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# Cross-Cultural Differences in Mental Representations of Time: Evidence From an Implicit Nonlinguistic Task

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**Abstract**

Across cultures people construct spatial representations of time. However, the particular spatial layouts created to represent time may differ across cultures. This paper examines whether people automatically access and use culturally specific spatial representations when reasoning about time. In Experiment 1, we asked Hebrew and English speakers to arrange pictures depicting temporal sequences of natural events, and to point to the hypothesized location of events relative to a reference point. In both tasks, English speakers (who read left to right) arranged temporal sequences to progress from left to right, whereas Hebrew speakers (who read right to left) arranged them from right to left, replicating previous work. In Experiments 2 and 3, we asked the participants to make rapid temporal order judgments about pairs of pictures presented one after the other (i.e., to decide whether the second picture showed a conceptually earlier or later time-point of an event than the first picture). Participants made responses using two adjacent keyboard keys. English speakers were faster to make ''earlier'' judgments when the ''earlier'' response needed to be made with the left response key than with the right response key. Hebrew speakers showed exactly the reverse pattern. Asking participants to use a space-time mapping inconsistent with the one suggested by writing direction in their language created interference, suggesting that participants were automatically creating writing-direction consistent spatial representations in the course of their normal temporal reasoning. It appears that people automatically access culturally specific spatial representations when making temporal judgments even in nonlinguistic tasks.

*Keywords:* Writing direction; Space; Time; Language; Culture

## 1. Introduction

Spatial representations of time are ubiquitous around the world. People use graphs and spatial timelines, clocks, sundials, hourglasses, and calendars to represent time. Time is also

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heavily related to space in language, with spatial terms often used to describe the order and duration of events (Clark, 1973; Lakoff & Johnson, 1980; Lehrer, 1990; Traugott, 1978). In English, for example, we might move a meeting forward, push a deadline back, attend a long concert or go on a short break. Further, people appear to access spatial representations when processing temporal language (e.g., Boroditsky, 2000; Boroditsky & Ramscar, 2002; Núñez, Motz, & Teuscher, 2006; Núñez & Sweetser, 2006; Torralbo, Santiago, & Lupianez, 2006) and even simple nonlinguistic temporal judgments are affected by spatial information (e.g., Casasanto & Boroditsky, 2008).

While many languages and cultures share the practice of using spatial representations for time, they differ in terms of how time is laid out in space. For example, Núñez and Sweetser (2006) observed that the Aymara talk about the future as being behind them and the past as being ahead of them, and gesture accordingly. English and Mandarin speakers differ in terms of how often they talk about time vertically, with Mandarin speakers being more likely to use vertical metaphors for time than are English speakers (Chen, 2007; Chun, 1997a,b; Scott, 1989).

In this paper, we will focus on a different aspect of culturo-linguistic experience: the writing system. Previous studies have found that the direction of writing in a language affects the way people graphically lay out time (Tversky, Kugelmass, & Winter, 1991). For example, English-speaking participants (who read from left to right) spontaneously mapped a sequence of events (such as the meals of the day) onto a horizontal line directed rightward, placing earlier events to the left and later events to the right. In contrast, Arabic speakers (who read from right to left) showed the reverse pattern, placing earlier events further to the right and later events further to the left.

Writing direction has also been shown to affect people's patterns of perceptual exploration, drawings, aesthetic preferences, and mental images of scenes (e.g., Nachshon, 1985; Nachshon, Argaman, & Luria, 1999; Tversky et al., 1991). For example, Maass and Russo (2003) asked Italian and Arabic speakers to draw action scenes described in sentences. Italian speakers drew the action as happening from left to right, putting the agent of the sentence to the left of the patient. However, Arabic speakers showed a reverse pattern and tended to draw the agent of the sentence to the right of the patient. Dobel, Diesendruck, and Bölte (2007) demonstrated that this pattern in behavior is closely related to reading and writing experience: German- and Hebrew-speaking preliterate kindergarteners did not show the spatial bias found in literate adults in both languages.

Writing direction has also been found to affect numerical reasoning. Readers of languages like English and French that are written from left to right represent numbers spatially on a ''mental number line'' with numbers positioned from left to right in order of increasing magnitude (Dehaene, Bossini, & Giraux, 1993), while readers of languages like Farsi or Arabic that are written right to left show the opposite pattern (Zebian, 2005). For example, English and French readers are faster to respond to small numbers using a left response key and faster to respond to large numbers using a right response key (Bachtold, Baumuller, & Brugger, 1998; Dehaene et al., 1993). This left-right pattern is weakened or reversed for Farsi-French bilinguals, depending on the amount of exposure to the French left-to-right writing system (Dehaene et al., 1993). In another set of studies Arabic-speaking mono-literates showed a right-to-left mental number-line effect, while Arabic-English bi-literates showed a weakened right-to-left mental number-line, and illiterate Arabic speakers showed no effect (Zebian, 2005).

Importantly, the mental number line effect is observed even when number magnitude is irrelevant to the task (e.g., in parity judgments [Dehaene et al., 1993]), and even without semantic processing of the numbers at all (Fias, Lauwereyns, & Lammertyn, 2001). These findings have led researchers to conclude that people automatically access or create spatial representations when processing numbers, and that the specific spatial representations that people create depend on their linguistic and cultural experiences.

In this paper, we focused on the domain of time and asked whether culturo-linguistic artifacts like writing direction structure people's nonlinguistic representations of time. A number of previous studies have demonstrated cross-cultural differences in people's representations of time (e.g., Tversky et al., 1991; Boroditsky, 2001; Núñez & Sweetser, 2006). These studies provide an important foundation for the understanding of cross-cultural differences in temporal thinking. However, each study is subject to at least one of the key common criticisms directed at findings of cross-linguistic differences in general: (a) the tasks are explicit or ambiguous, and (b) the stimuli or responses are linguistic.

For example, in Tversky et al. (1991), Hebrew, Arabic, and English speakers were asked to explicitly produce a spatial diagram for time. There were many possible correct answers; the participants were free to create a diagram that organized time from left to right or right to left or vertically on the page, or diagonally, etc. Results from such measures leave open several possibilities for interpretation. For example, it is possible that people do not think about time spatially at all, unless they are explicitly asked to produce a spatial representation. When asked to make such a representation, participants may be fully aware that the task is ambiguous and that different spatial layouts are possible. They may also be aware of what are standard or normal representations in their culture. A participant may think to herself ''Well, I have to lay out time somehow, might as well do it the way I am expected to in my culture.'' Thus, it is possible that people from different culturo-linguistic backgrounds will give different answers when they have to explicitly report their beliefs to others (especially when faced with an ambiguous task), but the representations they construct and use in the privacy of their minds are not in fact affected by cultural or linguistic patterns.

A further question is whether people access or produce culturally specific representations only when the tasks themselves are in some way linguistic, prompting participants to conform with cultural norms. In Boroditsky (2001) and Núñez and Sweetser (2006) participants were either processing or producing language as part of the measures of interest. Do people access culturally specific representations even when not required to process or produce language? The next step in extending the existing work is to determine whether people access culturally specific representations of time automatically, and in nonlinguistic contexts.

There are currently no demonstrations of a cross-cultural difference in thinking about time as shown in an implicit, nonlinguistic task. The studies described in this paper provide the first such demonstration. To do so, we built upon the methods used in previous studies to establish automatic nonlinguistic associations between space and time (Gevers, Reynvoet, & Fias, 2003; Ishihara, Keller, Rossetti, & Prinz, 2008; Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo et al., 2006; Weger & Pratt, 2008) and extended these to the cross-cultural context.

In three experiments, we examined the role of writing direction in shaping the direction of time for English speakers (who read left to right) and Hebrew speakers (who read right to left). In Experiment 1, we sought to replicate previous findings (e.g., Tversky et al., 1991). We asked people to spatially arrange picture cards depicting temporal sequences and to place events or time-points in a 3-dimensional space. In both cases we found an effect of writing direction, with English speakers arranging time from left to right, and Hebrew speakers arranging time from right to left, confirming previous work.

We designed Experiments 2 and 3 to test for automatic associations between side of space (left vs. right) and temporal order (earlier vs. later). We reasoned that if people automatically access right-to-left or left-to-right representations for time, then asking them to make a space-time mapping that is incongruent with this representation should cause interference.

A further question is whether these culturally specific spatial associations are present only for highly conventional temporal sequences (e.g., days of the week, months of the year), or whether the same spatial structures are invoked for reasoning about a wide variety of temporal sequences, especially ones that people have not seen laid out on timelines or in calendars. The stimuli used in Experiments 2 and 3 were pictures showing everyday actions and events that our participants likely had not previously seen in any kind of spatial arrangement. We were interested in whether people would access culturally specific spatial representations even when making on-the-fly judgments about these diverse nonlinguistic stimuli that were not part of conventionally spatialized ordinal sequences. The results showed the predicted culturally specific patterns. Further, we found that the size of the congruency effect depended on the relative duration of the depicted time interval, with events spanning larger time intervals showing a larger congruency effect.

## 2. Experiment 1

### 2.1. Methods

#### 2.1.1. Participants

Twenty-four Stanford University undergraduates participated in the experiment in exchange for course credit (10 males, *M*age = 18.71, *SD* = 1.14). They were all native English speakers, and none were proficient in a language with a right-to-left writing direction (according to self-report in a language experience questionnaire). Twenty-four Tel-Aviv University students were paid to participate in the experiment (seven males, *M*age = 25.25, *SD* = 2.30). They were all native Hebrew speakers, and although they all reported a proficiency level in English of above 3 on a 1–5 scale, none of them learned English before the age of 8 nor lived in a foreign country before that age. All participants were right-handed (as self-reported in a preselection questionnaire).

*2.1.2. Materials and procedure*

Participants completed two tasks: card arrangement and 3D pointing (described below). English and Hebrew speakers were given instructions in their respective native language. Participants were tested individually in a well-lit testing room. For each participant there were two sittings. In the first sitting, participants completed half of the trials of the card arrangement task (either group A or group B as described below, counterbalanced across participants) and half of the trials of 3D pointing. They were then rotated 180 degrees around the table and tested on the remaining trials of card arrangement and then the remaining trials of 3D pointing. (The 180-degree rotation was included because this task was designed to be used around the world, including in language groups where absolute facing direction may be an important consideration for laying out time. While absolute facing direction was not relevant for our English and Hebrew speakers, we wanted to keep the procedure the same, to facilitate future comparisons across language groups.)

*2.1.2.1. Card arrangement:* Materials used in this task consisted of eight sets of four printed pictures each. Each set showed a temporal progression (e.g., a chicken hatching from an egg, a person aging, an apple being eaten). The picture sets were divided into two groups (group a and group b) for counterbalancing purposes. For a full list of the stimuli, see Appendix A. Within each sitting, the presentation order of the picture sets was randomized across participants. At the beginning of each trial in card arrangement, participants were handed a set of shuffled cards. Participants were asked to look through the cards and arrange them on the table ''so that they are in the correct order, from the earliest to the latest.'' The experimenter stood behind the participant and recorded each arrangement on a scoring sheet. Each participant arranged each set only once.

*2.1.2.2. 3D pointing:* Instead of laying out temporal sequences on a table-top, we asked participants to arrange time in 3-dimensional space by pointing to locations in the air around them. The experimenter sat to the right of the participant, facing the same direction as the participant. For each trial, the experimenters held their hand out in front of themselves at chest level, about a foot away from the chest, and asked the participants to hold their hand out the same way. Once the participants located the point in front of them, they were asked (for example), ''If this is today, where would you put yesterday?'' After they pointed, the experimenter asked, ''And where would you put tomorrow?'' The experimenter diagrammed the responses on a scoring sheet (out of view of the participant). There were 12 temporal sequences used in this procedure (see Appendix B). Participants were always given the middle reference point first (e.g., today) and were then asked about an earlier time-point in the sequence (e.g., yesterday), followed by the later time-point (e.g., tomorrow). The 12 stimulus sequences were divided into two sittings of six sequences each. The selection of sequences into sittings and the order of sequences within the sittings were random across participants.

## 2.2. Results

Results are plotted in Fig. 1.

### 2.2.1. Results of the card-arrangement task

Trials in which the participants did not arrange the cards in the correct order consisted of only 3.65% of all trials, and they were discarded from analysis.

Responses on the transverse axis comprised the vast majority of trials (95.83%). Sagittal arrangements comprised only 4.17% of all trials in this task, and they were performed by two participants who used the sagittal axis on all of the trials in this task (one English speaker and one Hebrew speaker). Because we were interested in differences as a function of writing direction, we focused on the responses that fell on the transverse axis (were either left to right or right to left).

As predicted, the direction in which participants laid out the cards corresponded to the writing direction of their native language. All English speakers who used the transverse axis for this task laid out the cards from left to right (100% of the trials, *SE* = 0), whereas only one Hebrew speaker who used the transverse axis consistently laid out the cards in this direction (4.35%, *SE* = 4.3%), and the remaining 22 Hebrew speakers laid out the cards from right to left (95.65%). An unpaired t-test by participants on the proportions of left-right arrangements (of the transverse responses) between the two language groups revealed that the group difference was significant, $t(44) = 22$, $p < .0001$ ($n = 46$ because one English and one Hebrew speaker did not produce transverse arrangements as described above).

### 2.2.2. Results of the 3D-pointing task

For the purpose of these analyses, we treated the two responses (for the earlier and later time-points) made for each temporal sequence as one item.

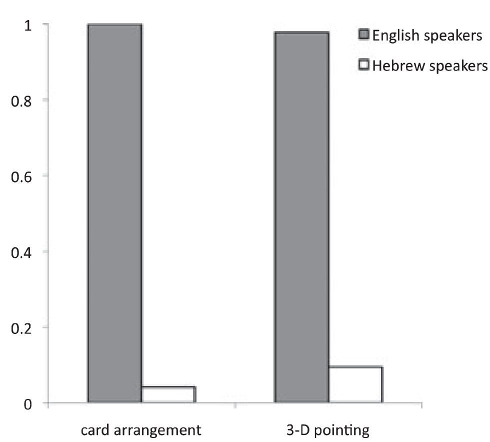


Fig. 1. Results from Experiment 1. The *Y*-axis plots proportions of left-to-right arrangements (of all transverse arrangements) made by English and Hebrew speakers.

Again, because we were interested in differences as a function of writing direction, we focused on the responses that fell on the transverse axis (were either left to right or right to left). These again comprised the vast majority of responses (74.7%).

Just as in the card-arrangement task, there was an overwhelming effect of writing direction in the transverse responses (see Fig. 1). When pointing in the transverse axis, English speakers laid time out from left to right (placing the earlier event to the left of the midpoint and the later event to the right of the midpoint) 97.8% of the time ($SE = 0.84$). Hebrew speakers did so only 9.5% of the time, instead laying out time from right to left 90.5% of the time ($SE = 0.18$). A by-participants unpaired t-test on the proportions of left-right arrangements (of the transverse responses) between the two language groups revealed that the group difference was significant, $t(41) = 13.13$, $p < .0001$ ($n = 43$ because two of the English speakers and three of the Hebrew speakers did not produce transverse arrangements).

There were no other significant cross-linguistic differences in the pointing task. Beyond responses on the transverse axis (which made up 74.7% of responses), 18.2% of responses fell on the sagittal axis. Responses on the sagittal axis put later events further in front of the body 93% of the time. On the remaining 7.11% of trials, people produced infrequent pointing patterns (ones that occurred fewer than 10 times across both groups of participants) such as pointing in the same direction to mark both ends of the temporal interval, or pointing on two different axes, as in ''below-right.''

### 2.3. Discussion

English speakers laid out temporal sequences to proceed from left to right, while Hebrew speakers laid out the same sequences from right to left. This pattern is consistent with the direction of writing in the two languages. Speakers of Hebrew and English appear to arrange time in the same direction as they read and write: Time proceeds from left to right for English speakers, and from right to left for Hebrew speakers.

Results from Experiment 1 confirm previous work showing the effects of writing direction on people's explicit layout of time (Tversky et al., 1991) and extend these findings to new stimuli and different testing methods. Taken together the results demonstrate that people create culturally specific spatial representations of time across a wide range of tasks, including linguistic and nonlinguistic stimuli, 2- and 3-dimensional response spaces, and for novel as well as familiar or conventional sequences.

To test whether these culturally specific representations of time are automatically activated when English and Hebrew speakers make temporal judgments, we used an interference paradigm in Experiment 2. If English speakers automatically map earlier events onto the left side of space, then their performance in a temporal judgment task should be disrupted or slowed down if they are asked instead to map earlier events to the right side of space. Likewise, if Hebrew speakers automatically map earlier events onto the right side of space, then their performance in the same task should be disrupted if they are asked to map earlier events to the left side of space.

In Experiment 2, participants were shown pairs of pictures, presented one after the other in the same location. The pictures represented two points in a temporal sequence, and the participants were asked to judge whether the second picture represented a conceptually earlier or later time-point than the first picture. Participants made their response by pressing one of two buttons designated ''earlier'' and ''later.'' On half of the trials the button designated ''earlier'' was to the left of the ''later'' button, and on half of the trials it was to the right. We predicted that English speakers should respond faster to earlier events when using the left response key, and to later events when using the right response key, whereas Hebrew speakers should show the reverse pattern.

## 3. Experiment 2

### *3.1. Methods*

#### *3.1.1. Participants*

Forty-three Stanford University undergraduates participated in the study in exchange for course credit or payment (20 males, *M*age = 21.03, *SD*age = 1.16). They were all native English speakers, and none were proficient in a language with a right to left writing direction (according to self report in a language experience questionnaire). Forty Tel-Aviv University students were paid to participate in the experiment (18 males, *M*age = 24.95, *SD*age = 2.58). They were all native Hebrew speakers, though they all reported a proficiency level in English of above 3 on a 1–5 scale. However, none of the participants in the Hebrew speaking group learned English before the age of 8 or lived in a foreign country before that age. All participants were right-handed as self-reported in a preselection questionnaire. None of the participants in Experiment 2 had participated in Experiment 1.

#### *3.1.2. Materials and design*

Materials used in this study consisted of 18 triplets of pictures, each depicting a temporal sequence with an ''early,'' ''middle,'' and ''late'' time-point. For example, one triplet showed a banana being eaten, such that the ''early'' picture showed a whole banana, the ''middle'' picture a half-peeled banana, and the ''late'' picture—just the peel. The sequences included a range of temporal intervals: 9 of the 18 triplets depicted short intervals that would span only seconds or minutes while the other nine triplets depicted longer intervals that would span hours, days, months or even years. Examples of the stimuli used are shown in Appendix C.

#### *3.1.3. Procedure*

Participants were tested individually in a quiet testing room, all using the same IBM ThinkPad T43 laptop computer. The experiment was implemented in Matlab. Both English and Hebrew speakers completed the same experimental task, but they read instructions in their native language at the beginning of each testing block.

On each trial, participants saw a fixation cross for 500 milliseconds, followed by two pictures presented one after the other in the same location in the center of the screen. The first picture always showed a ''middle'' time-point from one of the 18 sequences (e.g., the half-peeled banana). The image was displayed for 2 seconds, and was then replaced by the second picture, which showed either the earlier or the later time-point from the same sequence (e.g., either the whole banana, or the empty banana peel). Participants were instructed to decide whether the second picture showed a conceptually earlier or later time-point than the first picture. Participants made their responses by pressing one of two adjacent keys that were designated ''earlier'' and ''later'' (''מוקדם'' and ''מאוחר'' for the Hebrew-speaking group). The target picture remained on the screen until a response was made. Participants were instructed to respond as quickly and as accurately as possible, using their dominant (right) hand.

Participants completed two testing blocks, each consisting of 72 trials. In one block, the left key was designated as ''earlier'' and the right key as ''later,'' and in the other block this mapping was reversed. The order of the blocks was counterbalanced across participants. Each of the ''earlier'' and ''later'' pictures appeared twice in every block. Each block started with 10 randomized practice trials. Participants received feedback about their performance during the practice block, but not during the rest of the experiment. The items used in the practice trials were not used subsequently in the testing blocks.

### 3.2. Results

The results of interest are shown in Fig. 2.

Responses of seven participants (three English speakers and four Hebrew speakers) were discarded from analysis due to an exceptionally high error rate (less than 75% correct in either block). Accuracy rate in the responses of the remaining 76 participants was 96.98%. Error responses were not included in the analysis. The top and bottom 2% of reaction times of all correct responses were also removed from analysis.

The remaining correct responses were submitted to a by-participants $2 \times 2 \times 2$ mixed ANOVA, with Language (English/Hebrew) and Block order (whether the ''Left is earlier'' or the ''Right is earlier'' block was first for that participant) as between participants factors, and Key Mapping (whether the left key was designated as earlier or later) as a within participants factor. A by-items ANOVA (Language × Block Order × Key mapping) was also computed (there were 18 stimuli triplets, which produced 36 comparisons [midpoint-earlier, midpoint-later]).

#### 3.2.1. Effects of writing direction

As predicted, English and Hebrew speakers were able to respond faster when the arrangement of response keys was congruent with the writing direction of their native language, as revealed by a significant Language by Key Mapping interaction: $F(1, 72) = 10.5$, $p < .01$. English speakers were faster to respond when the ''earlier'' response was mapped to the left side and the ''later'' response to the right side ($M = 1275$, $SD = 444$), relative to the opposite key-mapping ($M = 1358$, $SD = 437$). The opposite pattern was observed in the Hebrew-

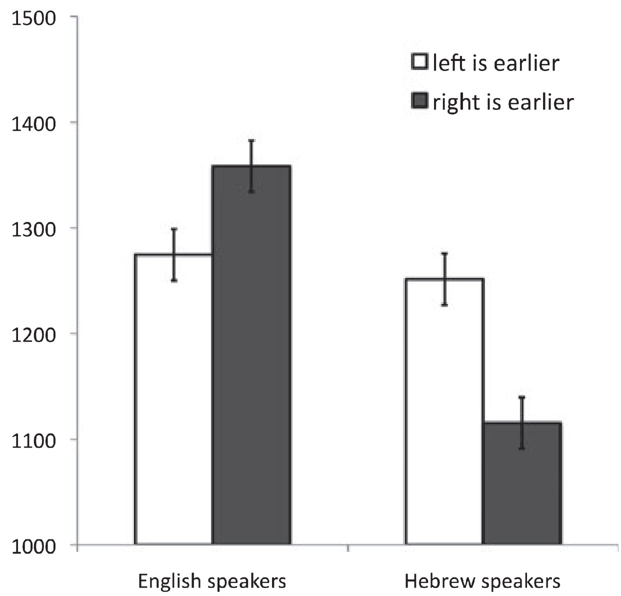


Fig. 2. Results of Experiment 2. The *Y*-axis plots mean reaction time in milliseconds. Error bars represent standard error.

speaking group. Hebrew speakers were faster in the ''right is earlier, left is later'' key mapping ($M$ = 1115, $SD$ = 340) than in the reverse key-mapping ($M$ = 1251, $SD$ = 390). There was no significant main effect of language, $F(1, 72) = 2.82$, $p = .097$. The by-items ANOVA confirmed the language by key mapping interaction found in the by-participants analysis, $F(1, 34) = 23.0$, $p < .001$.

### *3.2.2. Analyses of accuracy*

Overall, accuracy was near ceiling at 96.98%. We analyzed the error rates to make certain that the reaction time differences of interest reported above did not stem from speed-accuracy trade-offs. This was a worry because both English and Hebrew speakers were slightly less accurate when the arrangement of response keys was congruent with the writing direction of their native language than when it was incongruent (English: 96.4% and 98.8% correct for congruent and incongruent trials, respectively; Hebrew: 95.2% and 97.4% correct for congruent and incongruent trials, respectively, a significant Language by Key Mapping interaction: $F(1, 72) = 15.3$ $p < .01$). That is, in those conditions when participants responded faster, they were also less accurate. This raised the possibility that the differences we observed in reaction times may have been driven by speed-accuracy trade-offs. To test for this possibility, we reran the reaction time analyses, including the difference in accuracy rates between key-mappings as a covariate. When the difference in accuracy rates was accounted for, the reaction time data still showed a robust Language × Key-mapping interaction [$F(1, 71) = 5.35$, $p < .05$], confirming that the patterns in reaction time were not simply the result of speed-accuracy trade-offs.

### 3.3. Discussion

Our results reveal that people automatically access and use culturally specific associations between space and time. English speakers who read left to right were faster to respond to earlier events with a left response key, while Hebrew speakers who read right to left were faster to respond to earlier events with the right response key. It appears that when the space-time mapping provided by the experimenter conflicted with the mapping suggested by writing direction, participants suffered from interference, and their response times slowed. These results suggest that people automatically access and use culturally specific associations between space and time that are congruent with writing direction. Importantly, these results were obtained even though all of the stimuli were nonlinguistic, and the response required was a simple objective judgment in the form of a button press. Further, the results were obtained on stimuli that did not include highly conventionalized sequences (e.g., days of the week or months of the year) that participants were likely to have previously seen laid out spatially.

In Experiment 3, we sought to extend and replicate the findings of Experiment 2 and further refine the design of the study. While all of the stimuli used in Experiment 2 were nonlinguistic, the response keys were marked with the words ''earlier'' and ''later'' (in either English or Hebrew). Is it possible that these linguistic labels cued participants to the direction of writing? Would the same results obtain even if no linguistic labels were present on the response keys? In Experiment 3, we eliminated these labels and instead color-coded two keys (black for earlier and white for later). We also expanded the set of stimuli from 18 picture sequences in Experiment 2 to 38 sequences in Experiment 3, and we replaced any sequences that participants informally reported to be unclear or confusing in Experiment 2.

## 4. Experiment 3

### 4.1. Methods

#### 4.1.1. Participants

Forty-two Stanford University undergraduate students participated in the experiment in exchange for course credit or payment (18 males, *M*age = 19.34, *SD*age = 1.63). They were all native English speakers, and none were proficient in a language with a right-to-left writing direction (according to self-report in a language experience questionnaire). Forty-two Bar-Ilan University students were paid to participate in the experiment (19 males, *M*age = 23.94, *SD*age = 1.84). They were all native Hebrew speakers, though they all reported a proficiency level in English of above 3 on a 1–5 scale. However, none of the participants in the Hebrew-speaking group learned English before the age of 8 or lived in a foreign country before that age. All participants were right-handed (as self-reported in a preselection questionnaire). None of the participants in Experiment 3 had participated in Experiments 1 or 2.

#### *4.1.2. Materials and design*

Materials used in this study were similar to those used in Experiment 2. Thirty-eight picture sequences were constructed (these included a subset of the stimuli used in Experiment 2). Each triplet showed a temporal sequence with an ''early,'' ''middle.'' and ''late'' time-point. The pictures were chosen to represent a range of object types and temporal intervals: From events that last only a few seconds (e.g., filling a cup of coffee) to intervals that spanned decades (e.g., a person at different stages in life). A sample of the stimuli can be seen in Appendix D.

#### *4.1.3. Procedure*

The procedure was the same as in Experiment 2 with the following exceptions.

Participants were presented with two testing blocks, each consisting of 76 trials. Overall, each of the ''earlier'' and ''later'' pictures appeared once in every block. Participants made their responses by pressing one of two adjacent keys that were covered with black and white stickers, where ''black'' represented ''earlier'' and white, ''later.'' The keys were not labeled linguistically. For one block, the left key was covered with the black (earlier) sticker and the right key with the white (later) sticker, and for the other block this mapping was reversed. Each subject completed both blocks. The order of the blocks was counterbalanced across participants. Participants were tested on a MacBook, and the experiment was implemented in PsyScope.

### *4.2. Results*

The results of interest are shown in Fig. 3.

Responses of nine participants (three English speakers and six Hebrew speakers) were discarded from analysis due to an exceptionally high error rate (over 40%). Accuracy rate in the responses of the remaining 75 participants was 94.2%. Error responses were not included in the analyses. The top and bottom 2% of reaction times of all correct responses were also removed from analysis.

The remaining correct responses were submitted to a by-participants $2 \times 2 \times 2$ mixed ANOVA, with Language (English/Hebrew) and Block order (whether the ''Left is earlier'' or the ''Right is earlier'' block was first for that participant) as between participants factors, and Key Mapping (whether the left key was designated as earlier or later) as a within participants factor.

#### *4.2.1. Effects of writing direction*

As predicted, English and Hebrew speakers were faster when the arrangement of response keys was congruent with the writing direction of their native language than when it was incongruent, as was revealed by a significant Language by Key Mapping interaction: $F(1, 71) = 15.5$, $p < .001$. English speakers were faster to respond when the ''earlier'' response was mapped to the left side and the ''later'' response to the right side ($M = 1148$, $SD = 295$), relative to the opposite key-mapping ($M = 1326$, $SD = 405$). The opposite pattern was observed in the Hebrew-speaking group, with shorter reaction times in the ''right is

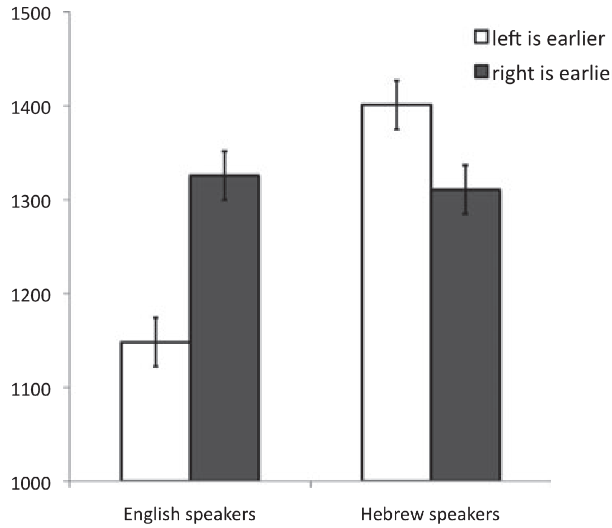


Fig. 3. Results of Experiment 3. The *Y*-axis plots mean reaction time in milliseconds. Error bars represent standard error.

earlier, left is later'' key mapping ($M$ = 1,311, $SD$ = 474) than the reverse ($M$ = 1,401, $SD$ = 450). There was no significant main effect of language, $F(1, 71) = 1.99$, $p = .163$.

The by-items analysis revealed the same pattern of interest. Note that for the by-items ANOVA there were 38 stimuli triplets, that produced 76 comparisons (midpoint-earlier, midpoint-later) per block. As in the by-participants analysis, a Language by Key-mapping interaction was also found in the by-items analysis, $F(1, 74) = 195$, $p < .001$.

### 4.2.2. *Effects of depicted time interval*

The temporal sequences depicted in this study spanned a large range of durations, from events that took only seconds to occur to changes spanning decades. A separate group of English speakers was asked to estimate the duration of the time interval depicted in the sequences. The sequences were printed in paper questionnaires that were part of a larger questionnaire packet handed out to 168 Stanford undergraduates. The sequences were distributed throughout the questionnaires such that each rater estimated a subset of the sequences, and each sequence was estimated by a subset of the raters. We then used the average estimated duration for each sequence to test for any effects of depicted duration on the results. We calculated a writing-direction congruency effect for each item by subtracting the average reaction time in the writing-direction-congruent key mapping from that in the writing-direction-incongruent key-mapping.

As shown in Fig. 4, the congruency effect was present across the wide range of durations used in this study. It appears that constructing a culturally specific spatial representation for time is not restricted to a particular range of durations (e.g., not just durations typically depicted on calendars), but is rather a generative representational strategy people use across a wide range of durations.

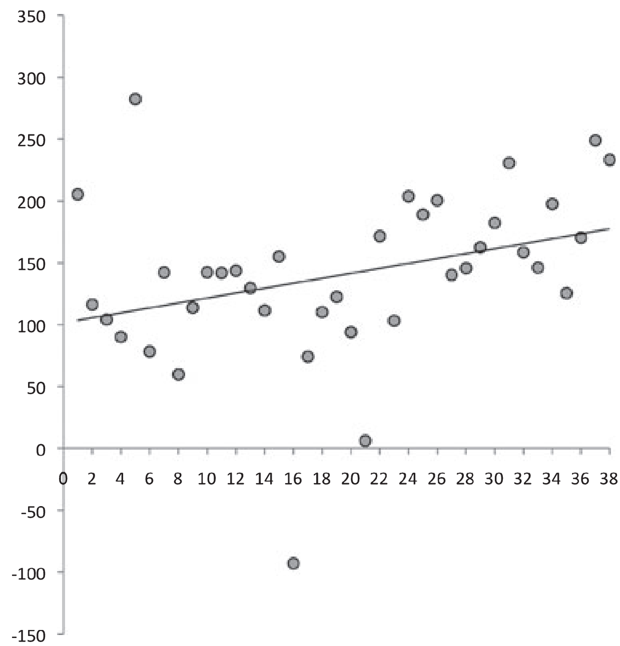


Fig. 4. Results of Experiment 3 shown by item. The *X*-axis shows each stimulus set used in Experiment 3 arranged in order of depicted duration, from shortest (1) to longest (38). The *Y*-axis plots the size for the writing-direction congruency effect for each item (in milliseconds). The congruency effect was calculated by subtracting the average RT in the writing-direction-congruent key-mapping (left = earlier for English speakers and right = earlier for Hebrew speakers) from that in the writing-direction-incongruent key-mapping (right = earlier for English speakers and left = earlier for Hebrew speakers).

At the same time, picture sequences that depicted long time-intervals (e.g., a person at different stages of life) did show a larger congruency effect than those that depicted shorter intervals (e.g., a banana being eaten). We performed a median-split on the items by average estimated depicted duration. Temporal sequences depicting longer durations showed a bigger congruency effect ($M = 163$, $SD = 56.7$) than those depicting shorter durations ($M = 117.4$, $SD = 71.1$), $t(36) = 2.22$, $p < .05$, two-tailed. One interpretation of this finding is that events that are more separated in time are represented as being spatially further apart on the mental timeline. The further apart on the mental timeline two events are, the more interference an incongruent response mapping appears to create. We return to this point in the general discussion.

### *4.2.3. Analyses of accuracy*

Overall, accuracy was very high at 94.2%. We analyzed the error rates to make certain that the reaction time differences of interest reported above did not stem from speed-accuracy trade-offs. There was no evidence of such a trade-off, and indeed the accuracy results supported the effects found in reaction time. English and Hebrew speakers made fewer errors when the arrangement of response keys was congruent with the writing direction of their native language than when it was incongruent (English: 96.4% and 95.6% correct for congruent and incongruent trials, respectively; Hebrew: 92.5% and 91.9% correct for congruent and incongruent trials, respectively). There was a main effect of Language [$F(1, 71) = 8.50$, $p < .01$], with English speakers showing higher overall accuracy, and no Language by Key Mapping interaction: $F(1, 71) = 0.59$, $p = .45$.

### 4.3. Discussion

Results of Experiment 3 confirmed and extended those of Experiment 2. Once again English speakers (who read left to right) were faster to respond to earlier events with a left response key, while Hebrew speakers (who read right to left) were faster to respond to earlier events with the right response key. This was true even though all of the stimuli and the responses in this study were nonlinguistic. When the space-time key-mapping provided by the experimenter conflicted with the mapping suggested by writing direction, participants suffered from interference, and their response times were slowed. These results suggest that people automatically access and use culturally specific associations between space and time that are congruent with writing direction. Further, these results were obtained on stimuli that spanned a wide range of durations and did not include highly conventionalized sequences (e.g., days of the week or months of the year) that participants were likely to have previously seen laid out spatially. Previous research on the mental number line has also observed effects of writing direction. However, people often see numbers laid out spatially in order on graphs, rulers, radio dials, and so on. In this study, the stimuli were new to the participants in the sense that the participants were unlikely to have seen those stimuli arranged spatially. Finally, we found an effect of the size of the depicted temporal interval. The more separated the two depicted events were in time, the greater the culturally specific spatial congruity effects we observed. This suggests that people place events that are more separated in time a greater distance apart on their mental timelines.

## 5. General discussion

In this study, we found evidence for a mental timeline that follows writing direction. We found that people create spatial representations of temporal sequences in a way that mirrors the writing direction of their respective languages; English speakers laid out temporal sequences of natural events as proceeding from left to right, whereas Hebrew speakers showed the reverse pattern (Experiment 1). Even when participants were not limited to a two-dimensional space to create temporal sequences, a similar pattern was observed; English speakers represented earlier time-points by pointing to the left of a reference point, whereas Hebrew speakers pointed to the right of the reference point (Experiment 1).

Most importantly, the results of Experiments 2 and 3 revealed an automatic culturally specific association between side of space (left vs. right) and temporal order (earlier vs.

later). English speakers (who read left to right) were faster to respond when earlier events were mapped to the left side of space, while Hebrew speakers (who read right to left) were faster to respond when earlier events were mapped to the right. That is, providing participants with a space-time mapping that conflicted with the mapping suggested by writing direction created interference. This interference was manifested as a cost in response times. This was true even though all of the stimuli were nonlinguistic (presented as images in the center of the screen), and the spatial location of the response keys was irrelevant to the task. Further, we found that these culturally specific associations between space and time are not restricted to highly familiar ordinal sequences (like numbers, letters of the alphabet or months of the year). It appears that people automatically access and use culturally specific spatial representations as a generative representational strategy (and not simply for sequences they may have already seen represented spatially on calendars or timetables).

These findings highlight the role of reading and writing practice in the development of attentional and representational habits. In order to read a language like English, we must learn to visually scan text in a particular direction, from left to right. In this fashion, the written word organizes our visual behavior, and also it appears to create an association whereby earlier time-points in our experience are to the left and later time-points are to the right.

The findings also raise interesting questions about the nature of the spatial representations people construct for time. For example, the present findings suggest that people represent events as falling on a spatial continuum. One possibility is that a standard-sized spatial continuum is invoked for representing all types of durations, and temporal intervals are scaled to fit this standard representation. For example, the timeline people imagine may always take up 20 degrees of visual angle in the mind's eye, but the temporal duration this timeline represents could be anything from a split second to centuries (depending on the task at hand). Another possibility is that people create timelines of different sizes to represent different durations. For example, a timeline to represent the passage of centuries may be larger in the mind's eye than a timeline to represent the passage of seconds. These timelines could further be scaled by factors such as the number of events to be represented, the richness of detail or the salience of the events in question, and so on. In our data, the size of the congruency effect did vary as a function of the size of the temporal intervals implied in the image sequences (Experiment 3). This finding is consistent with the idea that people's mental timeline forms a spatial continuum, and it suggests that events that are more separated in time are placed further apart on the spatial timeline.

The results reported in this paper also add to the broader body of work on cross-cultural differences in cognition. The findings demonstrate a robust cross-linguistic difference in people's representations of time. These findings are particularly important, since some demonstrations of cross-linguistic differences in the domain of time (Boroditsky, 2001) have recently been brought into question (e.g., Chen, 2007). Importantly, the cross-linguistic differences we observe here are evident even as measured in an implicit, nonlinguistic task, a gold standard for demonstrating effects of culturo-linguistic factors on thinking.

## 6. Conclusions

In three studies, we find that speakers of different languages organize the domain of time differently. In both explicit and implicit measures, English speakers (who read from left to right) associate earlier events with the left side of space, while Hebrew speakers (who read from right to left) associate earlier events with the right side. Our results demonstrate that people automatically access culturally specific spatial representations when reasoning about time even in entirely nonlinguistic contexts. Written languages appear to organize their readers' attention in a vector from where text usually begins to where it usually ends.

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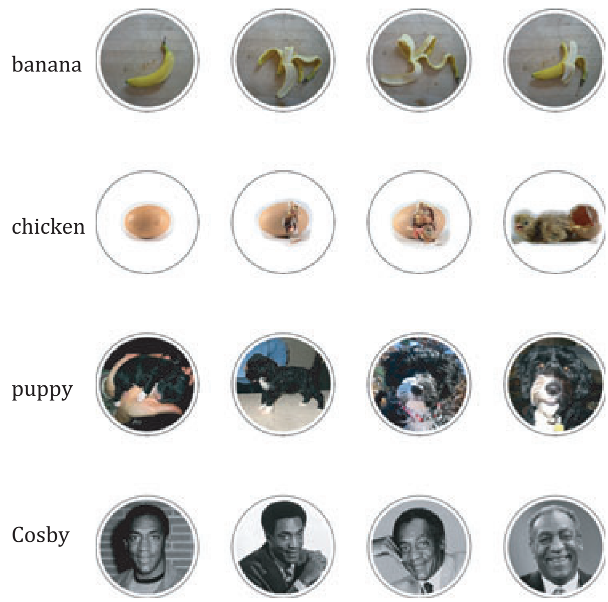
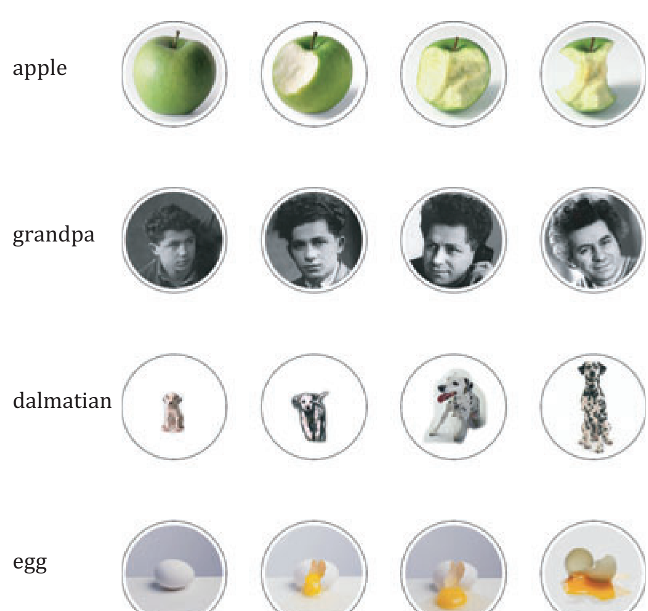
## Appendix A: Stimuli used in Experiment 1

Group a (correct order from left to right):




Group b (correct order from left to right):



## Appendix B

(a) Questions used in Experiment 1 (English)

1. This here is today. Where would you put yesterday? Where would you put tomorrow?
2. This here is nowadays. Where would you put long ago? Where would you put the future?
3. This here is this week. Where would you put last week? Where would you put next week?
4. This here is summer (or this season). Where would you put spring (or previous season)? Where would you put autumn (or next season)?
5. This here is midday. Where would you put morning? Where would you put evening?
6. This here is when you are sleeping. Where would you put it when you are just going to bed? Where would you put when you wake up from sleeping?
7. This here is Wednesday. Where would you put Tuesday? Where would you put Thursday?
8. This here is the age you are now. Where would you put it when you were a baby? Where would you put it when you will be very old?
9. This here is this month. Where would you put last month? Where would you put next month?
10. This here is this year. Where would you put last year? Where would you next year?
11. This here is noon. Where would you put sunrise? Where would you put sunset?
12. This here is middle of the night. Where would you put dusk? Where would you put dawn?

(b) Questions used in Experiment 1 (Hebrew)

1. כאן זה היום. איפה היית שם את אתמול? איפה היית שם את מחר?
2. כאן זה עכשיו. איפה היית שם את מזמן? איפה היית שם את העתיד?
3. כאן זה השבוע. איפה היית שם את השבוע שעבר? איפה היית שם את השבוע הבא?
4. כאן זה הקיץ. איפה היית שם את האביב? איפה היית שם את הסתיו?
5. כאן זה צהריים. איפה היית שם את הבוקר? איפה היית שם את הערב?
6. כאן זה הזמן שאת/ה ישן. איפה היית שם את הזמן שאת/ה הולכ/ת לישון? איפה היית שם את הזמן שאת/ה מתעורר/ת?
7. כאן זה יום רביעי. איפה היית שם את יום שלישי? איפה היית שם את יום חמישי?

8. כאן זה הגיל שלך היום. איפה היית שם את (הזמן) כשהיית תינוק? איפה היית שם את (הזמן) שתהיה זקן?

9. כאן זה החודש הזה. איפה היית שם את החודש שעבר? איפה היית שם את החודש הבא?

10. כאן זה השנה. איפה היית שם את השנה שעברה? איפה היית שם את השנה הבאה?

11. כאן זה הצהריים. איפה היית שם את הזריחה? איפה היית שם את השקיעה?

12. כאן זה אמצע הלילה. איפה היית שם את שעת בין הערביים? איפה היית שם את השחר?

## Appendix C: Examples of materials used in Experiment 2

## Appendix D: Examples of materials used in Experiment 3

Short time interval:

Long time interval: