Left-right mental timeline is robust to visuospatial and verbal interference

Rose K. Hendricks* (rhendricks@ucsd.edu)
Esther J. Walker* (e1walker@ucsd.edu)
Benjamin K. Bergen (bkbergen@ucsd.edu)
Lera Boroditsky (lera@ucsd.edu)
Rafael Núñez (nunez@cogsci.ucsd.edu)
Department of Cognitive Science, 9500 Gilman Dr.
La Jolla, CA 92093 USA
* *Joint first authors who contributed equally to this work*

Abstract

We test the robustness of American college students' mental timeline to dual tasks that have interfered with spatial and verbal reasoning in prior work. We focus on the left-right axis for representing sequences of events. We test American college students, who read from left to right. We test for automatic space-time mappings using two established space-time association tasks. We find that their tendency to associate earlier events with the left side of space and later events with the right remains under conditions of visuospatial and verbal interference. We find this both when participants made time judgments about linguistic and non-linguistic stimuli. We discuss the relationship between these results and those obtained for mental timelines that result from learning new metaphors in language (Hendricks & Boroditsky, 2015), and the effects of the same interference tasks on number tasks (mental number-line and counting; van Dijck et al., 2009; Frank et al., 2012).

Keywords: space; time; mental timeline; metaphor; working memory; interference; implicit association

Introduction

Space and time are intricately linked in the human mind. Systematic associations between time and space show up not only in how we talk about time (e.g., *I'm looking forward to the weekend*), but also in co-speech gesture (Cooperrider & Núñez, 2009), in a variety of cultural artifacts (e.g., calendars, timelines), and in how we reason about time (e.g., Boroditsky, 2000; for review, see Núñez & Cooperrider, 2013).

In this paper we focus on representations of the order of events on the left-right axis. Prior work has shown that people who read and write from left to right (as English speakers do) tend to form a left-right representation of time with earlier events mapped to the left and later events mapped to the right (e.g., Tversky, Kugelmass & Winter, 1991; Weger & Pratt, 2008). People who read and write from right to left (as Hebrew and Arabic speakers do), accordingly tend to associate earlier events with the right side of space, and later events with the left (e.g., Fuhrman & Boroditsky, 2010).

Here we ask whether such left-right representations of time are robust to two forms of dual task interference: verbal and visuospatial. We used interference paradigms that have been shown to selectively interfere with other tasks. The current paper reports two experiments. The experiments were designed and conducted independently by two subgroups of the authors (E.W., B.B., R.N. [Exp. 1] and R.H. and L.B. [Exp. 2]), with some differences in methods and materials. Despite the differences, these independently conducted studies yielded remarkably similar results.

Both studies tested American college students on implicit space-time association tasks on the left-right axis. In both studies, participants made speeded judgments about the order of sequential events under either verbal, visuospatial, or no interference. In Experiment 1, the stimuli used were linguistic (sequences of words describing life events). In Experiment 2, the stimuli were entirely non-linguistic (picture sequences). In both studies, results revealed an implicit left-right association for time (as expected), and in both studies this left-right mapping was robust to both verbal and visuospatial interference; that is, dual tasks that are typically considered "interference" did not in fact interfere with participants' left-right mental timelines.

We discuss the relationship between these results and those obtained for mental timelines that result from learning new spatiotemporal metaphors in language (Hendricks & Boroditsky, 2015), and the effects of the same interference tasks on number tasks (mental number-line and counting; van Dijck et al., 2009; Frank et al., 2012).

Experiment 1: Linguistic Stimuli

Methods

Participant & Inclusion Criteria

72 undergraduate students at the University of California, San Diego participated for course credit.

Participants were excluded if performance was below 20% on the visuospatial or verbal interference task (five participants) or below 50% on the time judgment task (seven participants). One additional participant was removed because the program crashed halfway through the experiment. This left a total of 58 participants for analysis (22 in the verbal interference condition, 18 in the control condition, and 18 in the visuospatial interference condition).

Only trials where participants responded accurately to the time judgments were included in the analysis (93.8% of trials). Furthermore, only reaction times that were within 3 standard deviations of each participant's cell mean (97.8% of correct trials) were included in analysis.

Procedure

The design of the experiment was modeled after van Dijck, Gevers, and Fias (2009), who conducted a similar dual-task experiment on spatial representation of number. Each participant was randomly assigned to one of three conditions: control (no interference), verbal interference, or visuospatial interference. First, a baseline measure of performance was taken for the time judgment task. Then, each participant's working memory span was measured using either a visuospatial or a verbal task. This span was used to calibrate the final portion of the study, a dual-task, which is described below.

Time Judgment Task

Participants held two computer mouses, one in each hand, with each thumb placed over a single mouse button. Participants held one mouse with their left hand on their left side and the other mouse in their right hand on their right side. Before each block, participants were presented with instructions that explained the stimulus-response mappings (e.g., left response for earlier events, right response for later events) they would use for that block. The stimulus-response mappings were changed after each block. After the presentation of a fixation cross for 1000ms, participants read a reference life event written in the center of the computer screen (e.g., "high school graduation"), which remained on the screen for 2000ms. A white screen was then presented for 500ms and the text of a second life event (e.g., "college graduation") was presented and remained on the screen until the participants responded, up to 5000ms. Reaction times were measured from the onset of the second event. Participants received new instructions before each block. Participants completed four practice trials, followed by forty experimental trials during each of two blocks. Whether the participants received congruent or incongruent mappings during their first block was counterbalanced across participants.

Interference Task / Working Memory Measures

After the baseline time judgment task was completed, the verbal or visuospatial working memory spans of the participants were measured, depending on which condition they were randomly assigned to. For both the visuospatial and verbal calibration tasks, strings of items were presented in an increasing number (from three to eight items, with three strings of items per testing length). The participant's span was then defined as the highest sequence length where they recalled at least two of the three strings for that length.

The verbal working memory span was modeled after Szmalec and Vandierendonck (2007). Each trial started with a blank screen, followed by a string of single consonants, which were each separated by an empty screen. Participants were then asked to type their responses after all of the consonants were presented.

A computerized Corsi task was employed to measure visuospatial working memory. Nine white squares were presented on a black background and were positioned in the same manner as used by van Dijck et al. (2009). Each trial started with an image of the white squares, followed by a sequence of squares flashing blue, one at a time. When the sequence was over, all of the squares were left on the screen and the participant had to reproduce the sequence by clicking on the squares in the order that they saw them flash.

Dual Task

Participants in the dual task conditions were first presented with either a verbal or visuospatial sequence to remember. To ensure the dual-task was challenging, but not too difficult, the participant's working memory span minus one was used to calibrate the dual task setup. They then completed 2 time judgment trials. Finally, they were asked to recall the verbal or visuospatial sequence. This cycle was repeated 20 times for each mapping (either incongruent or congruent), for a total of 80 temporal judgment trials and 40 span trials. Each participant completed two blocks of dual-task trials, with each block using a particular set of stimulus-response mappings (congruent or incongruent). Participants in the control condition simply completed the time judgment task once more, rather than completing the dual task version.

Results

Reaction Times

A 3 (type of interference group: control, verbal, visuospatial) x 2 (congruency: congruent or incongruent) x 2 (load type: baseline or under load, which includes the Control, Verbal, and Visuospatial Interference groups) ANOVA on reaction times revealed an overall congruency effect, $F(1,55)=25.62$, $p<.001$, where participants were faster to respond to congruent (M=1360 ms) than incongruent (M=1529 ms) trials. There was also a main effect of load type, $F(1,55)=5.88$, $p=.005$, where participants were faster under load (1345 ms) than at baseline (1544 ms). However, this doesn't imply that the "under load" condition was easier. Rather, the "under load" condition was also the second time they completed the time judgment task, so this effect likely reflects a practice effect. There was, however, an interaction between interference type and load condition, $F(2,55)=5.88$, $p=.005$. Follow-up tests revealed that while participants in the Control ($F(1,21)=30.51$, $p<.001$) and Verbal ($F(1,17)=21.42$, $p<.001$) interference conditions got faster the second time they completed the task, participants in the visuospatial interference condition showed no such improvement, $p=.62$.

There was no main effect of type of interference ($p=.66$), nor was there an interaction between interference condition and congruency ($p=.16$). There was also no interaction between congruency and load type, $p=.78$, suggesting that congruency effects did not change between the baseline and when the load was introduced. Finally, no three way interaction emerged, $p=.62$. Reaction times for the load conditions are shown in Figure 1a.

Time Judgment Accuracy

A 3 (type of interference: control, verbal, visuospatial) x 2 (congruency: congruent or incongruent) x 2 (load type: baseline or under interference) ANOVA was also conducted on the accuracy of the time judgment trials. There was an overall main effect of congruency, $F(1,55)=7.87$, $p=.007$, where participants were more accurate on congruent (94.8%) than incongruent (92.7%) trials. There was also a main effect of load, $F(1,55)=7.24$, $p=.009$, again reflecting practice effects, as participants were more accurate the second time through the task (94.8%) than during baseline (92.7%). There was no main effect of interference type, $p=.26$, nor were there any interactions.

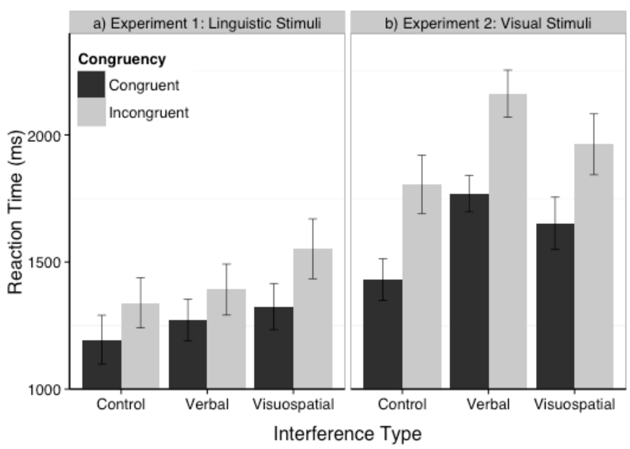

Figure 1 Reaction times to make time judgments in the main task in Experiment 1 (a) and Experiment 2 (b)

Interference Task

Based on the working memory span calibration, there was no difference in the number of interference items assigned to participants in the verbal (M=4.0, SD=1.195) and visuospatial (mean: 4.5, sd: 1.0) interference groups, $p=.15$.

Performance on the working memory interference tasks (visuospatial task or verbal task) was analyzed using a 2 (congruency: congruent/incongruent) x 2 (type of task: visuospatial or verbal) ANOVA on secondary task accuracy. Participants were more accurate in the interference task on trials that occurred with congruent time judgment trials (63.9%) than those that occurred with incongruent time judgment trials (57.6%), $F(1,38)=6.49$, $p=.015$. Participants also performed better on the verbal interference task (71.3%) than on the visuospatial interference task (47.9%), $F(1,38)=12.91$, $p<.001$. When the different interference tasks were analyzed separately, post-hoc paired t-tests revealed that participants performed better in the visuospatial interference task when the temporal judgment trial was congruent (52.6%) than when the temporal judgment was incongruent (43.4%), $t(17)=2.45$, $p=.025$. Such a congruency effect was not observed for the verbal interference task, $p=.25$ (see Figure 2a).

Discussion

In Experiment 1, we found no effect of visuospatial or verbal interference on the left-right mental timeline. Similar space-time congruency effects were observed in the control, verbal and visuospatial interference conditions, suggesting a robust left-right mental timeline. However, while an effect of interference on time judgment reaction times was not observed, evidence of interference appeared in other, more subtle, forms. First, as each participant completed the time judgment task twice (once for baseline and once under interference), one would expect them to improve the second time through the task. While this improvement was observed in the control and verbal conditions, it was not seen in the visuospatial interference condition. This suggests that participants in the visuospatial condition were more impacted by load than those in the verbal condition, reflected by slower reaction times the second time through in the visuospatial group. Second, participants performed worse on the visuospatial memory task during the incongruent blocks of the time judgment task than during the congruent blocks. This effect was not seen on the verbal memory task. While this analysis was exploratory, it suggests that the visuospatial interference task, but not the verbal interference task, requires some of the same cognitive resources as the main task. It is possible that the visuospatial interference did not impact congruency effects in the time judgment task because the stimuli were linguistic. To test for this possibility, Experiment 2 involved making similar time judgments, but the stimuli used were nonlinguistic, in the form of pictures.

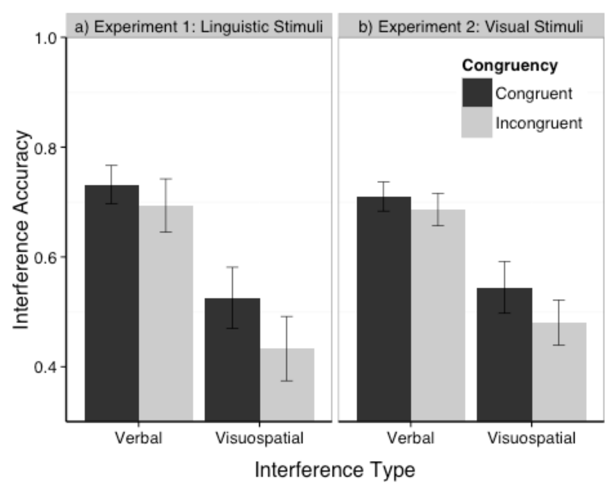

Figure 2. Interference Accuracy in both interference groups in Experiment 1 (a) and Experiment 2 (b).

Experiment 2: Visual Stimuli

Methods

Participants & Inclusion Criteria

A total of 102 UC San Diego undergraduates participated for course credit. They received a link to participate through the Psychology participant recruitment site.

We excluded 5 participants with accuracies below 25% for one time judgment task block and 7 additional participants whose accuracies on one or both blocks of the time judgment task were greater than 3 standard deviations from the sample mean accuracy. For the secondary interference task, participants who performed below 3 standard deviations from the sample mean accuracy for their interference type were eliminated. This resulted in eliminating only one participant from the verbal interference condition. After exclusions, all three conditions included 30 participants.

Only trials for which the time judgment was correct (91.0% of all trials) and reaction times were within 3 standard deviations of each participant's cell mean (97.9% of correct trials) were included.

Materials and Procedure

Each participant was randomly assigned to one of three conditions: control (no interference), verbal interference, or visuospatial interference. Participants in the interference conditions completed a calibration block at the beginning of the experiment. Everyone completed two blocks of the time judgment task with opposite key mapping instructions. The time judgment task included either visuospatial or verbal interference for participants in those conditions.

Interference Task Calibration

Participants in the verbal and visuospatial interference groups first completed a calibration task to ensure that the memory tasks were properly tuned for individual ability. The materials and calibration procedure were identical to those used in Frank et al (2012). Both conditions followed a staircase method, increasing difficulty (the number of distractors to remember) when participants got 2 consecutive trials correct, and decreasing it when they got one wrong. The number of items that a person could successfully remember was determined after 60 trials.

Time Judgment Task

The main task involved the same nonlinguistic stimuli and procedures used in prior work examining effects of writing direction and linguistic metaphors on representations of time (Fuhrman & Boroditsky, 2010; Hendricks & Boroditsky, 2015). Participants responded on a QWERTY keyboard. To begin each trial, they pressed the 'G' key. Then, the first of two images appeared on the screen (e.g., Julia Roberts in her 20s). After 2000ms, this image was replaced by a second image (e.g., either a younger or older Julia). For the congruent time judgment block, participants were instructed to press the 'D' key if the second image showed a conceptually earlier time point than the first, and the 'J' key if it showed a conceptually later point. This instruction was reversed for the incongruent block. All participants completed one congruent and one incongruent block, and whether the first block was congruent or incongruent was counterbalanced across participants.

There were 10 practice trials and 56 experimental trials in each block. Sequences of images were selected in a random order, and each sequence was shown only once in each block.

In the two interference groups, participants remembered either a string of consonants or a pattern of boxes while performing the time judgments. After completing the temporal judgment, people in the verbal interference group were prompted to type in the letter sequence they had been rehearsing. For the visuospatial interference group, the string of letters was replaced by a set of blue squares that appeared sequentially in different locations on a 4x4 grid of white blocks. After the time judgment trial, participants clicked on the appropriate boxes when given a blank grid.

Results

Reaction Times

As in Experiment 1, a 3 (interference type) x 2 (congruency) ANOVA revealed that participants were overall faster for congruent trials (M=1617ms) than incongruent trials (M=1977ms; $F(1,87) = 51.55$, $p < .00001$). This was true in all three conditions (all ps $< .0001$). The size of the congruency effect did not differ among the three conditions, confirmed by a lack of interaction between congruency and interference type ($p = .78$). Reaction times are shown in Figure 1b.

There was a main effect of interference type on overall reaction times, ($F(2,87) = 3.84$, $p = .03$). Pairwise comparisons demonstrated that those in the verbal interference group were slower overall than those in the control ($F(1,58) = 9.06$, $p = .004$), but not slower than those in the visuospatial interference group ($p = .21$). There was no difference in overall reaction times between the visuospatial interference and control groups ($p = .30$).

Time Judgment Accuracy

People were overall more accurate on congruent time judgment trials (92.4%) than on incongruent trials (89.6%; $F(1,87) = 14.93$, $p = .0002$). There was also a main effect of interference type on time judgment accuracies ($F(2,87) = 4.73$, $p = .01$). Pairwise tests revealed that participants in the visuospatial interference group were less accurate on the time judgment task (88.8%) than the participants in the verbal interference (91.5%; $F(1,58) = 4.73$, $p = .03$) and control (92.6%; $F(1,58) = 7.54$, $p = .008$) groups. There was no difference in accuracy between the verbal interference and control groups ($F(1,58) = 0.77$, $p = .38$).

Interference Task

The number of distractor items assigned to the participants for the time judgment task based on calibration was the same for both the verbal (M=4.47, SD = 1.14) and visuospatial (M=4.90, SD = 1.42) interference groups ($p = .20$).

Accuracies on the secondary memory task were higher for congruent trials (62.7%) than incongruent trials (58.3%; $F(1,58) = 6.05$, $p = .02$). They were also higher for participants who experienced verbal interference (69.8%) than those who experienced visuospatial interference (51.2%; $F(1,58) = 14.2$, $p = .0003$). As in Experiment 1, a post-hoc analysis was conducted on accuracies for each interference group separately. Participants in the visuospatial interference group were more accurate at remembering the box pattern when the time judgment trial was congruent than when it was incongruent (t(29) = 2.30, p = .03), but there was no difference in accuracy between congruent and incongruent trials in the verbal interference group (t(29) = 1.06, p = .30). Interference task accuracies are shown in Figure 2b.

Discussion

In this experiment, the canonical left-right mental timeline was again robust to both visuospatial and verbal interference conditions. Despite the use of visual (picture) stimuli, the canonical mental timeline persisted amidst a visuospatial load, suggesting that people are able to recruit space to think about time while also maintaining visuospatial information in memory. As in Experiment 1, however, there was a subtle indication that making time judgments while experiencing a visuospatial load was more difficult than making the same judgments under a verbal load. Exploratory analyses revealed that accuracy for the visuospatial interference task was worse in incongruent trials than in congruent, but this same discrepancy was not present in the verbal interference condition.

General Discussion

Across two experiments, American undergraduates consistently demonstrated strong congruency effects (faster responses for early on the left and later on the right than for the reverse), even when faced with visuospatial or verbal dual task. These effects were also robust to differences in stimuli presentation, as they were observed in cases where the stimuli were linguistic (Experiment 1; words presented on a screen), as well as nonlinguistic (Experiment 2; images presented on a screen). However, though the interference tasks did not affect performance on the time judgment task, exploratory analyses revealed that the time judgment task appeared to affect performance on the visuospatial interference task. In both studies, participants performed worse on the visuospatial interference task during the incongruent blocks of the time judgment task than during the congruent blocks. This effect was not seen in the verbal memory task. However, due to the post-hoc nature of those analyses, future work should more carefully investigate the influence of temporal reasoning on visuospatial working memory performance.

These findings lead us to ask: what is the nature of the representation that underlies American college students' left-right mental timelines? What is it most like? Does it have important similarities or differences from the mental number line effects observed in prior work (e..g, van Dijck et al., 2009)? Or is it more like spatial representations for time that are shaped by linguistic forces?

Connection to Mental Number Lines

Left-right mental timelines are often compared to mental number lines, as they both express serial order in terms of spatial position across the lateral axis (Bonato et al., 2012). In both cases, Americans associate earlier items (e.g., 1, 2, "yesterday") with the left side of space and later items (e.g., 7, 8, "tomorrow") with the right side of space. Furthermore, writing direction influences the directionality of both mental timelines (Tversky, Kugelmass & Winter, 1991) and mental number lines (Dehaene, Bossini & Giraux, 1993). However, the persistence of a left-right mental timeline under conditions of verbal and visuospatial interference contrasts with work on the mental number line in which the same visuospatial interference task used here eliminated the bias to associate smaller numbers with left-space and larger numbers with right-space (van Dijck et al., 2009). In addition, while verbal interference did not affect the presence of a left-right mental timeline in our participants, the same verbal interference tasks have eliminated evidence of a spatial representation for number when making parity decisions (van Dijck et al., 2009), as well as eliminating people's ability to count (Frank et al., 2012).

Other work has observed differences in the mental timelines and mental number lines of blind people (Bottini et al., 2015). While the mental number line is anchored on an anatomical frame of reference for blind people and on an external frame of reference for sighted people, the mental timeline is anchored on an external frame of reference for both sighted and blind people. This is interpreted as evidence of different experiential bases for spatial representations of time and number.

Linguistic Metaphor and Mental Timeline

Our mental timelines can be shaped by the linguistic metaphors we use to talk about time (Hendricks & Boroditsky, 2015). Learning a new metaphor (that placed earlier events as either above or below later ones) in a lab setting fostered new metaphor-consistent vertical representations for time. The robustness of those new representations was tested using the same dual task conditions used in Experiment 2. Consistent with the findings we report here, neither the visuospatial nor the verbal dual task interfered with the metaphor-consistent representation for time. Together, the novel metaphor experiment and experiments reported here suggest that our spatial representations of time, though evident in a nonlinguistic implicit association task, do not rely on the same cognitive resources as those needed to complete the visuospatial and verbal dual tasks described here.

The similarities in the robustness of the space-time association between the metaphor work and current studies are notable because the origins of the associations in these experiments were very different. In the case of linguistic metaphor, participants learned a new metaphor in the lab. They practiced that metaphor for about 10 minutes before showing evidence of nonlinguistic associations consistent with the metaphors they had just acquired. Associations between space and time on the lateral axis, however, are absent from the English language. English speakers do not refer to Wednesday as to the left of Thursday, or moving a meeting to the right by 2 hours, for example. Although these associations are not evident in spoken language, they follow the direction of reading and writing (Tversky, Kugelmass & Winter, 1991, Fuhrman & Boroditsky, 2010), an experience that accumulates throughout a person's life. Despite very different origins and developmental time scales, the robustness of the spatial representation of time remained consistent.

Spatial Representations

It is important to remember that although we use the same word, *spatial*, in different contexts, our spatial abilities are not one monolithic entity. Our conceptualization of number and time may both be grounded in an understanding of space, but as we have explored here, those spatial representations need not be the same. Similarly manifesting spatial representations can also come from different origins, developed on different time scales, though this does not necessarily mean that the representations truly share the same nature either. Because *spatial* cognition is not a single concept, a single dual task cannot be expected to interfere with all mental processes that rely on some form of spatial cognition.

In addition to exploring additional dual tasks that may interfere with congruency effects while making time judgments, future work might explore individual differences in spatial abilities. For example, Viarouge and colleagues (2014) found that stronger spatial computation and numerical semantic skills both independently predicted greater SNARC effects, suggesting that spatial conceptualizations of number are influenced by both spatial computation and number semantics. A similar individual differences approach could be useful in exploring the nature of spatial representations for time.

Conclusion

Taken together, the experiments reported here conceptually replicate findings showing that American college students think of sequences of events as unfolding from left to right (Weger & Pratt, 2008). They also demonstrate the persistence of this mental timeline to traditional interference tasks that eliminate mental number line effects involving parity judgments and counting (verbal interference; van Dijck et al., 2009; Frank et al., 2012) and magnitude judgments (visuospatial interference; van Dijck et al., 2009). These experiments highlight a difference between the way we think about time and number, encouraging us to better understand the complexity of what it means for an abstract representation to be spatial.

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