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New Space–Time Metaphors Foster New Nonlinguistic Representations

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Abstract

What is the role of language in constructing knowledge? In this article, we ask whether learning new relational language can create new ways of thinking. In Experiment 1, we taught English speakers to talk about time using new vertical linguistic metaphors, saying things like "breakfast is above dinner" or "breakfast is below dinner" (depending on condition). In Experiment 2, rather than teaching people new metaphors, we relied on the left–right representations of time that our American college student participants have already internalized through a lifetime of visuospatial experience reading and writing text from left to right. In both experiments, we asked whether the representations (whether newly acquired from metaphor or acquired over many years of visuospatial experience) are susceptible to verbal interference. We found that (a) learning new metaphors created new space–time associations that could be detected in a nonlinguistic implicit association task; (b) these newly learned representations were not susceptible to verbal interference; and (c) with respect to both verbal and visual interference, representations newly learned from linguistic metaphor behaved just like those on the left–right axis that our participants had acquired through years of visuospatial experience. Taken together, these results suggest that learning new relational language can be a powerful tool in constructing new representations and expanding our cognitive repertoire.

Keywords: Metaphor; Space; Time; Representation; Nonlinguistic; Relational language

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1. Introduction

What is the role of language in constructing knowledge? In this article, we consider the systems of metaphors that exist in natural languages. Do the analogical relations implied in natural language metaphors guide how we construct our knowledge? Much previous work has singled out analogical learning as a key mechanism in the human ability to construct complex knowledge (e.g., Gentner, 2010; Holyoak, Gentner, & Kokinov, 2001) and has demonstrated the role of relational language, in particular, in conceptual development (e.g., Christie & Gentner, 2014; Gentner & Christie, 2010). Here we ask, does the structure of our mental representations depend in part on the analogical relations passed on to us stealthily by the metaphorical systems in our languages?

We take up this question in the example domain of time, specifically people's representations of the temporal order of events. We ask whether learning new linguistic metaphors for talking about time creates new cognitive patterns that can be detected in nonlinguistic tasks. Further, we ask, what is the nature of these newly learned representations? Are people creating new linguistic routines that "run alongside" other representations? Or can learning relational language create new nonlinguistic patterns in thought? Are representations acquired purely through language necessarily different from those acquired through visuospatial experience?

1.1. Spatiotemporal metaphor: A brief overview

In English, the way people talk about time strongly overlaps with the way they talk about space, with many of the same words and constructions used to talk about the relationship between objects in space and events in time (Clark, 1973; Lakoff & Johnson, 1980). Just as we might say that an egg *flew by*, we can say that an hour *flew by*. We can *push forward* a log or a meeting, believe that a cactus or a winter is *behind us*, or worry that a bear or a deadline is *approaching*. Prior work has demonstrated that people do not just talk about time using spatial words; they also appear to use specific spatial representations when thinking about time.

For example, in one early set of studies, participants answered questions about time differently, depending on how they had just been thinking about space (Boroditsky, 2000). Some participants were asked to imagine themselves moving through space toward a goal, while others imagined an object coming toward them instead. Then they were asked a seemingly unrelated question about time. They were told that "Next Wednesday's meeting has been moved forward 2 days." What day is the meeting now that it has been rescheduled? The phrase "moved forward" is ambiguous in this context (McGlone & Harding, 1998; Miller & Johnson-Laird, 1976). If you imagine yourself moving forward in time, then forward is further in your direction of motion (from Wednesday to Friday). But if you imagine time moving toward you, then forward can be further in the direction that time is moving (from Wednesday to Monday). Participants who had earlier imagined themselves moving forward through space were more likely to say the meeting would be on Friday (further in their direction of motion) than those who had imagined an object traveling toward them.

These results suggest that when interpreting spatiotemporal metaphors, people draw on the analogous spatial representations they have readily available in mind.

Further, people appear to construct metaphor-consistent spatial representations for time even when not processing spatiotemporal metaphors in language. For example, English metaphors commonly place events on a horizontal mental timeline with the future "ahead" or "in front" and the past "behind." Correspondingly, English speakers are faster to make decisions about events when doing so involves moving their arm or pushing a slider forward to indicate that an event is in the future and pulling their arm or slider back toward the body to indicate that an event is in the past than for the reverse mapping (Sell & Kaschak, 2011; Ulrich et al., 2012). They are also faster to make past-future judgments to words shown in front of an image of a person for future concepts and behind for past concepts (Torralbo, Santiago, & Lupiáñez, 2006). In addition, people are faster to step forward when they hear words related to the future than the past and faster to step backward for the past than the future (Rinaldi, Locati, Parolin, Bernardi, & Girelli, 2016). In a deliberate gesture task, they gesture to the front when talking about the future and the back when talking about the past (Casasanto & Jasmin, 2012).

These studies suggest that English speakers have representations of time that align with spatiotemporal metaphors in English. However, this does not necessarily mean that metaphors in language played any role in constructing these representations. Patterns in language may simply reflect representations that have emerged through some combination of physical experience and innate predisposition. To examine this possibility, researchers have compared representations of time in speakers of different languages, focusing on cases where different languages rely on different spatial metaphors for time.

For example, English uses primarily front-back metaphors that place the future in front of us (i.e., *looking forward to the future*) and the past behind (*putting the past behind us*). In Aymara, this pattern is reversed, so that past events are in front and future events are behind (Núñez & Sweetser, 2006). Consistent with their linguistic metaphors, Aymara speakers gesture about future events as behind them and past events as in front (in contrast to Spanish speakers from the same region whose gesture patterns and metaphors place the future in front, as in English) (Núñez & Sweetser, 2006).

Researchers have also empirically examined cross-linguistic differences in the representation of time on the horizontal and vertical axes. While English relies primarily on horizontal spatial terms for talking about time, Mandarin commonly relies both on horizontal (front/back) and on vertical (up/down) terms. In Mandarin, earlier events are said to be "up" and later events are "down." Although English does occasionally use vertical metaphors (like *passing knowledge down the generations*), these metaphors are not as systematic, productive, or frequent as they are in Mandarin (Scott, 1989). This difference between Mandarin and English in their use of the vertical axis to talk about time has provided opportunities to investigate corresponding differences in thinking about time.

A variety of experimental methods have revealed that Mandarin speakers are more likely to create vertical representations for time than are English speakers, both in linguistic and nonlinguistic tasks (e.g., Boroditsky, 2001; Boroditsky, Fuhrman, & McCormick, 2010; Fuhrman et al., 2011; Gu et al., 2013; Lai & Boroditsky, 2013; Miles, Tan, Noble, Lumsden, & Macrae, 2011; Yang & Sun, 2015). For example, Mandarin speakers are more likely than English speakers to arrange picture sequences vertically when asked to indicate time progression, more likely to place events on the vertical axis in an elicited pointing task, and more likely to make spontaneous co-speech gestures on the vertical axis when talking about time. The tendency to arrange time vertically is modulated by a number of linguistic variables: It is stronger when participants are tested in Mandarin, in participants who are more fluent in Mandarin, and when the task includes vertical metaphors in Mandarin.

Nonlinguistic tasks that use pictures as stimuli and button presses as responses have also revealed that Mandarin speakers have an active earlier=up implicit association between space and time (Boroditsky et al., 2010; Fuhrman et al., 2011; Miles et al., 2011). In the task used by Boroditsky et al. (2010) and Fuhrman et al. (2011), which was adapted for this current work, participants see an initial image (e.g., Julia Roberts in her 20s) followed by a second image (e.g., either a younger or older Julia). Their task is to determine whether the second image shows a conceptually earlier or later time point than the first and press a key corresponding to their decision. The response keys are arranged so that the *earlier* key is either above or below the *later* key. On these tasks, Mandarin speakers show an implicit association of earlier=up, responding faster when the earlier key is above the later key than the reverse. English speakers tested on the same task show either no evidence of a specific space–time association on the vertical axis or a significantly weaker effect than Mandarin speakers.

The findings discussed so far establish differences in temporal representations between speakers of different languages. Are linguistic metaphors in part responsible for these differences in thought? Of course, metaphors in language are not the only source of space–time mappings. For example, in addition to representations of time on the front-back axis that align with linguistic metaphors, English speakers also show robust representations of time on the left–right axis, with earlier or past events on the left and later or future events on the right. There are no widely used left–right metaphors in English; we do not say things like "Tuesday is left of Wednesday." Instead, these left–right patterns appear to emerge from visuospatial cultural practices in reading and writing. Speakers of Hebrew and Arabic, who read and write from right to left, show right-to-left mental timelines (e.g., Fuhrman & Boroditsky, 2010; Ouellet, Santiago, Israeli, & Gabay, 2010; Tversky, Kugelmass, & Winter, 1991; see also Bergen & Chan Lau, 2012). These findings suggest that cross-cultural differences in thinking about time can come about through sources other than spatiotemporal metaphor, including cultural practices like reading and writing.

1.2. Does language play a causal role?

The cross-linguistic work reviewed so far shows that speakers of different languages represent time differently, in ways that appear to correspond to the patterns of space–time metaphors in their language, and covary with aspects of their linguistic experience (e.g., how fluent they are in the language of interest). Of course, simply establishing such correlations does not establish that linguistic metaphors play a causal role in constructing different representations of time. It is possible, for example, that both the differences in thinking and differences in metaphors arise because of some other set of underlying cultural differences, unrelated to language. Whenever studies compare behavior across different linguistic groups, the design is necessarily quasi-experimental. It is not possible to randomly assign participants to be English or Mandarin speakers—they are already English or Mandarin speakers when they come in, and with these differences come a potentially infinite set of other confounding factors. How then, can we establish whether patterns in metaphorical language can indeed shape how people think?

1.3. Plan of paper

In this article, we experimentally created two new "language communities." We taught English speakers new metaphors for time, with one group learning to say things like "Tuesday is above Wednesday" and the other group learning to say things like "Tuesday is below Wednesday." We examine whether learning new metaphors can create the same kinds of differences in implicit associations between space and time as have been found across cultures. To investigate whether learning new linguistic metaphors induces the same kinds of differences in implicit associations as have been found across cultures, participants completed a nonlinguistic time judgment task that has been used in prior work to establish cross-cultural differences in representations of time (Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011).

Further, we investigate the locus of these effects. Do the newly learned mappings reside strictly in the linguistic sphere? Or are they nonlinguistic representations (ones that are not disrupted by verbal interference)? To this end, some participants did the task without any secondary task, while others did it under conditions of either verbal interference or visual interference (as a control).

Prior work using verbal interference as a probe has uncovered striking examples of linguistic routines or representations being involved in a variety of cognitive tasks that we previously did not expect to involve language. For example, verbal interference has been found to specifically change people's performance (in ways predictable from patterns in language) when making basic color judgments, counting dots, performing simple algebra, reorienting in a small room, and judging the similarity of motion events (Athanasopoulous et al., 2015; Frank & Barner, 2011; Frank, Fedorenko, Lai, Saxe, & Gibson, 2012; Hermer-Vazquez, Spelke, & Katsnelson, 1999; Winawer et al., 2007). Taken together, these findings suggest that even when people are not required to use language to speak or understand, normal human cognition is in fact language-augmented cognition. Human brains recruit linguistic processes in a wide variety of seemingly nonlinguistic tasks, in a way that has real consequences for cognition and behavior.

Some scholars have suggested that this "in the moment" meddling is the only way in which experience with language can influence cognition (e.g., Munnich & Landau, 2003; Papafragou & Selimis, 2010). That is, we can create new linguistic representations and processes that "run alongside" nonlinguistic representations, but experience with language does not create new nonlinguistic representations or processes. Here, we ask whether this is indeed the case. Can learning a new way of talking act as a formative force, creating new nonlinguistic representations that will continue to manifest in cognition and behavior even when our ability to recruit linguistic resources is disrupted?

Finally, we asked whether the new representations we created using purely linguistic training in Experiment 1 differ from those that arise from visuospatial experience. In Experiment 2, we looked at representations of time on the left–right axis that arise from experience in reading and writing text arranged from left to right. We ask whether English speakers' naturally acquired left–right mental timelines behave just as the vertical timelines did in Experiment 1 when paired with verbal and visual interference.

2. Experiment 1

2.1. Methods

Detailed information about participant and trial inclusion criteria, materials, and procedure can be found in the Supporting Information.

2.2. Participants

A total of 206 UC San Diego undergraduates were recruited through the psychology recruitment system and participated for payment or course credit. Participants who were excluded (see inclusion criteria in Supporting Information) were replaced to result in a total of 192 participants for a fully counterbalanced design.

2.3. Procedure

In this experiment, all participants learned a new way to talk about time (see Metaphor Training for details). After training, participants completed a time judgment task (detailed in "Time judgments" section). We used the same nonlinguistic space–time implicit association task that has been used to establish cross-cultural differences in time representations between English, Mandarin, and Hebrew speakers in prior work (Boroditsky et al., 2010; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011). In this task, participants see sequences of two photos and indicate whether the second image shows a conceptually earlier or later time point than the first. Responses are made using button presses, and in different conditions, the *earlier* key is located either above or below the *later* key. Participants completed these judgments under conditions of either verbal, visual, or no interference. For the visual and verbal interference conditions, participants first completed a calibration block (see "Interference calibration" for details) to ensure that the interference difficulty was appropriately scaled across individuals.

The study proceeded in the following phases: (a) interference calibration block (described in Supporting Information); (b) metaphor training block; (c) time judgment block (shown in Fig. 1); (d) second metaphor training block (identical to the first, used as a refresher); and

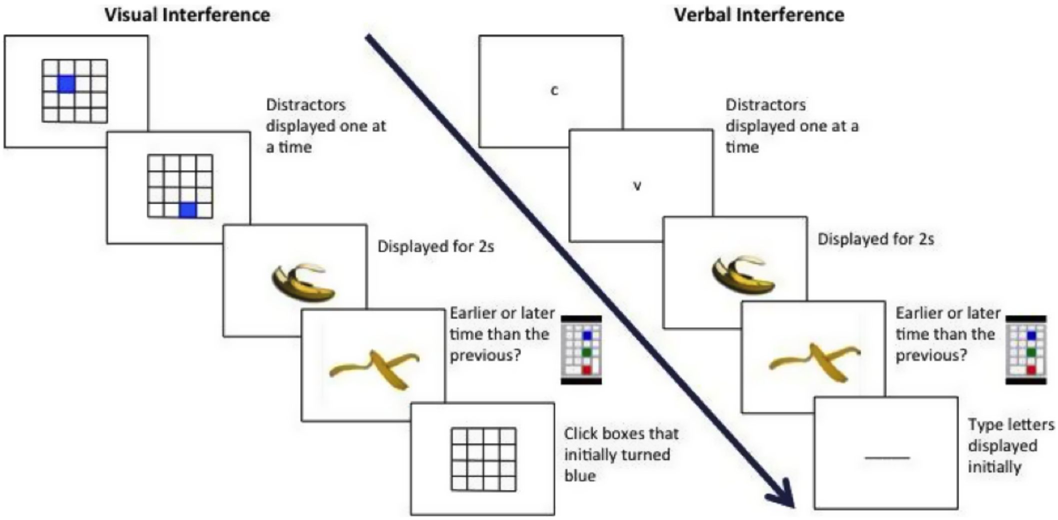

Fig. 1. Task with interference. Participants in the visual and verbal interference conditions saw boxes turn blue or a string of consonants flash, one at a time. They then completed a time judgment trial, in which they saw an image for 2,000 ms, followed by a second image, and reported whether the second image showed a conceptually earlier or later time than the first by pressing one of the response keys (above or below their starting position). Finally, they recalled the interference distractors they had seen at the beginning of the block. Participants in the condition without interference completed only the time judgment trials.

(e) a final time judgment block. For a given participant, the first and second time judgment blocks had opposite assignments of response keys; in one block, the *earlier* key was above *later* and in the other the *earlier* key was below *later*. This made it so that each participant completed one time judgment block for which the arrangement of the response keys was congruent with their metaphor training and one for which it was incongruent. Which metaphor system people were trained on and whether the first time judgment block was congruent or incongruent with the training were counterbalanced across participants.

2.4. *Interference calibration*

Participants in the verbal and visual interference groups first completed a calibration task to ensure that the interference tasks were properly tuned for individual ability. The materials and calibration procedure were identical to those used in Frank et al. (2012). A full description of the procedure is available in Frank et al. (2012). We kept the procedures identical to this prior work because it provides a clear precedent, showing that this same verbal interference task, calibrated in this same way, strongly interferes with people's ability to engage a linguistic routine like counting. If our congruency effects are also due to participants employing an online linguistic routine, then we should find the same deleterious effects of verbal interference.

2.5. Metaphor training

After interference calibration (or at the beginning of the experiment, for participants in the no interference condition), participants were told that they would learn a new way of talking about time. First they read five example sentences showcasing this new system of talking. For half of the participants, earlier events were said to be *above* or *higher* and later events were said to be *below* or *lower* (e.g., Thursday is higher than Friday; When you eat breakfast, dinner is below you). This system was reversed for the other half of participants so that earlier events were *below/lower* and later events were *above/higher* (Thursday is lower than Friday; When you eat breakfast, dinner is above you).

Participants then completed 90 training trials to practice this new system. On each trial, they saw a new sentence describing a temporal relation (e.g., Lincoln was president _________ than Carter) and were asked to type in the correct spatial term (selecting from the two options provided: *higher* and *lower* for the previous example). If the answer was incorrect, the computer provided feedback and required the participant to correct their answer. The keyboard was flat on the surface of the table so that participants could type normally.

2.6. Time judgments

We used the same space–time implicit association task as has been used in prior work (Boroditsky et al., 2010; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011). Participants pressed a central key to begin the trial, and the first of two images appeared on the screen (e.g., Julia Roberts in her 20s). After 2 s, this image was replaced by the second image (e.g., either a younger or older Julia). Their task was to determine whether the second image showed a conceptually earlier or later picture than the first and press a key corresponding to their decision. For all participants, the *earlier* key was above the starting key in one block, and the *later* key was above the starting key in the other. This meant that in one block, the key mapping of responses was spatially congruent with the system of metaphors participants had learned, and in one block, the key mapping was incongruent. In this portion of the experiment, participants made responses on a keyboard mounted vertically (perpendicular to the table surface).

At the beginning of each time judgment block, participants completed 10 practice trials with feedback. After the practice trials, there were 56 experimental trials without feedback. After completing the time judgments, participants returned to another block of training on the same metaphor, and then did another time judgment block (this time with the key mapping reversed from their first run). At the end of the experiment, we collected information about participants' language backgrounds.

2.7. Analyses

We fit the data with mixed effects models using Laplace Approximation using the lmer() function within the lme4 analysis package in R (Bates, Maechler, & Dai, 2008; R

Development Core Team, 2008). The full mixed effects model included time judgment, training, interference conditions, and block order (whether the congruent block was the first or second time judgment block) as fully crossed fixed effects, and subjects and items as random effects.

To examine main effects and interactions, we constructed reduced models that were identical to the full model but did not include the main effects or interactions of interest and compared these reduced models to the full model. Both models had random intercepts plus random slopes for the within-subjects variable of task condition.

2.8. Results

Learning new spatiotemporal metaphors created new nonlinguistic representations of time. That is, English speakers adopted vertical representations for thinking about time that were consistent with the system of metaphors they learned in the lab. These metaphor-consistent representations were not disrupted by either verbal or visual interference.

Participants were faster when the time judgment response keys were arranged congruently with their newly learned metaphors (1,559 ms) than when the responses were arranged incongruently (1,619 ms), confirmed by a significant interaction between training and time judgment conditions, $\chi^2(1) = 8.47$, $p = .004$. There were no speed-accuracy tradeoffs, as participants in the congruent conditions were faster and numerically slightly more accurate. Table 1 shows mean reaction times for each group of participants in each time judgment block.

The congruency effects did not differ between the no interference, verbal interference, and visual interference conditions; there was not a three-way interaction between interference type, training condition, and time judgment condition ($\chi^2(2) = 1.31$, $p = .52$). Pairwise comparisons of the congruency effect between all possible interference types revealed the same null effect (between verbal and no interference, $\chi^2(1) = 1.44$, $p = .23$; between visual and no interference, $\chi^2(1) = 0.79$, $p = .37$; between verbal and visual interference, $\chi^2(1) = 0.02$, $p = .88$). Fig. 2 shows results across the interference conditions (Table 2).

Table 1
Metaphor training reaction times (SD)

	No Interference		Verbal Interference		Visual Interference	
	Earlier Key Is Above	Earlier Key Is Below	Earlier Key Is Above	Earlier Key Is Below	Earlier Key Is Above	Earlier Key Is Below
Learned earlier is UP metaphor	1,500 (414)	1,517 (396)	1,662 (390)	1,769 (412)	1,472 (391)	1,604 (370)
Learned earlier is DOWN metaphor	1,432 (338)	1,392 (333)	1,759 (333)	1,698 (301)	1,635 (458)	1,630 (396)

All reaction times are in ms.

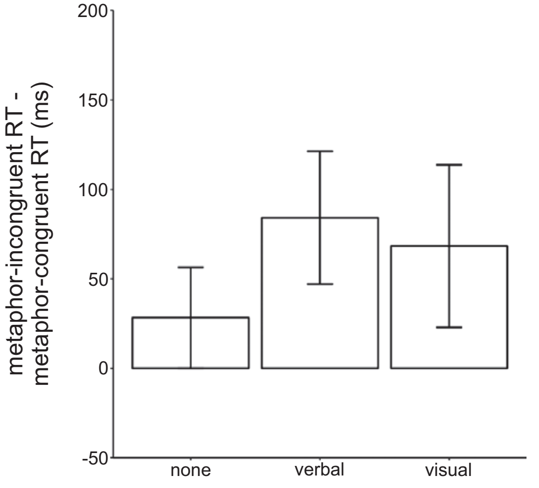

Fig. 2. Results of Experiment 1: Congruency effects were calculated for each participant by subtracting their mean reaction time on trials congruent with their newly learned metaphor from their mean reaction time on trials incongruent with their newly learned metaphor. Error bars show SEMs.

There was no difference in overall reaction times between the groups that learned the two metaphor systems ($\chi^2(1) = 0.007$, $p = .94$).

People were equally accurate on congruent (94.0%) and incongruent (93.9%) trials, suggesting that results in response times were not due to speed-accuracy trade-offs, including congruency in the analysis as a factor (instead of inferring congruency from the interaction between training and task conditions), $F(1, 186) = 0.07$, $p = .80$.

2.9. *Experiment 1 discussion*

In this experiment, we asked whether learning a new way to talk about time can change the way people think about it. To do so, we taught participants new vertical spatiotemporal metaphors, and then probed their representations of time using a nonlinguistic task that has demonstrated culturally consistent representations of time in prior work (Boroditsky et al., 2010; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011). We asked further whether newly learned linguistic metaphors shape representations beyond simply teaching people new linguistic routines. To do so, we introduced verbal interference, using the same procedure that has eliminated people's ability to engage in linguistic routines in prior work (e.g., Frank et al., 2012; Winawer et al., 2007).

We found that after learning the new ways to talk about time, participants showed metaphor-consistent representations in the nonlinguistic task. That is, learning new metaphors in the lab induced the same kinds of differences between our two experimental groups as have been observed previously across cultures. Further, we found that the newly learned representations persevered even under conditions of verbal interference. These findings suggest that relational language, in this case new sets of metaphors, can

Table 2
Metaphor training accuracies

		No Interference		Verbal Interference		Visual Interference	
		Earlier Key Is Above	Earlier Key Is Below	Earlier Key Is Above	Earlier Key Is Below	Earlier Key Is Above	Earlier Key Is Below
Time judgments	Learned earlier is UP metaphor	94.3	95.4	94.1	92.7	94.1	92.6
	Learned earlier is DOWN metaphor	94.6	94.6	93.2	93.1	94.9	93.8
Interference memory	Learned earlier is UP metaphor	——	——	79.6	79.6	68.1	67.0
	Learned earlier is DOWN metaphor	——	——	75.9	76.7	66.2	63.3

indeed act as a formative force in creating new nonlinguistic representations. It appears that participants who learned to say things like *Tuesday is above Wednesday* did more than simply learn a new way of talking. They created new representations of time on the vertical axis, representations that went beyond the specific linguistic forms and persisted even under conditions of verbal interference. When we encounter relational language, it appears we are invited to create new mental models. Language can invite us to imagine and represent the world in new ways.

A further question arises from the results of the visual interference condition. In Experiment 1, we saw that linguistically acquired space–time mappings were not susceptible to visual interference from a block-grid interference task. Is this a special feature of space–time mappings that is acquired through language? Or would space–time mappings acquired through visuospatial experience likewise be unaffected by this kind of visual interference (and verbal interference)? That is, are representations acquired through language necessarily different from those acquired through other means?

To explore these questions, in Experiment 2 we tested American college students' representations of time on the left–right axis and used the same conditions of verbal and visual interference as in Experiment 1. Representations of time on the left–right axis have been shown to arise from visuospatial experience, especially practice with reading and writing. People who read and write text arranged from left to right organize time with earlier events on the left, and those who read from right to left organize time accordingly with earlier events to the right (e.g., Fuhrman & Boroditsky, 2010; Ouellet et al., 2010; Tversky et al., 1991). Importantly for our purposes, representations of time on the left-to-right axis in English speakers could not have arisen from linguistic metaphors. English does not canonically use the terms *left* and *right* to talk about the order of events; we don't say "let's move the meeting to the right" or "The party is left of Sunday." This allows us to compare the existing left–right representations of time acquired through visuospatial experiences with the newly learned vertical representations of time acquired through linguistic metaphor in Experiment 1.

3. Experiment 2

Are mental representations of time that result from reading and writing experience robust to the verbal and visual interference, as those arising from linguistic metaphor in Experiment 1 were? To address this question, we adapted the methods used in Experiment 1 to test American college students' left–right mental timelines.

3.1. Methods

3.1.1. Participants and trial inclusions

A total of 102 UC San Diego undergraduates participated for course credit. They received a link to participate through the Psychology participant recruitment site. Participants were excluded based on inclusion criteria detailed in the Supporting Information. After exclusions, the three conditions included 30 participants each, for a total of 90 participants.

3.2. Materials and procedure

The materials and procedure were identical to those of Experiment 1 with two exceptions. Participants did not learn a new way of talking about time, and the response keys were arranged on the left–right axis.

As in Experiment 1, participants in the interference conditions completed the same calibration block at the beginning of the experiment, and everyone completed two blocks of the time judgment task with opposite key-mapping instructions. The time judgment task included either visual or verbal interference for participants in those conditions. There were again 10 practice trials and 56 experimental trials in each block.

3.3. Analyses

We again fit the data with mixed effects models. The full mixed effects model included congruency (with the canonical left–right timeline), interference condition, and block order (whether the congruent block was the first or second time judgment block) as fully crossed fixed effects, and subjects and items as random effects. As in Experiment 1, we compared reduced models to the full model to investigate main effects and interactions.

3.4. Results

American college students showed robust left–right mental timelines that were not changed by either verbal or visual interference.

Participants were faster when the response keys were arranged with *earlier* on the left (1,578 ms) than with *earlier* on the right (1,968 ms), as confirmed by a main effect of congruency, $\chi^2(1) = 51.8$, $p < .00001$. Table 3 shows mean reaction times for each group in each time judgment block.

Table 3
Left–right reaction times (SD) and accuracies

	No Interference		Verbal Interference		Visual Interference	
	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
RT (ms)	1,430 (450)	1,805 (631)	1,770 (415)	2,129 (483)	1,534 (501)	1,971 (642)
Accuracy %	93.3	91.8	92.8	90.3	91.1	86.5

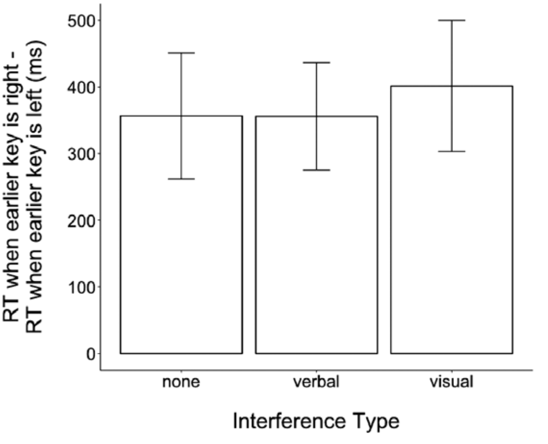

Fig. 3. Results of Experiment 2: Congruency effect for representations on the left–right axis (ms). Congruency effects were calculated for each participant by subtracting their mean reaction time for congruent trials (*earlier* response key is to the left of the *later* key) from their mean reaction time for incongruent trials. Error bars show 95% SEMs.

As in Experiment 1, each participant's congruency effect was calculated by subtracting their mean reaction time on congruent (earlier = left; later = right) trials from their mean reaction time on incongruent trials (shown in Fig. 3). Congruency effects did not differ among the interference types, as there was no interaction between interference type and congruency, ($\chi^2(2) = 0.47$, $p = .79$). Pairwise comparisons of the congruency effect between all possible interference types revealed the same null effect (all ps > .50). In sum, manifestations of people's left–right mental timelines were unaffected by the interference conditions they experienced while making time judgments.

People were overall more accurate on congruent time judgment trials (92.4%) than on incongruent trials (89.6%) ($F(1, 87) = 14.93$, $p = .0002$). This suggests that the congruency results observed in response times were not due to a speed-accuracy tradeoff, as participants were both faster and more accurate on congruent trials.

3.5. Comparing Experiments 1 and 2

We combined the data from Experiments 1 and 2 to investigate differences in the congruency effects that arise from linguistic metaphor (Exp 1) and from visuospatial experience (Exp 2). Although participants demonstrated a larger congruency effect on the left–right than on the vertical axis ($\chi^2(1) = 75.1$, $p < .0001$), the interference types did not differently influence the congruency effect between the two studies ($\chi^2(2) = .87$, $p = .65$). In other words, there was no difference in the robustness of people's spatiotemporal representations to the interference types between the group whose representations arose from new metaphors and the group whose representations arose from visuospatial experience.

Our studies included another kind of interference intrinsic to the experiment design. On incongruent blocks, participants were asked to use key mappings that contradicted their representations (whether newly learned or long established). This instruction can itself be viewed as a kind of training—creating a new association between space and time. This allowed us the opportunity to ask whether this new instruction also had an effect on people's representations, and if so whether that effect was different for those whose representations resulted from learning new vertical metaphors than those whose representations resulted from a lifetime of visuospatial experience. To examine this, we computed the size of the congruency effect across trials. That is, as participants completed more and more trials with either the congruent or incongruent instruction, did the difference in reaction times between congruent and incongruent responses decrease, increase, or stay the same? If the response instruction is indeed providing a kind of counter-training, we might expect that the congruency effect should be stronger in earlier trials and weaker in later trials, decreasing as the number of "counter-training" trials increases.

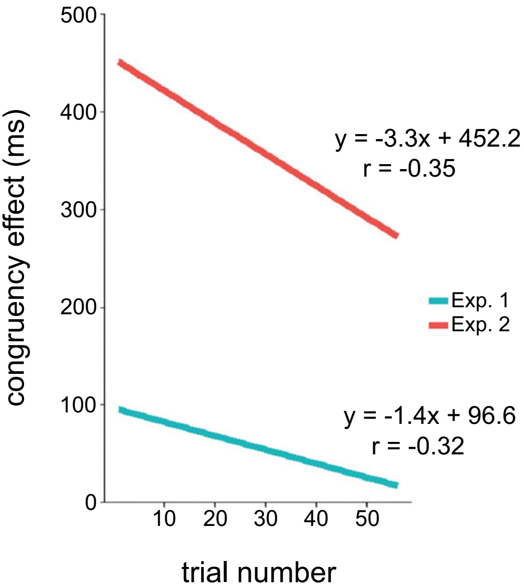

Fig. 4. Congruency effect (in ms) plotted over the course of time judgment blocks for Experiments 1 and 2. Congruency effect (faster responses for congruent blocks than incongruent blocks, whether with respect to newly learned metaphors or long-term visuospatial experience) over the course of time judgment blocks.

This is indeed what we found for both experiments, as shown in Fig. 4. There was a significant negative correlation between trial number and the congruency effect both in Experiment 1 ($r(54) = -0.32$, $p = .02$) and in Experiment 2 ($r(54) = -0.35$, $p = .009$). These findings suggest that the instructions for a block of time judgments act as a separate kind of training, strengthening the instruction-consistent representation of time over the course of a block.

It is striking that even representations that have been established over many years of experience (here, the left–right representations in Experiment 2) can be changed or partially overridden by a new mapping introduced in the lab (here, the arrangement of response keys). These findings, along with the results of Experiment 1, suggest that our representations of time are malleable and dynamic. People appear willing and able to learn new psychologically real spatializations for time through a variety of means (whether through verbal metaphor or through a pattern of motor movements to response keys).

4. General discussion

Results of two experiments show that learning a new way to talk about time can foster new nonlinguistic mental representations, ones that are not susceptible to verbal interference. Further, representations of time arising from linguistic metaphor do not appear to differ from those arising from visuospatial experience.

In Experiment 1, we taught English speakers to talk about time using new vertical linguistic metaphors, saying things like "breakfast is above dinner" or "breakfast is below dinner." We then tested whether the space–time associations implied in the metaphors would be detectable in a nonlinguistic space–time association task. We used the same nonlinguistic task as has been used previously in work establishing cross-cultural differences in thinking about time. In Experiment 2, rather than teaching people new metaphors, we relied on the left–right representations of time that our American college student participants have already internalized through a lifetime of visuospatial experience reading and writing text arranged from left to right. In both experiments, we asked whether the representations (whether newly acquired from metaphor or acquired over many years of visuospatial experience) are susceptible to verbal interference. We used the same verbal interference paradigm that has disrupted verbal processes in prior work.

We found that (a) learning new metaphors created new space–time associations that could be detected in a nonlinguistic implicit association task; (b) these newly learned representations were not susceptible to verbal interference; and (c) with respect to both verbal and visual interference, representations newly learned from linguistic metaphor behaved just like those on the left–right axis that our participants had acquired through years of visuospatial experience.

Importantly, both types of interference (verbal and visual) did to some extent interfere with performance. As would be expected, people were overall slower when performing the task under interference than with no interference. This helps assure us that the interference paradigms were indeed engaging limited cognitive resources. What we do not find is a differential effect of either kind of interference across congruency conditions: People were not disproportionally slower under interference in the incongruent key-mapping condition as compared to the congruent condition. That is, while both interference paradigms made the task more difficult overall, neither kind of interference eliminated the specific mapping between space and time (e.g., up=earlier) being measured in the task.

If tying up linguistic or visual resources in general does not eliminate people's specific space–time associations, what would? Our results suggest that what does affect the strength of specific space–time associations is exposure to new space–time associations. For example, throughout the course of a block (56 time judgments in these experiments), participants become increasingly acclimated to the response key assignments for that block. In effect, the current block's key assignment acts as a new space–time association training, and the congruency effect gradually decreases. We found this in both Experiment 1 and Experiment 2, suggesting that representations newly learned through metaphors and those learned through years of visuospatial experience were both affected by new space–time associations enforced by the arrangement of key responses.

A similar story emerges in other work, where we have trained Chinese-English bilinguals to use the vertical metaphors used here in Experiment 1. Chinese natural language metaphors refer to earlier events as above later ones, but bilinguals who learned the opposite system in the lab (that earlier events are below later ones) showed a significantly smaller earlier is up bias than those who learned Chinese-consistent metaphors or no metaphors at all (Hendricks & Boroditsky, unpublished data). That is, when people learn a new space–time association, whether as a result of response key assignments or through new linguistic metaphors, their previously held associations (measured as congruency effects) are diminished.

These results suggest that our representations of time are highly dynamic and can quickly change with new experience. Even patterns acquired over years of experience can be significantly pushed around by relevant new mappings. These findings also offer a context for thinking about the effects of linguistic training. Some theorists may find it surprising that a brief linguistic training in the lab could produce new patterns in nonlinguistic behavior. These data suggest that instruction and experience of many types can shift our representations of time; even representations of a fundamental conceptual domain like time are more dynamic and less etched in stone than previously supposed.

Results of Experiment 1 show that we can use purely linguistic training to induce the same kinds of differences in thinking about time as have been found previously between cultures. These results are important for establishing that patterns in language, and specifically metaphor, can play a causal role in shaping people's representations of time. Experimentally changing what metaphors people use changes the way they think.

The training paradigm allows us the needed experimental control to make causal inferences. Of course, learning metaphors in the lab is very different from natural language experience. Further work using the same methods used in this article to test native Mandarin speakers' representations of time on the vertical axis has shown that these are also robust to the same visuospatial and verbal interference tasks applied here (Hendricks & Boroditsky, unpublished data). At least with respect to susceptibility to generic verbal and visuospatial interference, representations arising from new metaphors and those consistent with long-term linguistic experience do not appear to differ. In future work, exploring relevant ways in which the two kinds of experience might differ would shed further light on the mechanisms through which exposure to metaphors in language might shape cognition.

5. Conclusions

Experimentally changing what metaphors people use changes the way they think. We found that teaching people new space–time metaphors in language encouraged them to create new representations of time. Further, it appears that language experience acted as a formative force, creating new nonlinguistic representations. First, the newly acquired representations were detectable in an entirely nonlinguistic task, and further, they were not disrupted by verbal interference. Finally, these newly learned representations that originated in language behaved just like long-established representations of time on the left–right axis that arose from visuospatial experience in reading and writing. Neither kind of representation was susceptible to generic verbal or spatial interference, and both were affected by a specific incongruent space–time association imposed by a motor response instruction. Taken together, these results suggest that learning new relational language can be a powerful tool in constructing new representations and expanding our cognitive repertoire. That is, we found both that language can *shape* thought and that language can shape *thought.*

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Fig. S1. Interference calibration. Participants began by seeing two boxes turn blue or two consonants, one at a time. They then searched for an "L" among an array of Ts, pressed the "L" key if the "L" was present ("K" otherwise), and recalled the interference array by either clicking on boxes or typing in consonants.

Data S1. Detailed methods.