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How the physicality of space affects how we think about time

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Abstract
Time is an abstract concept that may be better understood when mapped onto space. For English speakers, typically a timeline is used that runs horizontally from left (past) to right (future) (Boroditsky, Fuhrman, & McCormick, 2011) and can be separated into regions, past and future. However, it is unclear from prior research how these regions along the timeline are differentiated. In addition, although for English speakers time is typically thought of in terms of a left–right axis, gestures and metaphors that conceptualize the past as behind and the future as ahead are prevalent, implicating the use of a front–back axis. In three experiments, participants made temporal judgments of pictures while holding their hands in various positions around their bodies, to assess whether the body or hands or both are used as anchors to differentiate regions and whether the front–back axis can be used as a timeline. In Experiment 1 we found independent influences of the body and the hands in anchoring the left–right axis. In Experiment 2 we found support for the use of the front–back axis to map time, with independent influences of the body and the hands in anchoring this axis as well. In Experiment 3 we demonstrated that the timeline must be configured in a way that is consistent with underlying conceptualizations of time, by showing that the above–below axis is not used for English speakers. Together, these results indicate that time is mapped onto space, with this mapping being constrained by underlying conceptualizations of time.

Keywords Space · Time · Front–back · Left–right

If someone told you the meeting scheduled for Wednesday of this week had been moved forward two days, when would you think the meeting was now taking place—two days earlier (i.e., Monday) or two days later (i.e., Friday)? McGlone and Harding (1998; see also Boroditsky, 2000; Clark, 1973) found that if they first encouraged participants to think about moving through time toward the future, the participants were then more likely to report that the meeting would be on Friday. From this ego-moving perspective, time is fixed and the meeting has moved forward in the direction of motion of the individual. However, if participants were encouraged to think about time moving from the future to the past like a river flowing past them, they were more likely to report that the meeting would be on Monday. From this time-moving perspective, the individual is fixed and the meeting has been moved forward in the direction of the motion of time. In both cases, time is being mapped onto the domain of space through the use of the imagined front–back axis of the individual. The ambiguity is in the way this mapping is accomplished. Such confusion stems in part from the fact that time is an abstract concept that can be difficult to think about. To make this easier, the more concrete domain of space can be used.

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Using space to understand time

There is solid evidence to suggest that time is often mapped onto space. For example, spatial metaphors are used to talk about time, such as *in the weeks ahead* or *the past is behind you now* (Boroditsky, 2000; Lakoff & Johnson, 2003), which use the front–back axis. In addition, gestures are made when we talk about time, and English speakers often gesture to the left to emphasize the past and to the right to emphasize the future (Casasanto & Jasmin, 2012). Finally, strong empirical support has documented the use of space to organize time, including studies that have examined how people arrange cards in spatial orders to depict temporal events (Bergen & Chan Lau, 2012; Fuhrman & Boroditsky, 2010; Miles, Tan, Noble, Lumsden, & Macrae, 2011; Tversky, Kugelmass, & Winter, 1991), how spatial information affects the way we think about temporal information (Boroditsky, 2001), how people point to different areas of space when instructed to point to temporal events (Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011), and how quickly people react when asked to respond spatially to temporal words or pictures (Boroditsky, Fuhrman, & McCormick, 2011; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011; Miles et al., 2011; Torralbo, Santiago, & Lupiáñez, 2006; Weger & Pratt, 2008). When using cards or a computer screen, only two dimensions of space are normally available (left–right and above–below). The different studies have shown that English speakers put temporal events in consistent two-dimensional spatial patterns (left to right), and thus respond faster when early or past judgments are made in left space and when late or future judgments are made in right space.

Spatial reference frame and its parameters

One possible mechanism for mapping time onto space is a spatial reference frame that comprises a set of axes that divide up space so we can easily determine and communicate about the locations of objects (Carlson, 2003; Carlson & van Deman, 2004; Levelt, 1984; Levinson, 1996; Logan, 1994). A spatial reference frame configures space by means of four parameters: origin, orientation, direction, and scale. The reference point is called the *origin*, and the intersection point of the axes is imposed onto space at this point. This is the anchor of the reference frame and serves to divide space along an axis into different regions. Orientation defines a given axis as either horizontal (left–right and front–back) or vertical (above–below), and direction differentiates the endpoints of a given axis (e.g., left and right on the left–right axis). Finally, scale corresponds to the spatial extent of the regions. This extent may vary, encompassing a small area, such as the surface of a desk or a large area, such as a city.

Orientation and direction are used consistently to map time onto two-dimensional space (Boroditsky et al., 2011; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011) and are often talked about together as a *timeline*. The timeline is the cornerstone of the empirical method used to study how time is mapped onto space, which is typically measured using the temporal judgment task (Boroditsky et al., 2011; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011), depicted in panel A of Fig. 1. Sets of three pictures (early, middle, late) illustrate a temporal

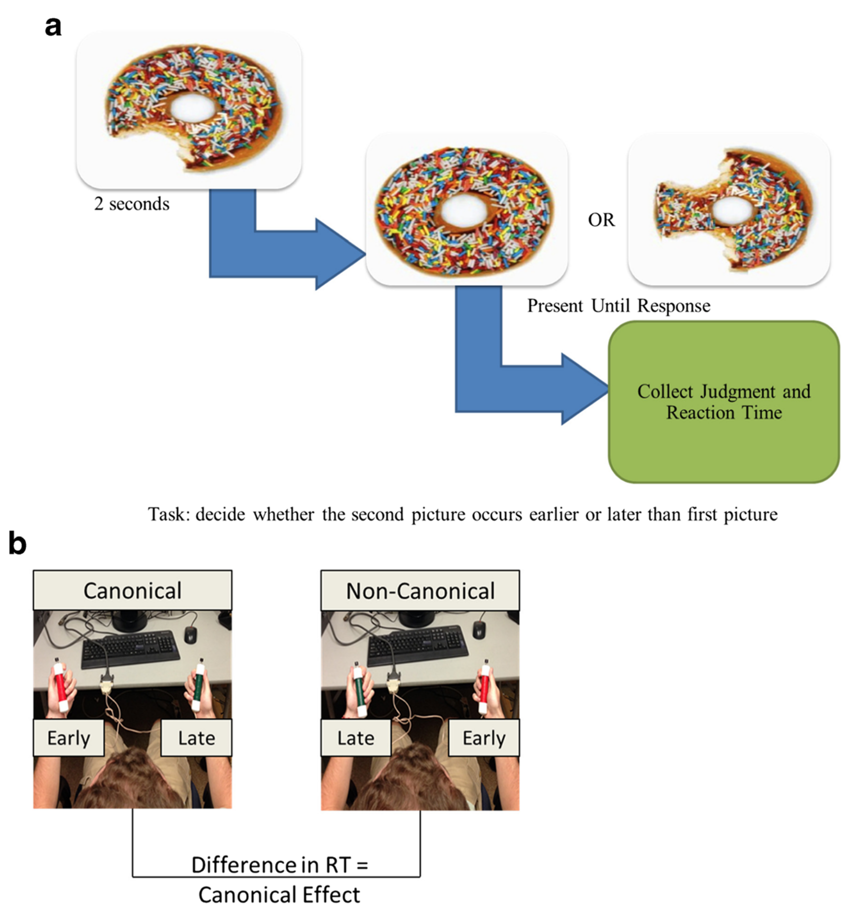

Fig. 1 Temporal judgment task. (A) The procedure on each trial of the temporal judgment task, borrowed from Fuhrman et al. (2011). (B) A canonical mapping condition (on the left) and a noncanonical mapping condition (on the right), if a participant was assigned to use the red switch to represent early and the green to represent late. The assignments of colored switches to responses were counterbalanced across participants

sequence, such as a full donut, a donut with a bite taken out, and a donut with two bites taken out. Participants are first shown the middle picture and then either the early or the late picture, and they are asked to determine whether the second picture occurred earlier or later than the first picture. Both the response and the response time are measured. The assignment of responses to directions, usually along the left–right axis, is manipulated, as is shown in panel B of Fig. 1, with a canonical mapping being defined as *early* judgments on the left side and *late* judgments on the right side, and a noncanonical mapping as *late* judgments on the left side and *early* on the right.

English speakers are usually faster to respond in canonical than in noncanonical mapping conditions (Boroditsky et al., 2011; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011; Ishihara, Keller, Rossetti, & Prinz, 2008; Miles et al., 2011; Torralbo et al., 2006), indicating a preference to organize time from early on the left to later on the right. This compatibility effect has been termed a *canonical effect* and is demonstrated by the difference in response time between the two conditions, as indicated in panel B of Fig. 1.

Present study

In this study, we performed three experiments to investigate possible mechanisms for mapping time onto space. Experiment 1 examined whether the body, the hands, or both contribute to defining the endpoints as early on the left and later on the right on the left–right axis. Experiment 2 examined whether the front–back axis can be used within this task to map time, and if so, whether there is a preferred direction (e.g., early events behind later events); it also examined whether the body, the hands, or both contribute to defining the endpoints of this mapping. Experiment 3 demonstrated that canonical effects are only found when the mapping matches participants' underlying conceptualization of time, by examining English speakers' responses on the vertical above–below axis, an axis not normally used for time.

Experiment 1

The origin parameter of a reference frame anchors the timeline to a specific point in space, thereby associating the endpoints with different times. One open question is what source of information is used to define the origin. For example, in Boroditsky et al. (2011), the body midline could be used, defining left space as that extending from the midline to participants' left sides, and right space as extending from the midline to participants' right sides. However, it is also possible that these regions may be defined by the hands, with the left hand defining left space and the right hand defining right space. In the paradigm used by Boroditsky et al., only the right hand made responses.

In the present study, we employed the factors of crossing and laterality, intending to separate any contributions of the hands and sides of the body. Specifically, we compared uncrossed-hand conditions, in which the hands and the body were aligned, with crossed-hand conditions, in which the hands and body defined the endpoints differently. In addition, we compared bilateral conditions, in which participants held one hand on each side of their body, to unilateral conditions, in which participants held both hands on one side of the body. These conditions are shown in Fig. 2.

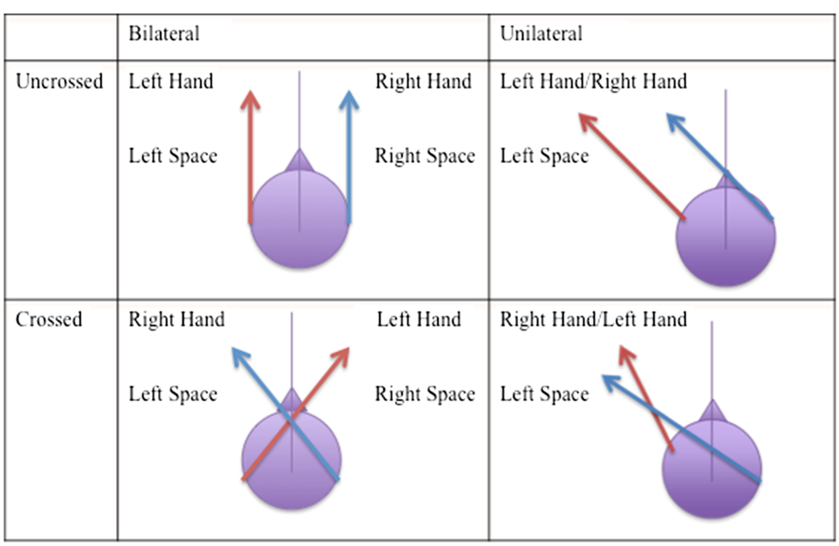

Fig. 2 Schematic for Experiment 1. Participants completed canonical and noncanonical trials in each of the four conditions above. For the unilateral conditions (right side), whether the hands were placed on the left or the right side of the body was counterbalanced across participants. For each specific judgment, we categorized it by both the hand it was made with and the side of the body it was made on, to look for independent contributions of the hands and body

This research follows well-estiablished literature on spatial compatibility (Brebner, Shephard, & Cairney, 1972; Dittrich, Dolk, Rothe-Wulf, Klauer, & Prinz, 2013), the Simon effect (Hommel, 2011), and stimulus response compatibility (Cho & Proctor, 2003; Stins & Michaels, 2000). Previous research has attempted to separate out the contributions from spatial locations and from the hands in different paradigms (Brebner et al., 1972; Nicoletti, Anzola, Luppino, Rizzolatti, & Umiltà, 1982; Roswarski & Proctor, 2000; Wallace, 1971) by using these two manipulations of crossing and hand placement. With respect to crossing, the paradigm most often used includes presenting a stimulus on the left or right of the screen and obtaining responses on the left and the right. A compatibility effect is demonstrated when participants are faster to respond to the left stimulus with a left response and to the right stimulus using a right response.

Using this paradigm, Wallace (1971) compared crossed and uncrossed conditions and found compatibility effects between stimuli and response locations with both crossed and uncrossed hands. Brebner, Shephard, and Cairney (1972) also used this paradigm to compare responses with crossed and uncrossed hands. They found a compatibility effect between the left and right hands and whether responses were made on the left or right side. They also found an effect between the stimulus location (left or right) and whether responses were made on the left or right side. Roswarski and Proctor (2000) looked at compatibility with auditory presentation of stimuli to the left or right ear. They found that responses were faster with a compatible than with an incompatible mapping, and were also faster with uncrossed than with crossed hands, but there was no interaction. In their first experiment, Nicoletti, Anzola, Luppino, Rizzolatti, and Umiltà (1982) looked at the effects of crossing the hands. They found that the uncrossed position led to overall faster responses than the crossed position. When the hands were uncrossed, the right hand responded faster to a right light and the left hand to a left light. However, when the hands were crossed, the left hand (on the right side) responded faster to the right light and the right hand (on the left side) responded faster to the left light. These results indicate that spatial compatibility effects may be driven by the location where responses are made and not necessarily by the hand making the responses.

With respect to placement, Nicoletti, Anzola, Luppino, Rizzolatti, and Umiltà (1982) ran a second spatial-compatibility experiment looking at unilateral placement. They found a compatibility effect between the hand responding and the location of the stimuli. This was the only spatial-compatibility effect that involved the hand responding, but in this paradigm the hands were not crossed just placed off to the side. Also looking at the effects of both hand and side, Blom and Semin (2013) asked participants to retrieve a year-old memory and to move marbles from one box to another. The marble movement was either on their left side (between left and center boxes) or on their right side (between center and right boxes), marbles were moved with the left hand or the right hand, and movement progressed to the left or to the right. The dependent variable was how far away participants felt the memory was after the task. Blom and Semin found that both using the left hand and moving on the left side increased the felt distance to the retrieved event. This demonstrated that both hand and space may influence aspects of the mental timeline.

For the present study, in the uncrossed-bilateral conditions, each hand was placed in its respective space, so that both the hands and the body sides defined the endpoints of the timeline in a consistent manner. When *early* judgments are made with the left hand on the left side and *late* judgments are made with the right hand on the right side, English speakers should respond more quickly, as compared to when *early* judgments are made with the right hand on the right side and *late* judgments are made with the left hand on the left side. This is consistent with a two-dimensional conceptualization of time as going from left to right.

In the uncrossed-unilateral conditions and crossed-unilateral conditions, the hands were both placed on one side of the body so that the hands defined space in one way, but according to the body sides, both hands represented only one side of the body timeline. If the hands make an independent contribution, then participants should respond more quickly when making *early* judgments with the left hand and *late* judgments with the right hand. However, in terms of body side, both hands represented only one side of time (early if placed left, later if placed right); if the body matters, no canonical effect should be present.

Finally, in the crossed-bilateral conditions, the hands and the sides of the body defined space exactly oppositely, creating conflict. *Early* judgments made with the left hand in right space were canonical by hand but noncanonical by body side. *Early* judgments made with the right hand in left space were canonical by body side but noncanonical by hand. If both body and hands play a role, this conflict might eliminate the canonical effect.

To assess the contributions of the body and hands independently, we examined each response, defining it in two ways: first, by the hand used, enabling us to assess any preference for a left-hand–early and right-hand–late mapping; second, by the side of the body on which the response was made, enabling us to assess any preference for a left-side–early and a right-side–late mapping. Significant differences within these analyses should reveal the contributions of the hands and body to differentiating the spaces along the timeline.

Method

Participants Fifty-nine University of Notre Dame students completed this experiment for course credit. All participants were right-handed, with normal or corrected-to-normal vision. Twelve participants were excluded due to malfunctioning of one of the custom-made handheld switches, such that it did not record responses; this was fixed once identified. Two participants were excluded due to low accuracy (<70% correct responses), and five participants were excluded due to familiarity with a language written differently from English, leaving 40 participants whose data were included in the analyses.

Materials The stimuli consisted of 54 sets of three pictures that depicted a sequence of events occurring over time, adapted from Fuhrman et al. (2011). The picture sets showed an event that unfolded over time, such as a banana being eaten (closed banana, peeled banana, leftover peel); or an individual at various times in his or her life (infant, child, adult); or technology advancing, such as telephones changing over a large period of time.

Experiment 1 was programmed and run using the E-Prime software. Participants responded by pressing one of two handheld switches, one colored red and one colored green. The handheld switches were created by soldering input cords to simple switches and fitting them into PVC pipes. The participants held one switch in each hand and were instructed as to which switch represented early and which represented late. The assignments of switch color to responses were counterbalanced across participants.

Design and procedure The experiment had a 2 (crossing: crossed, uncrossed) × 2 (laterality: unilateral, bilateral) × 2 (mapping: canonical, noncanonical) design, with all factors manipulated within subjects. For the unilateral conditions, half the participants placed both hands to the left, and the other half placed both hands to the right. The four types of conditions are shown in Fig. 2. Note that the uncrossed-bilateral conditions (top left quadrant) correspond to the typical testing configuration from previous research using the temporal judgment task (Boroditsky et al., 2011; Fuhrman & Boroditsky, 2010; Fuhrman et al., 2011). For the purposes of our analyses, the canonical condition was always defined as *early* judgments on the left side and *late* judgments on the right side, regardless of hand, on the basis of previous research showing a stronger effect of side than of hand (Roswarski & Proctor, 2000). When the hands were crossed, this meant that *early* judgments made with the right hand on the left side and *late* judgments made with the left hand on the right side were considered canonical, and *early* judgments made with the left hand on the right side and *late* judgments made with the right hand on the left side were noncanonical.

At the beginning of the experiment, all participants watched a PowerPoint presentation with all 54 sets of three pictures. The pictures were shown in temporal sequence, from earliest to latest. The purpose was to familiarize participants with all of the images being used in the experiment. This was followed by a routine in which participants were asked to press either the early or the late switch in response to instructions in the display six times. Participants were shown how to hold the switches at the beginning of each of the eight conditions, and the experimenter monitored the switch position throughout the experiment. Each participant completed eight conditions in a counterbalanced order. Whether the hands were placed to the left or the right on unilateral conditions was counterbalanced across participants. Each condition included 54 trials, such that each picture set appeared once in each condition. Participants were allowed to take breaks between conditions if they wished.

On each trial, participants were shown a fixation cross for 500 ms, followed by an image at the center of the screen for 2 s, and then a second image in the same location. This procedure is depicted in panel A of Fig. 1. The task was to determine whether the second image shown occurred earlier or later in time than the first image. Participants were instructed to respond as quickly and as accurately as possible. The second image remained on the screen until the participant had responded. The first image shown was always the middle image from its set of three.

Results and discussion

We removed the slowest and fastest responses from each participant in each condition, as described in Bush, Hess, and Wolford (1993). This method maintains the distributions of responses.[1] These trimmed responses accounted for 3.7% of the total trials. Only correct responses were included in the analyses, which constituted 96.9% of the remaining trials. We also compared all eight conditions through an analysis of variance (ANOVA) to determine whether the conditions themselves affected response times via the comfort or awkwardness of a hand position. We found no differences, and both the slowest (noncanonical mapping) and the fastest responses (canonical mapping) were obtained in the most comfortable condition (uncrossed bilateral).

Since in some conditions, specifically the crossed conditions, the mapping was in conflict between the hands and the body, we completed paired *t* tests of the canonical and noncanonical conditions within each placement of the hands. Table 1 shows that the only significant canonical effect occurred in the uncrossed-bilateral condition, in which there was no conflict between body and hands. This serves as preliminary evidence that both the hands and the body may play roles in differentiating the regions of the timeline. If the uncrossed-bilateral condition were simply more comfortable than the other conditions, we would expect the other conditions to have longer response times. However, the slowest response times occurred in the most comfortable position, demonstrating that the other hand positions were neither distracting from the task nor leading to overall longer response times.

[1] We thank an anonymous reviewer for this suggestion, and note that the pattern of results does not change if a ±3 standard deviation outlier removal method was used for trimming.

Table 1 Experiment 1 results

Pair	Canonical Mean	Noncanonical Mean	Mean Difference	Std. Error	$t(39)$	p
Crossed unilateral	977	985	8	66	– 0.127	.900
Crossed bilateral	971	979	8	34	– 0.247	.806
Uncrossed unilateral	935	922	12	35	0.348	.730
Uncrossed bilateral	895	1,016	121	43	– 2.788	.008

All values are in milliseconds.

To better assess the separate contributions of the hands and the side of the body, we collapsed across laterality and crossing of the hands and coded each response on the basis of the hand responding, the body side on which the response was made, and whether the judgment was an *early* or *late* judgment. We then conducted a 2 (Body Side: left, right) × 2 (Judgment: early, late) repeated measures ANOVA that included only the bilateral conditions, because in unilateral conditions both judgments were made on only one body side. We found a significant interaction between body side and judgment type, $F(1, 39) = 5.698$, $p = .022$, with participants responding faster to *early* judgments on the left side and *late* judgments on the right side. This interaction can be seen in panel B of Fig. 3. There were no significant main effects, including no effect of judgment.

To complement this analysis, we ran a 2 (Hand: left, right) × 2 (Judgment: early, late) repeated measures ANOVA using both the bilateral and the unilateral conditions. No significant main effects emerged, including no effect of judgment or interaction. However, a big difference between this analysis and the side analysis was that this analysis also included unilateral conditions. If the time-to-space mapping did not occur in a systematic way in the unilateral conditions, this could have wiped out any effect in this analysis. Therefore, we also

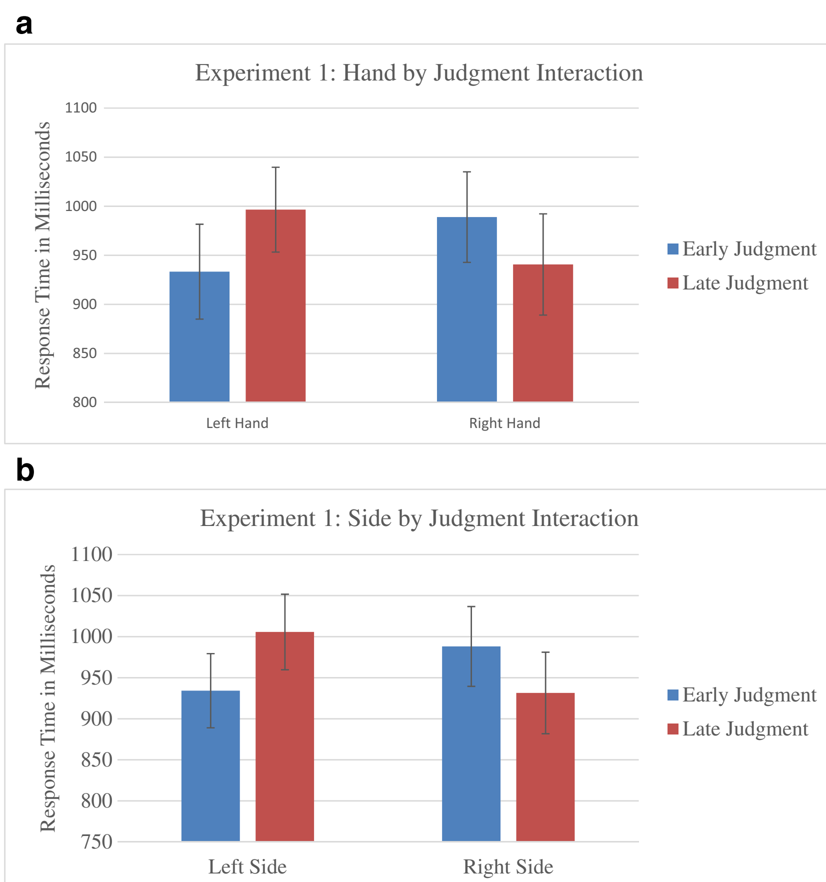

Fig. 3 Hand × Judgment interaction and Side × Judgment interaction in Experiment 1. Participants were faster to make *early* judgments with their left hand and to make *late* judgments with their right hand across all possible placements of the hands. Participants were also faster to make *early* judgments in left space and to make *late* judgments in right space

completed a 2 (Hand: left, right) × 2 (Judgment: early, late) repeated measures ANOVA using only the bilateral conditions and found a trending interaction, $F(1, 39) = 3.9$, $p = .055$, with participants responding faster to *early* judgments with the left hand and to *late* judgments with the right hand. This interaction can be seen in panel A of Fig. 3. These two interactions suggest that the body and the hands both have some importance in differentiating the regions of a timeline and defining the endpoints, consistent with the observed canonical effect when these two sources were not in conflict.

Experiment 2

Metaphors for time in English refer almost exclusively to the front–back axis (Lakoff & Johnson, 2003). In fact, both the ego-moving and time-moving perspectives use the front–back axis to illustrate time, as is shown in Fig. 4. For example, when using the ego-moving perspective, people may say *we are coming up on the holidays.* This implies a forward motion through time. When using the time-moving perspective, people will still use front–back metaphors such as *December is approaching quickly.* This also implies a forward motion of time toward the individual. These examples suggest that people can use the front–back axis to organize time, but it may not be available in the usual research paradigm using computer screens' two-dimensional (left–right and above–below) space.

However, prior research looking at the use of the front–back axis for time has produced limited support. On the one hand, Torralbo, Santiago, and Lupiáñez (2006) demonstrated a canonical effect mapped to the front–back axis, as defined by a side view of a face on a computer screen. Spanish speakers were asked to discriminate between past words and future words presented on the screen at the front or back of the profile head (left or right of the screen). When participants responded verbally, a canonical (past–back, future–front) effect was found with respect to the head. However, when participants responded with the left or right hand, a canonical

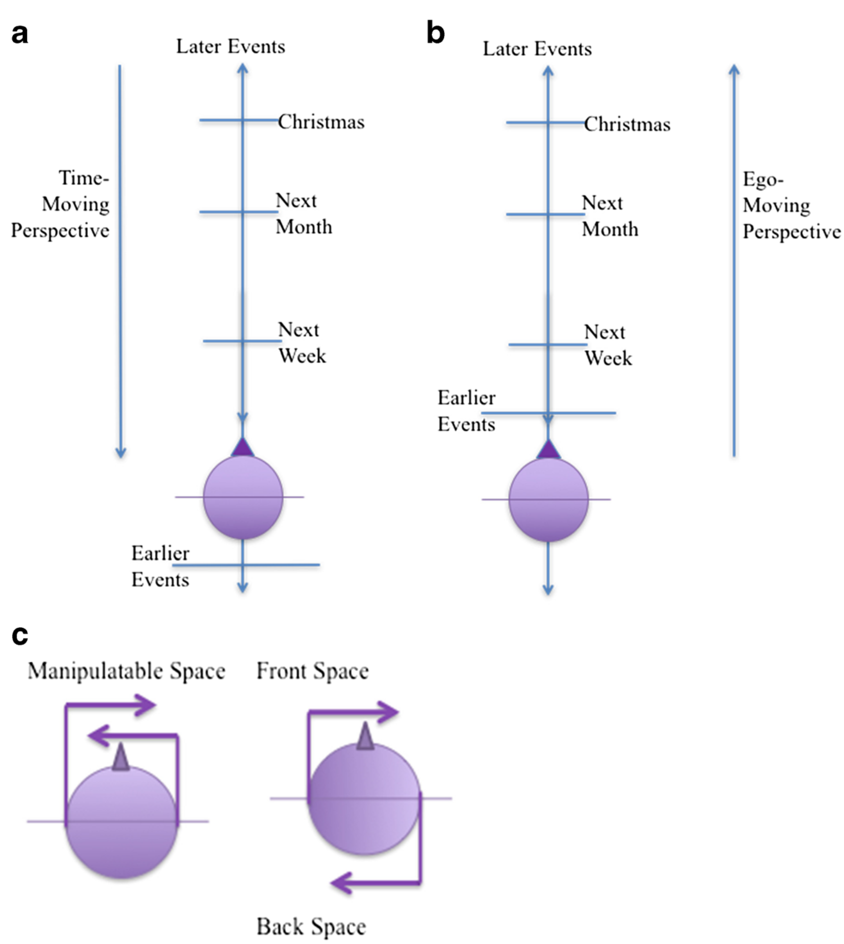

Fig. 4 Experiment 2. (A) One conceptualization of a timeline mapped onto the front–back axis, with the body serving as the anchor. (B) Another conceptualization of a timeline mapped onto the front–back axis, in which all events are in manipulatable space in front of the body. (C) Schematic of the space conditions. Participants completed conditions using only manipulatable space by placing their hands in front of them, one in front of the other (left). They also completed conditions using body space, in which one hand was placed in front of and the other hand behind the body (right). We examined the canonical effects in both conditions

(past–left, future–right) effect was observed. This pattern indicates flexibility in mapping time onto different axes and demonstrates that the specific task may impact the type of time-to-space mapping. On the other hand, Fuhrman et al. (2011) failed to find a canonical effect for temporal judgments made on the front–back axis.

One possible reason for the weak support for the use of the front–back axis in this prior work is that there are two possible ways in which this mapping to front–back space can be accomplished, consistent with the time-moving and ego-moving metaphors. The difference in the mappings depends on where the anchor is located. In English, if an object does not have an intrinsic front, people tend to place the front on the side facing the speaker (Clark, 1973; Hill, 1982; Levelt, 1984, 1996). However, this is not always the case. When driving in a car (or in motion generally), people describe objects farther along the path as being in front. This mapping during motion is similar to the conceptualization of space by Hausa speakers (Hill, 1982). Specifically, if an object does not have an intrinsic front, Hausa speakers tend to place the front on the side away from the speaker, in the same direction as the speaker's front.

Therefore, English speakers may map time to the front–back axis using one of the two mappings, as can be seen in Fig. 4. They may place earlier events behind their bodies and later events in front of their bodies as if they were static. Alternatively, they may place earlier events in front of their body closer to them, and later events in front of those events, as if the origin was in between the earlier and later events, and they were moving. The latter mapping is what normally occurs during motion (as in a car) and may be applied when people adopt the ego-moving perspective, which implies motion through time.

In Experiment 2, we compared conditions in which the front–back space was split by the body to conditions in which both hands were in manipulatable space (in front of the body). Participants placed their hands either both in front of them (with one in front of the other; using manipulatable space) or one in front and one behind (body space), as is shown in panel C of Fig. 4. With respect to the canonical mapping, participants completed canonical trials in which early was behind and later in front, and noncanonical trials in which early was in front and later was behind. Experiment 1 suggested roles for both the body and the hands in configuring the left–right timeline. If both play a role across all axes, we would expect to observe influences of both. Specifically, if the body is important for defining the origin for the front–back axis, we would expect to see a canonical effect in the body space condition. If the hands are important for defining the origin, we would expect to see a canonical effect also in the manipulatable space condition.

Method

Participants Fifty-one University of Notre Dame students completed this experiment for course credit. All participants were right-handed, with normal or corrected-to-normal vision. One participant was excluded from the analysis due to technical problems, leaving 50 participants whose data were included in the analyses.

Materials The stimuli and handheld switches were the same as those in Experiment 1. Experiment 2 was programmed and run using the E-Prime software.

Design and procedure The experiment had a 2 (Space: body space, manipulatable space) × 2 (Mapping: canonical, noncanonical) design, with both factors manipulated within subjects. Which hand was placed in front was counterbalanced between participants, so that half the participants always placed their left hand in front, and the other half always placed their right hand in front. The procedure and task were the same as in Experiment 1, with four conditions. Each participant completed all four conditions in a randomized order, and each condition included 54 trials, so that each picture set appeared once in each condition.

Results and discussion

We removed the slowest and fastest responses from each participant in each condition, as in Experiment 1. These trimmed responses accounted for 3.7% of the total trials. Only correct responses were included in the analyses, which constituted 94.9% of the remaining trials. With only four conditions, we completed pairwise analyses to determine whether the hand placements affected response times via the comfort or awkwardness of holding the hands. We found no difference between the unilateral and bilateral placements with canonical mappings, and no difference between the unilateral and bilateral placements with noncanonical mappings.

To determine whether the canonical effect was present when we used both body space and manipulatable space, we ran paired *t* tests comparing the canonical and noncanonical mapping conditions within each space condition. When the body served as the anchor of body space, a trending canonical effect was found, $t(49) = -1.89$, $p = .064$, with participants responding faster in canonical conditions ($M = 1{,}006$, $SE = 56$) than in noncanonical conditions ($M = 1{,}090$, $SE = 74$). When both hands were placed in manipulatable space in front of the body, a significant canonical effect was again found, $t(49) = -3.06$, $p = .004$, with participants responding faster in canonical conditions ($M = 1{,}040$, $SE = 58$) than in noncanonical conditions ($M = 1{,}132$, $SE = 61$). These results are shown in Fig. 5. This is consistent with English metaphors that place the past behind us and the future ahead of us. English speakers

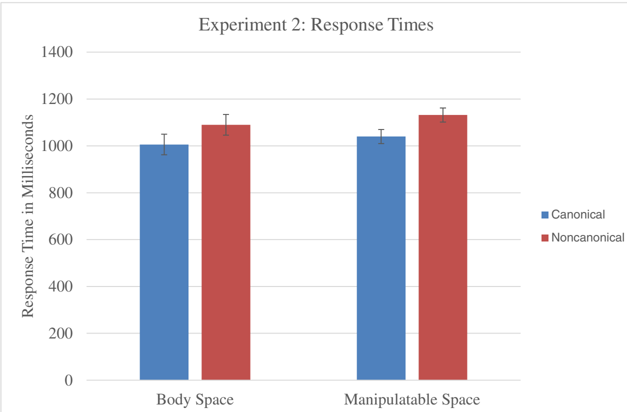

Fig. 5 Experiment 2 response times. When the body served as the anchor of space, a significant canonical effect was found, $t(49) = -1.89$, $p = .064$, with participants responding faster in canonical conditions (M = 1,006, SE = 56) than in noncanonical conditions (M = 1,090, SE = 74). When both hands were placed in manipulatable space in front of the body, a significant canonical effect was also found, $t(49) = -3.06$, $p = .004$, with participants responding faster in canonical conditions (M = 1,040, SE = 58) than in noncanonical conditions (M = 1,132, SE = 61)

are able to map earlier events behind them or in front of them, as long as they are able to map later events in front of the earlier events. The front direction is still being determined by the body, but the body does not need to be at the center of the timeline.

To determine whether there was any effect of hand in this experiment, we ran a 2 (Mapping: canonical, noncanonical) × 2 (Judgment: early, late) × 2 (Hand in Front: left, right) ANOVA, with hand in front as a between-subjects factor. We found a main effect of mapping, $F(1, 48) = 9.31$, p = .004, with participants responding faster to canonical conditions (M = 1,024, SE = 56) than to noncanonical conditions (M = 1,110, SE = 64). We also found a main effect of judgment, $F(1, 48) = 6.84$, $p = .012$, with participants responding faster to *late* judgments (M = 1,047, SE = 56) than to *early* judgments (M = 1,087, SE = 62). This effect of judgment may have been due to reverse retrieval being a different process than forward retrieval (e.g., Li & Lewandowsky, 1995). With a forward order, which occurs when the earlier picture is presented first, accuracy is normally higher. When the later picture is shown first, participants have to reorder the events in their mind to respond correctly, but when the earlier picture is shown first, the events have already been presented in temporal order, and participants simply need to affirm this order. However, we detected no interactions and no effect of which hand was in front, indicating that hand did not affect judgments made on the front–back axis.

To compare the use of the front–back axis to the use of the left–right axis, we compared the canonical effects in the first two experiments. We looked specifically at the canonical effect in the body space conditions on the front–back axis and the canonical effect in the uncrossed-bilateral conditions on the left–right axis. We ran a mixed 2 (Experiment: 1, 2) × 2 (Mapping: canonical, noncanonical) ANOVA. A significant effect of mapping emerged, $F(1, 39) = 7.496$, $p = .009$, but no significant effect of experiment, $F(1, 39) = 2.026$, $p = .163$. The canonical effect was present on both horizontal axes, and which axis was chosen might depend on the task demands. An emphasis on two-dimensional space might have allowed use of the left–right axis to be demonstrated experimentally more often and more robustly than the use of the front–back axis. These effects might also be tied to language and writing. English speakers read from left to right, and also map time as moving from left to right in two dimensions. However, in language, the front–back axis is used in metaphors placing the past behind and the future in front.

We cannot rule out that participants simply used a midpoint between the hands, whether or not the body was there. However, if participants did not use the body, we would expect to see a canonical effect in the unilateral conditions in Experiment 1. Since we did not find a canonical effect on the left–right axis when the hands were placed on one side of the body, this might imply that the body plays a role in the mapping. It also might play a role along the front–back axis, but the effects are stronger when both hands are in front of the body, in manipulatable space.

Experiment 3

In Experiments 1 and 2, we asked participants to use the left–right and the front–back axis for time and observed significant canonical effects. We argue that this is because each of these mappings corresponds to an underlying conceptualization of time. In Experiment 3 we showed that this underlying conceptualization is critical, by asking English speakers to use an axis that is not typical for them to use in mapping time—specifically, vertical above–below.

Note that this mapping is consistent with some effects that have been observed in cultures that use vertical metaphors for time (Boroditsky et al., 2011). Using the temporal judgment task, Boroditsky et al. found that English speakers only showed a canonical effect on the left–right axis, but that Mandarin speakers showed canonical effects on both the left–right and the above–below axis. These effects were related to how Mandarin can be written (vertically), as well as to common metaphors that place earlier events up and later events down.

However, Chen (2007) found that the horizontal metaphor for time was much more prevalent in Mandarin than the vertical metaphor. Chen and O'Seaghdha (2013) used the temporal judgment task to compare English speakers with Mandarin speakers from China and from Taiwan. The picture sequences used represented events such as a man walking through a door. They found that both English speakers and Mandarin speakers from China showed a left–right congruency effect. However, Mandarin speakers from Taiwan only showed an above–below congruency effect, demonstrating that differences in how time is mapped to space can be based on more than just language.

On the basis of Boroditsky et al. (2011), we predicted no canonical effect on the above–below axis for English speakers. However, to offer a more stringent test, we examined conditions with the hands and/or body defining the anchor. Specifically, we compared three conditions. In the close position, both hands were in front of the chest, analogous to Boroditsky et al.'s vertical experiment. In the medium distance position, participants placed one hand in front of their chest and one below the chair, so that the center of the body (the waist) could serve as the origin. In the far position, participants placed one hand above their head and one below the chair, so that the entire body could serve as the origin. We also had participants complete two response mappings, one with the past above (which we labeled *canonical*) and one with the past below (which we labeled *noncanonical*).

Method

Participants Fifty University of Notre Dame students completed this experiment for course credit. All participants were right-handed, with normal or corrected-to-normal vision. Two participants were excluded from the analysis due to technical issues, one participant was excluded due to less than 70% accuracy, and 12 participants were excluded due to exposure to languages written differently from English, leaving 35 participants whose data were included in the analyses.

Materials The stimuli and handheld switches were the same as those used in Experiments 1 and 2. Experiment 3 was programmed and run using the E-Prime software.

Design and procedure The experiment had a 2 (Mapping: canonical, noncanonical) × 3 (Spacing of the Switches: close, medium, far) design, with both factors manipulated within subjects. Which hand was placed above was counterbalanced between subjects, so that half of the participants always placed their left hand above and the other half always placed their right hand above. The canonical condition was defined as *early* judgments made above and *late* judgments made below, on the basis of Mandarin metaphors for time. The noncanonical mapping was defined as *early* judgments made below and *late* judgments made above. The procedure and task were the same as in Experiment 1, with six conditions. Each participant completed all six conditions in a randomized order, and each condition included 54 trials so that each picture set appeared once in each condition.

Results and discussion

We removed the slowest and fastest responses from each participant in each condition, as in the earlier experiments. These trimmed responses accounted for 3.7% of the total trials examined. Only correct responses were included in the analyses, which constituted 95.2% of the remaining trials. We also compared all six conditions in an ANOVA to determine whether the conditions themselves affected response times via the comfort or awkwardness of holding the hands. We found no differences, and both the slowest (canonical mapping) and fastest (noncanonical mapping) conditions were obtained with the same far hand placement.

We completed a 2 (Mapping: canonical, noncanonical) × 3 (Spacing of the Switches: close, medium, far) repeated measures ANOVA. No main effects were apparent, nor was an interaction between spacing and mapping.[2] The response times are shown in Fig. 6. These results demonstrate that participants did not show any effect of the different mappings they were asked to complete.

To examine whether there was a hand effect on this axis, we ran a 2 (mapping: canonical, noncanonical) × 2 (Judgment: early, late) × 2 (Hand on Top: left, right) mixed ANOVA, in which we found a three-way Mapping × Judgment × Hand on Top interaction, $F(1, 33) = 7.342$, $p = .011$. On the basis of the mapping condition and the hand on top, we determined which judgments were made with which hand. Participants were faster to make *early* judgments with the left hand ($M = 898$, $SE = 61$) than with the right hand ($M = 920$, $SE = 61$). They were also faster to make *late* judgments with the right hand ($M = 876$, $SE = 63$) than with the left hand ($M = 939$, $SE = 63$). We interpreted this as evidence that hands may play a stronger role when time is being mapped to a spatial axis not normally used for time.

General discussion

These experiments show that both the hands and the body are important for anchoring the timeline and defining the endpoints, and that the most successful mapping occurs when the hands and body are aligned. On the left–right axis, the only canonical effect present occurred when the hands were uncrossed and placed bilaterally, with the hands and body aligned. This condition was also faster than those with any other hand position. There was a preference to make *early* judgments with the left hand and *late* judgments with the right

[2] Looking for any evidence of a mapping effect, we also completed paired *t* tests of the canonical and noncanonical conditions within each placement of the hands The only significant difference was found between the two mappings at far distance, $t(39) = 2.986$, $p = .005$, with participants responding faster in the noncanonical condition ($M = 857$, $SE = 29$) than in the canonical condition ($M = 944$, $SE = 29$).

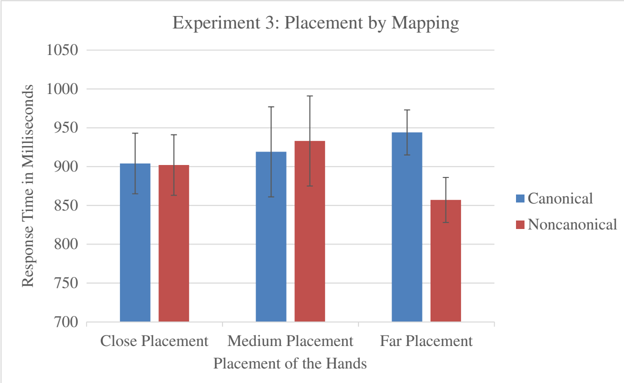

Fig. 6 Experiment 3 response times. Participants completed canonical and noncanonical trials with each of the three placements above. We found no main effects or significant interaction. Looking for any evidence of a mapping effect, we also completed paired *t* tests of the canonical and noncanonical conditions within each placement of the hands The only significant difference was found between the two mappings at far distance, $t(39) = 2.986$, $p = .005$, with participants responding faster in the noncanonical ($M = 857$, $SE = 29$) than in the canonical ($M = 944$, $SE = 29$) condition

hand, as well as to make *early* judgments on the left side and *late* judgments on the right side, showing contributions of both the hands and the body.

On the left–right axis, both endpoints may need to be defined. When the hands were placed on one side of the body, no effects of mapping direction were found. This may be because the endpoints are both on one side of the body. Participants may find this a difficult mapping situation, because both hands in the unilateral condition would fall into the same time region (e.g., both on the left, associated with early) when using the body as the origin. Although orientation and direction can be configured separately (Carlson, 2003), once one endpoint is defined, the other is as well, and this may be more difficult to do on one side of the body. These experiments demonstrated that it is important on the left–right axis to allow the body to anchor the timeline when mapping time onto space.

However, Experiment 2 demonstrated that on the front–back axis, time can be mapped with the body as the anchor of the timeline, and also mapped entirely in front of the body. This experiment also showed a canonical effect that is consistent with English metaphors for time using both body space and manipulatable space. Both the front and back endpoints are important, and because the front space is seen as having a special status (Clark, 1973; Franklin, Henkel, & Zangas, 1995), this may allow both endpoints to occur within the front space. This is notably different from the findings in Experiment 1, in which both endpoints could not occur effectively on the left or the right side of the body. We might be more comfortable using only the space in front of us than we are using only one side of space or the other.

On the vertical axis, we found no effect of body but an interaction between judgments and hand. Previous research has shown that English speakers do not have a preferred direction for time on the vertical axis (Boroditsky et al., 2011; Fuhrman et al., 2011). However, if there is no preference for mapping on this axis, participants may fall back onto an axis they do have a preference for by using their hands to define the space.

Finally, there is a clear spatial component to how time is mapped onto space. Together, the orientation and direction parameters can be used to define a timeline. This research has shown that the body can be used to define the origin, another parameter of a reference frame. Kolesari and Carlson (2017) have shown that the scale parameter of a reference frame that corresponds to how far apart in time the events on a timeline occur is also used during this mapping. Collectively, this work supports the idea that the mechanism for mapping space onto time is a spatial rather than a temporal reference frame.

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