noticed a sports car speeding across the road, and a cyclist following rapidly behind. The ticket inspector was rushing up and down the bus, looking annoyed with his job. Tom realized the next stop was his, and dashed towards the front of the bus very promptly. As he leaped off the bus, he accepted that today was going to be a fairly busy day.

manipulated, representing a 16.3% lexical difference between speed versions. Slow, neutral and fast words were equivalent in both orthographic length and number of syllables (both ***F***s<1). In addition, there was no significant difference between slow, neutral and fast word frequencies using Kucera and Francis (1967) norms, $F(2, 192)=1.46$, $p=.235$.

Design. Stories were divided into three lists to ensure participants read only one version (slow, neutral or fast) of each base story. Participants were randomly allocated to one of the lists, and stories were presented in a random order for each participant. Thus, the experiment was a 2 (time measure: actual, estimated) × 3 (speed: slow, neutral, fast) × 3 (list) design, with time measure and speed as within-participants variables and list manipulated between-participants.

Participants. Forty-five native speakers of English from Northumbria University volunteered to take part in this experiment. All participants had normal or corrected-to-normal vision and had no known reading impairments.

Procedure. Testing took place individually on portable computers running SuperLab software. Prior to the experiment, participants were asked to remove their wristwatches and place them face-down on a nearby table, and to switch off mobile phones and any other electronic devices with clock displays. Participants read instructions describing the experiment and instructing them to read each story normally and to estimate (in seconds) how long they thought they had spent reading. Participants were also asked to summarise the story in one sentence to ensure they were attending to the task.

Each trial began with a prompt to press any key to begin reading a story. Stories were displayed onscreen as 11 left-aligned lines of text (with line breaks located in the same place for each speed version of a base story). Response times (i.e., actual reading times) were measured from the display of the story until participants pressed the space bar to indicate they had finished reading. Following story presentation, a prompt was displayed asking participants to estimate their reading times, and then to provide a brief summary of the story.

Results & Discussion

One participant was excluded for using consistently incorrect keystrokes, and a further five were excluded for having mean actual reading times that were more than two standard deviations slower than the grand mean. All participants provided meaningful summaries for each story and no responses were excluded by this criterion.

Figure 1 shows actual and estimated reading times for the three speed conditions. Of 117 responses, 54% were overestimates of reading time (M_{diff} = 30.7 secs) and 46% were underestimates (M_{diff} = -13.4 secs). This led to analyses of variance showing a main effect of time measure with mean estimated reading times longer than actual reading times [$F(1, 36)=4.60$, $MSE=1200$, $p=.039$]. Planned pairwise comparisons showed that people estimated they had spent longer reading than they actually had in both the neutral ($p=.032$) and slow ($p=.048$) conditions, but the difference was only marginal in the fast condition ($p=.093$)

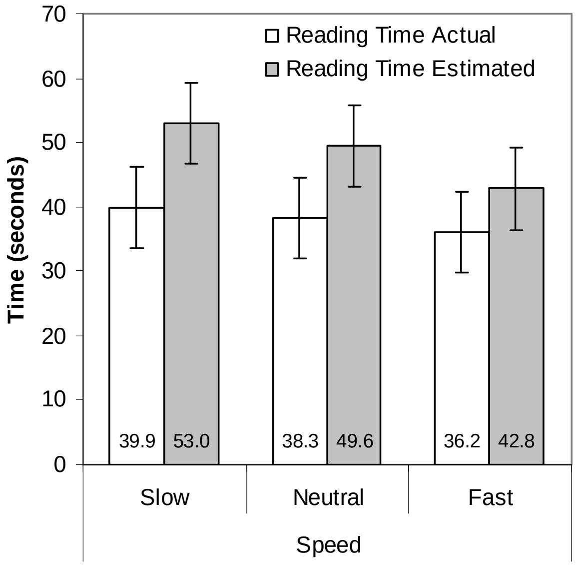

Figure 1: Actual and estimated readings times across the three speed conditions (means at base of bars). Error bars represent 95% confidence intervals for multifactor within-participant designs (Masson & Loftus, 2003).

(see Figure 1). The direction of this effect is against the general trend observed by Block and Zakay's (1997) meta-analysis (although there is some variability in the literature). One possible explanation is simply that participants did not find the stories particularly interesting, and hence experienced subjectively slower time (Hawkins & Tedford, 1976). There was also an overall main effect of speed [$F(2, 72)=3.76$, $MSE=229$, $p=.028$] but no reliable interaction between time measure and speed [$F(2, 72)=1.94$, $MSE=98.7$, $p=.179$]. However, since there were different predictions for estimated and actual reading times, the influence of story speed is explored further below in separate analyses. In this and all further analyses, the effect and interactions of the list variable were non-significant.

For estimated reading times, speed conditions differed significantly [$F(2, 72)=3.68$, $MSE=253$, $p=0.030$]. People thought they had spent less time reading the fast stories compared to the neutral (planned comparison $p=.046$) or slow ($p=.024$) stories. There was no difference between estimates of the neutral and slow stories ($p=.357$). This finding provides some support for the idea that we think about time in terms of space even for low-level tasks such as time estimation, and that language comprehension may involve simulating the attentional allocation of the protagonist. Reading about fast movement involves simulating short intervals between attentional markers (making time pass more quickly), while reading about slow and neutral movement involves simulating longer intervals between attentional markers (making time pass more slowly). The lack of significant difference between slow and neutral estimates suggests that the simulated speed of neutral stories was similar to that of slow stories in this materials set: for example, a ticket inspector ***moving*** up and down a bus (neutral) may be closer in speed to him ***crawling*** (slow) than ***rushing*** (fast).

For actual reading times, there was no significant effect of story speed [$F(2, 72)=1.66$, $MSE=75.6$, $p=0.197$]. Planned comparisons showed that the fast stories were marginally quicker to read than the slow stories ($p=.063$), although neither the slow nor fast stories were different in reading time to the neutral stories (ps>.3). This finding provides some support for the idea that closely-spaced events are easier to integrate into the reader's situation model of the narrative (Zwaan, 1996). Stories about fast movement (where there are short intervals between attentional markers) may be slightly quicker to process for this reason than stories about slow movement (where there are long intervals between attentional markers), although the 3.7 second difference between conditions in the current study is only marginal.

General Discussion

This work shows that people's perception of temporal progress is affected by their representation of spatial progress. Reading about fast movement caused people to make shorter estimates of temporal duration than for neutral or slow movement. Reading about slow movement, on the other hand, resulted in estimates similar to neutral movement.

So what does this study tell us about our understanding of time and space? It suggests that even low-level judgements of temporal duration are dependent on mapping to concrete space and are susceptible to influences of spatial movement. Fast movement in the real world causes landmarks, markers, and other objects that catch our attention to zoom by with relatively short temporal intervals between them. When participants read and simulate stories about fast movement, the short simulated intervals are reflected in short time estimates. It could be argued that time estimation is not a low-level task when compared, for example, to perception, but our use of the term is relative: the task of rescheduling hypothetical future events requires higher-level cognitive processing than making a short duration estimate. We can think about moving through time as we move through space not only at the relatively high level of moving events around like objects (Boroditsky & Ramscar, 2002), but also at the low-level perception of temporal duration.

These results are also consistent with the view that people represent the attentional allocation of the protagonist during narrative comprehension. Previous research showed that when participants read stories about movement, they simulated the implied motion (Zwaan et al., 2004) and speed (Matlock, 2004). This study further suggests that people simulate such stories using flexible temporal intervals: fast movement leads to short simulated intervals and short times estimates, while slow movement leads to long simulated intervals and long time estimates. An alternative possibility from psychophysical research (Brown, 1995; Poynter, 1989), suggesting that people may simulate the story using fixed temporal intervals, was not supported. Fast movement did not lead to long time estimates due to more perceived changes in a given interval, and slow movement did not lead to short time estimates due to fewer perceived changes in a given interval. The present finding underscores the difference between movement simulated during language comprehension and movement visually observed. Readers of text are free to simulate varying temporal intervals to fit the events in the narrative (see Zwaan & Radvansky, 1998), while viewers of onscreen movement must experience the temporal interval set by the experimenter.

Is there another explanation for the results? Prospective time estimations are shorter when more of a person's attentional resources must be allocated to processing a concurrent task instead of processing temporal information (Block & Zakay, 1997). It could be argued that readers in this study are not simulating the attentional allocation of the protagonist, but rather that the shorter estimates for stories about fast movement result from fast movement being more difficult to process. However, this explanation is not consistent with the findings reported here. Actual reading times for fast stories were marginally faster than those for slow stories, indicating that fast stories were not more difficult to process than slow stories. Indeed, this result suggests that fast stories may be slightly ***easier*** to process than slow stories, perhaps due to closely-spaced events being easier to integrate into the story simulation (Zwaan, 1996). Further research will investigate the influence of protagonist viewpoint, such as whether the effects reported here are dependent on having a protagonist on a clear trajectory, or whether they will still hold if multiple protagonists move in multiple directions.

As Aristotle argued, we measure and define time by movement through space. What this study shows is that it is not only real movement but imagined movement, as represented during language comprehension, that has the power to influence how we measure and define time.

Acknowledgments

This work was partly funded by the Division of Psychology in Northumbria University.

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