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RESEARCH REPORT

How Strongly Linked Are Mental Time and Space Along the Left–Right Axis?

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Different lines of research suggest that our mental representations of time and space are linked, though the strength of this linkage has only recently been addressed for the front–back mental timeline (Eikmeier, Schröter, Maienborn, Alex-Ruf, & Ulrich, 2013). The present study extends this investigation to the left–right mental timeline. In contrast to what was found in the cited previous study, the obtained space–time congruency effects were smaller than benchmark stimulus–response congruency effects in control conditions. This pattern of results suggests that the representations of time and space are less strongly linked for the left–right axis than for the back–front axis.

Keywords: spatial representation of time, space–time congruency effect, left–right mental timeline, strength of association

The concept of time is indispensable for our thinking, because time structures our thoughts and perceptions. Yet time is an elusive concept as it cannot be traced back to basic physical phenomena (Evans, 2004). Consequently, there is no adequate physical time stimulus and, thus, no time receptor system like the receptor systems for seeing or hearing (Grondin, 2001; Woodrow, 1951). Thus, the question arises how time emerges within the cognitive system. It has been assumed that we heuristically draw on the domain of space to conceptualize time (e.g., Boroditsky, 2000). This linkage between time and space is prominent in languages around the world, with almost all using spatial expressions to communicate about time (e.g., "Monday seems so far away," "the exam is behind him"; Clark, 1973; Haspelmath, 1997).

The notion that the mental representation of time is connected to our representation of space has also received strong experimental support. Response time (reaction time [RT]) studies have demonstrated interactions between the spatial domain and the temporal domain (e.g., Boroditsky, 2001; Santiago, Lupáñez, Pérez, & Funes, 2007; Torralbo, Santiago, & Lupiáñez, 2006; Weger & Pratt, 2008). For example, Santiago et al. (2007) asked participants to respond to the temporal content of a word with a left or right keypress. Responses were faster when future was mapped to a right keypress and past to a left keypress than when the mapping was reversed. This space–time congruency effect has been explained in terms of a mental timeline that runs from left (past) to right (future). Several follow-up studies have replicated this effect with different linguistic material (e.g., Kong & You, 2011; Ouellet, Santiago, Israeli, & Gabay, 2010; Ulrich & Maienborn, 2010). An analogous space–time congruency effect was demonstrated for the front–back axis, with faster responses when future was mapped to the front and past to the back (e.g., Sell & Kaschak, 2011; Ulrich et al., 2012). In addition, experiments have revealed that spatial information can influence temporal judgments, whereas the reverse influence has not been observed (Casasanto & Boroditsky, 2008; Casasanto, Fotakopoulou, & Boroditsky, 2010). This asymmetrical pattern is consistent with the notion that our spatial representations structure our thinking about time. Further, this pattern argues against the idea that our representations of time and space are manifestations of a common metric, as proposed by Bueti and Walsh (2009) and Walsh (2003).

Although the studies already described clearly showed that our representations of time and space are linked, they did not provide any evidence concerning the strength of this linkage. This issue was recently addressed by Eikmeier, Schröter, Maienborn, Alex-Ruf, and Ulrich (2013), drawing on concepts of the dimensional overlap model (Kornblum, Hasbroucq, & Osman, 1990). Specifically, Eikmeier et al. compared the size of the space–time congruency effect on RT to a benchmark stimulus–response (S-R) congruency effect. This benchmark S-R congruency effect defined the upper bound that the space–time congruency effect could attain. In the congruent condition, participants responded vocally with the word "future" to future-related stimuli and with the word "past" to past-related stimuli. This assignment was reversed in the incongruent condition. The resulting benchmark congruency effect was compared with the space–time congruency effect obtained with the same stimuli but with space-related vocal responses using the words "in front" and "behind." The two congruency effects did not differ from each other, indicating that

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the size of the space–time congruency effect on the back–front axis reached the upper bound defined by the benchmark effect. A similar second experiment used spatial stimuli (tones presented in front of or behind participants). In the benchmark condition, participants responded with the space-related words "behind" or "in front" to the location of a tone, whereas in the space–time congruency condition, participants responded with the time-related words "past" or "future." Again, the space–time congruency effect did not differ from the benchmark congruency effect. The observation of space–time congruency effects at the upper possible bound in both experiments suggests a strong linkage between space and time on the front–back axis.

Although RT studies have reported similar congruency effects for the front–back and the left–right axis, it is possible that the front–back axis has a privileged status when we think about time. In fact, linguistic data support this assumption: Although almost all languages use spatial terms referring to front and back to express temporal information, there is no language documented that uses left and right terms to express time (Clark, 1973; Haspelmath, 1997; Radden, 2004). For example, languages often use expressions like "the day before Christmas" but not expressions like "the day left of Christmas" (e.g., Ulrich & Maienborn, 2010, p. 128). Therefore, it could be argued that the linkage of time and space is weaker along the left–right axis than along the back–front axis.

In contrast, if the representations of time and space share a common metric, as postulated by Walsh's theory of magnitude (ATOM; Bueti & Walsh, 2009; Walsh, 2003), one would expect that the linkage between time and space does not vary with the orientation of the mental timeline. Specifically, ATOM states that time, space, and number share common processing mechanisms involving a common metric for these domains. The observed associations between the domains of time and space should therefore originate from these common processing mechanisms. Thus, within ATOM, there is no reason to assume that the association between time and space differs between the lateral (left–right) and sagittal (back–front) axes, because both associations are thought to be based on the same mechanisms. It should be noted, however, that sharing a common metric does not necessarily imply the same strength of association across all possible spatial axes. In its present version, ATOM does not allow for specific predictions for the lateral and the sagittal mental timeline. Rather, its present version suggests similar strengths of associations for both axes. Consequently, the same pattern of results should be observed for the lateral axis as for the sagittal axis in Eikmeier et al. (2013)—that is, the space–time congruency effect should again be of the same size as the benchmark congruency effect.

The purpose of the present study was to test these alternative hypotheses using the same experimental logic as in Eikmeier et al. (2013). Accordingly, the experiments were designed analogously to the previous study. Experiment 1 again used temporal stimuli (i.e., time-related sentences) and space-related responses in the experimental condition, whereas in the benchmark condition, both stimuli and responses were time related. Experiment 2 again used spatial stimuli (i.e., left and right tones) and time-related responses in the experimental condition and space-related stimuli and responses in the benchmark condition.

Experiment 1: Temporal Stimuli

Method

Participants. One hundred and twenty-five volunteers took part in this experiment. All were native speakers of German and naïve with respect to the experimental hypothesis. The data of four participants were excluded from the final analysis because they committed too many errors during the experiment (>20% error trials). The data of one further participant were excluded because he reported being dyslexic. The mean age of the remaining 120 participants (25 male, 95 female) was 22.7 years ($SD = 6.5$ years). All had normal or corrected-to-normal vision, and 112 reported being right-handed.

Apparatus and stimuli. The experiment took place in a dimly lit, sound-attenuated room. Sentences were presented in the center of a computer screen (viewing distance = 80 cm) in black font against a white background. The same set of time-related sentences as in Eikmeier et al. (2013) was used. This set consisted of 120 sensible and 120 nonsensical sentences. Sixty sentences of each group (sensible and nonsensical) referred to past, and 60 referred to future. Example sentences are given in Table 1. Vocal RTs were measured using a microphone, and responses were checked online by the experimenter.

Procedure and design. The procedure and design were virtually identical to those in Eikmeier et al. (2013). Each trial started with the presentation of a fixation cross for 200 ms. After an interstimulus interval of 500 ms, a sentence was presented in the center of the screen for up to 4,000 ms or until the participant responded. The sentence was with equal probability a future-related, past-related sensible, or nonsensical sentence, and each sentence was presented only once in each congruency condition (see the following). If the sentence was nonsensical, participants were instructed to refrain from responding. These no-go trials were used to ensure that participants read each sentence thoroughly. If the sentence was sensible, participants were asked to decide whether it referred to past or future. In the benchmark group, participants responded vocally with "Vergangenheit" ("past") or "Zukunft" ("future"), whereas the experimental group responded vocally with "links" ("left") or "rechts" ("right"). After incorrect responses (an incorrect response or any response to a nonsensical sentence), error feedback was given using a 440-Hz tone (duration = 500 ms). The next trial started after 2,000 ms.

Half of the participants were assigned to the benchmark group, and the other half were assigned to the experimental group. Each group per-

Table 1
Example Sentences (and Their English Translations)

Sentence type	Example
Sensible past related	*Hanna reparierte gestern das Fahrrad.* (Yesterday, Hanna repaired the bike.)
Sensible future related	*Morgen früh unterschreibt der Chef den Antrag.* (The boss will sign the application tomorrow morning.)
Nonsensical past related	*Die Tannen haben sich badend ihren Mantel angezogen.* (The fir trees have put on their coat while bathing.)
Nonsensical future related	*Nächsten Sonntag wird das Rathaus die Erbse heiraten.* (Next Sunday, the town hall will marry the pea.)

formed two congruency conditions. These conditions consisted of 240 trials each and were blocked. In the congruent condition, participants of the benchmark group responded with “Zukunft” (“future”) to future-related sentences and with “Vergangenheit” (“past”) to past-related sentences. This S-R mapping was reversed in the incongruent condition. Analogously, participants in the experimental group responded by saying “rechts” (“right”) to future-related sentences and by saying “links” (“left”) to past-related sentences in the congruent condition, and vice versa in the incongruent condition. The order of the two congruency conditions was balanced across participants. At the beginning of each block, eight additional practice trials were presented.

Results and Discussion

Mean RTs and mean error rates are shown in Figure 1. An analysis of variance (ANOVA) on RTs including the factors group (experimental vs. benchmark) and congruency (congruent vs. incongruent) showed no main effect of group, $F(1, 118) = 0.3$, $p = .58$, $\eta_p^2 = .003$, but a main effect of congruency, $F(1, 118) = 26.9$, $p < .001$, $\eta_p^2 = .19$. As expected, responses were faster in the congruent than in the incongruent condition (2,125 ms vs. 2,248 ms, respectively). This effect, however, was modulated by group, $F(1, 118) = 6.3$, $p = .01$, $\eta_p^2 = .05$, with a larger congruency effect in the benchmark group than in the experimental group (183 ms vs. 63 ms, respectively).[1] Additional (two-sided) *t* tests showed that the congruency effect was significant for both the benchmark, $t(59) = 5.0$, $p < .001$, and the experimental group, $t(59) = 2.1$, $p = .04$.

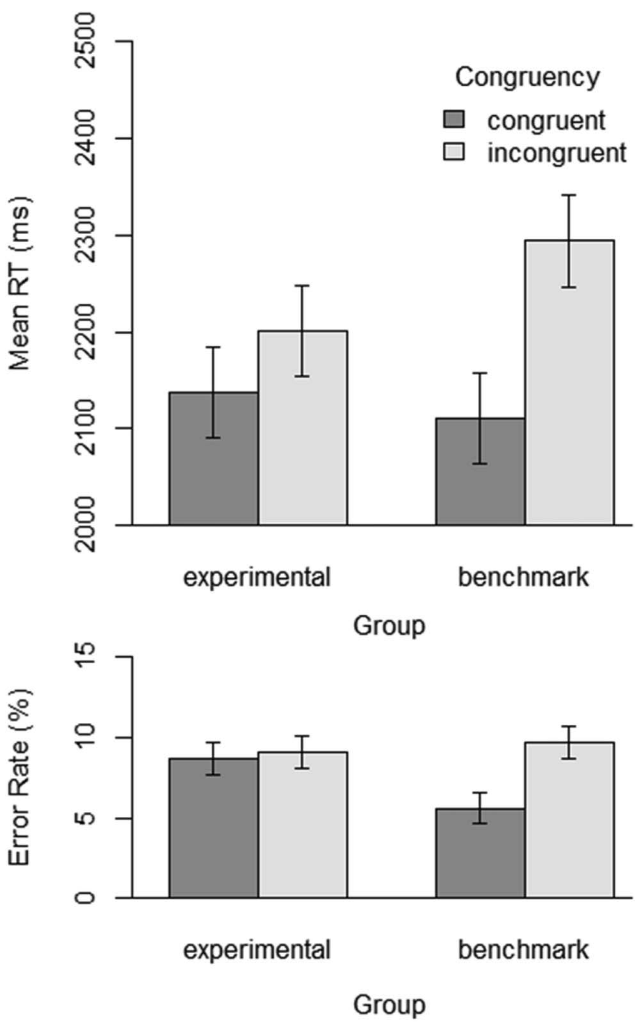

Figure 1. Experiment 1: Mean reaction times (RTs) and error rates for temporal stimuli as a function of congruency and group. Error bars represent 95% confidence intervals for the main effect of congruency and the Congruency × Group interaction (Masson & Loftus, 2003).

Similar results were found for error rates. There was no main effect of group, $F(1, 118) = 2.1$, $p = .15$, $\eta_p^2 = .02$, but error rates were lower in the congruent (7.1%) than in the incongruent condition (9.4%), $F(1, 118) = 20.8$, $p < .001$, $\eta_p^2 = .15$. This effect was again modulated by group, $F(1, 118) = 13.7$, $p < .001$, $\eta_p^2 = .10$, with a larger congruency effect in the benchmark group than in the experimental group (4.1% vs. 0.4%, respectively).[2] Follow-up *t* tests revealed that the congruency effect on error rates was significant in the benchmark group, $t(59) = 6.1$, $p < .001$, but not in the experimental group, $t(59) = 0.6$, $p = .56$.

Experiment 1 revealed an S-R congruency effect for time-related stimuli. Importantly, the size of this effect was smaller for space-related than for time-related responses, hinting at a weaker linkage of time and space on the left–right axis. Experiment 2 was conducted to examine whether this pattern of results could be replicated for spatial stimuli.

Experiment 2: Spatial Stimuli

Method

Participants. A new sample of 61 participants took part in this experiment. A smaller sample was used in Experiment 2 than in Experiment 1 because we expected less RT variability in Ex-

[1] An ANOVA also including the counterbalancing factor order (congruent condition first vs. incongruent condition first) yielded the same results. There was a main effect of congruency, $F(1, 116) = 57.5$, $p < .001$, which was modulated by group, $F(1, 116) = 13.5$, $p < .001$. In addition, an Order × Congruency interaction was observed, $F(1, 116) = 126.2$, $p < .001$. This interaction is, however, of no particular theoretical interest, because it simply reflected a practice effect. Because the congruency conditions were blocked in the experiment, one order group started with the congruent condition, and the other order group started with the incongruent condition. In the group that started with the incongruent condition and continued with the congruent condition, the practice effect enhanced the congruency effect. In contrast, in the group that started with the congruent condition and continued with the incongruent condition, the congruency effect was diminished by the practice effect. This pattern led to the Order × Congruency interaction (for a detailed explanation of this effect, see Ulrich et al., 2012, p. 488). Finally, an Order × Congruency × Group interaction was observed, $F(1, 116) = 10.4$, $p = .002$, which was most likely attributable to a stronger practice effect in the benchmark group than in the experimental group. No further effects were observed.

[2] Again, an ANOVA with the counterbalancing factor order yielded the same results: There was a main effect of congruency, $F(1, 116) = 23.8$, $p < .001$, which was modulated by group, $F(1, 116) = 15.6$, $p < .001$. A practice effect on error rates was reflected by the Congruency × Order interaction, $F(1, 116) = 16.3$, $p < .001$. No further effects occurred.

periment 2 as the task was simpler.[3] As in Experiment 1, all participants in Experiment 2 were native speakers of German and naïve with respect to the experimental hypothesis. The data of one participant were excluded from the final analysis because of high error rates (>20% error trials). The remaining sample of 60 participants consisted of 10 male and 50 female participants (age: M = 22.6 years, SD = 5.0 years). All had normal or corrected-to-normal vision and hearing, and 51 reported being right-handed.

Apparatus and stimuli. The experimental setup was the same as in Experiment 1 except for the following changes. Instead of time-related sentences, 440-Hz tones were presented for 100 ms via speakers on either the left or the right side of a participant. The speakers were placed on a table directly in front of participants, and each was at a distance of 50 cm from the participant.

Procedure and design. The procedure was the same as in Experiment 1, but tones were presented as stimuli instead of sentences. The presentation side of the tone was randomized across trials. After the presentation of the tone, participants had a maximum of 4,000 ms to vocally respond to the location of the tone. The benchmark group responded with the word "rechts" ("right") or "links" ("left"), and the experimental group responded with the word "Zukunft" ("future") or "Vergangenheit" ("past"). As in Eikmeier et al. (2013), there were no no-go trials in this experiment. If participants committed an error, written error feedback was displayed for 2,000 ms on the screen.

As in Experiment 1, half of the participants were assigned to the experimental group, and the other half were assigned to the benchmark group. Again, there were two congruency conditions. In the congruent condition, the benchmark group responded to tones presented on the right side by saying "rechts" ("right") and to tones presented on the left side by saying "links" ("left"). This S-R mapping was reversed in the incongruent condition. Following the same logic, participants in the experimental group responded in the congruent condition with the word "Zukunft" ("future") to tones on the right side and with the word "Vergangenheit" ("past") to tones on the left side. In the incongruent condition, this mapping was reversed again. The congruency conditions were blocked and consisted of 60 trials each. The order of the two congruency blocks was balanced across participants. As before, eight practice trials preceded each block. The experimental design was the same as in Experiment 1.

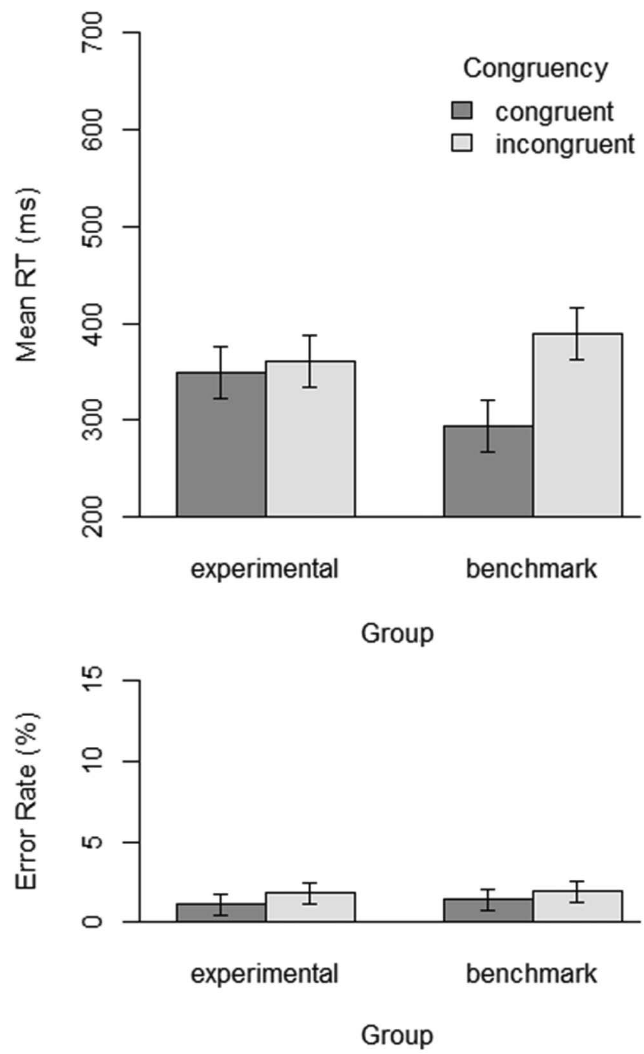

Figure 2. Experiment 2: Mean reaction times (RTs) and error rates for spatial stimuli as a function of congruency and group. Error bars represent 95% confidence intervals for the main effect of congruency and the Congruency × Group interaction (Masson & Loftus, 2003).

Results and Discussion

Mean RTs and error rates are depicted in Figure 2. An ANOVA on RTs revealed a main effect of congruency, $F(1, 58) = 16.6$, $p < .001$, $\eta_p^2 = .22$, with faster responses in the congruent than in the incongruent condition (321 ms vs. 376 ms, respectively). There was again no main effect of group, $F(1, 58) = 0.2$, $p = .62$, $\eta_p^2 = .15$. As in Experiment 1, the Congruency × Group interaction was significant, $F(1, 58) = 9.9$, $p = .003$, $\eta_p^2 = .004$.[4] Additional t tests revealed a significant congruency effect of 104 ms in the benchmark condition, $t(29) = 4.1$, $p < .001$. However, the difference of 12 ms between the congruent and incongruent condition in the experimental condition was not significant, $t(29) = 1.0$, $p = .32$. The overall error rate in this experiment was very low (1.5%), and an ANOVA on error rates showed no significant results.[5]

Experiment 2 documented only an S-R congruency effect with spatial stimuli when space-related responses were required—that is, when participants in the benchmark group were asked to respond by saying "left" or "right" to tones presented to their left or to their right. However, this effect disappeared in the experimental group when participants responded with the words "past" or "fu-

[3] Please note that the sample size of 60 for the present Experiment 2 was still greater than that for Experiment 2 of Eikmeier et al. (2013; n = 40), in which a significant time–space congruency effect was observed for spatial stimuli. Therefore, we are confident the present Experiment 2 had sufficient statistical power.

[4] An ANOVA with the counterbalancing factor order yielded again the same results: There was a main effect of congruency, $F(1, 56) = 17.6$, $p < .001$, which was modulated by group, $F(1, 56) = 10.5$, $p = .002$. A practice effect on RTs was reflected by the Congruency × Order interaction, $F(1, 56) = 5.7$, $p = .02$. No further effects occurred.

[5] In the ANOVA with the counterbalancing factor order, only the Congruency × Order interaction, reflecting a practice effect, was significant, $F(1, 56) = 5.3$, $p = .02$.

ture" to these spatial stimuli. This pattern of results provides further evidence for the notion that the mental linkage between space and time along the left–right axis is weak.

General Discussion

There is ample evidence from different strands of research that our mental representation of time is linked to our mental representation of space (e.g., Bender & Beller, 2014; Casasanto & Boroditsky, 2008; Núñez & Cooperrider, 2013; Saj, Fuhrman, Vuilleumier, & Boroditsky, 2014; Santiago et al., 2007; Walsh, 2003). However, only recently have efforts been made to assess the strength of this linkage of time and space (Eikmeier et al., 2013). Eikmeier et al.'s study revealed a strong association between space and time for the back–front axis. The aim of the present follow-up study was to examine whether a similarly strong linkage exists for the left–right axis, which has been commonly used in RT studies (Rolke et al., 2013; Santiago et al., 2007; Sell & Kaschak, 2011; Ulrich & Maienborn, 2010; Weger & Pratt, 2008). In contrast with Eikmeier et al.'s study, the results of the present study revealed a weaker linkage between time and space for the left–right axis, because the S-R congruency effects were smaller for the experimental than for the benchmark groups. Specifically, the time–space congruency effect on RTs (i.e., the RT difference between the incongruent and the congruent condition) for the experimental group of Experiment 1 was about 66% smaller than the time–time congruency effect for the benchmark group. In Experiment 2, the space–time congruency effect in the experimental group was virtually nonexistent, though a large space–space congruency effect emerged in the benchmark group. This pattern of results contrasts with that of Eikmeier et al.—in that study, equally large congruency effects were observed in the experimental and benchmark groups.

These contrasting patterns between the former and the present study are consistent with the observation that spatial terms referring to the back–front axis are widely used in languages around the world, whereas there is no known example of a language that uses spatial terms referring to the left–right axis when communicating about time (e.g., Haspelmath, 1997; Radden, 2004). Therefore, it seems plausible that there is a qualitative difference between the left–right timeline and the back–front timeline. The back–front axis may have a privileged cognitive status when people think about past and future—that is, about deictic time. Further, these contrasting patterns appear to be less compatible with the notion that time and space share a common metric (Walsh, 2003); at least additional assumptions would be necessary to explain why this linkage between time and space is modulated by the spatial orientation of the mental timeline.

It is possible that the front–back axis has a privileged status in our thinking about time because this orientation of the mental timeline might emerge from sensorimotor representations related to self-motion. For example, we typically walk forward to reach a place, which implies that places behind us are associated with the past, whereas places in front of us are associated with the future. Therefore, it is not surprising that in nearly all cultures, the front is associated with the future and the back with the past (for two exceptional cases, see de la Fuente, Santiago, Román, Dumitrache, & Casasanto, 2014; Núñez & Sweetser, 2006). Thus, the front–back mental timeline and its direction is a nearly universal phenomenon, supporting the idea that this timeline is deeply rooted in our cognitive system.

In contrast, the left–right mental timeline is associated with writing direction (Fuhrman & Boroditsky, 2010; Ouellet et al., 2010; Tversky, Kugelmass, & Winter, 1991) and, thus, seems to reflect cultural influences rather than universal principles of cognition. This idea is also in line with the finding that the left–right mental timeline can easily be reversed (Casasanto & Bottini, 2014), suggesting that the direction of this timeline is more flexible and, therefore, less hard-wired than the direction of the front–back mental timeline (Santiago, Román, & Ouellet, 2011). Following this argumentation, it could be reasoned that the left–right mental timeline is merely a cultural artifact emerging from experiences with calendars, written language, and graphs (Casasanto & Jasmin, 2012). However, it is still possible that the left–right mental timeline plays a major role in our thinking about time that might not be reflected in metaphoric speech, an idea that is consistent with results from gesturing studies (Casasanto & Jasmin, 2012).

Indeed, there are studies (e.g., Casasanto & Jasmin, 2012; Fuhrman & Boroditsky, 2010; Tversky et al., 1991) that show a preference for the left–right axis in gesture and spatial-arrangement tasks. It can be argued, however, that the lateral axis was preferred over the sagittal axis in these studies for pragmatic reasons. First, the lateral axis appears to be better suited for gesturing than is the sagittal axis because of anatomic constraints (see also Casasanto & Jasmin, 2012). In addition, gestures on the lateral axis are easier to see and discriminate by a conversational partner (Casasanto & Jasmin, 2012). Similarly, the lateral axis seems to be better suited for spatial-arrangement tasks than is the sagittal axis. In such tasks, pictures have to be arranged on a plane surface according to the temporal order of their content. The axis and direction used to achieve this can be chosen freely by a participant. However, it has to be noted that it is simply easier to use a lateral axis on a plane surface than a sagittal axis, which can easily be confused with a vertical axis (is the upper area of a page *in front* or *up*?). Preferring the sagittal axis over the lateral axis would therefore lead to an ambiguous representation, which is likely to be avoided by experimental participants.

Therefore, in our opinion, the existing data from gesture and spatial-arrangement tasks are not meaningful to answer the question of which axis is preferred in cognition. Consequently, these results do not contradict a stronger association on the back–front axis than the left–right axis. However, these data show that we can flexibly use one axis or the other, as required by a task.

Taken together, the present results and the results of Eikmeier et al. (2013) support the view that the strength of the linkage between time and space varies with the orientation of the mental timeline. The cognitive linkage between time and space appears to be stronger for the front–back than for the left–right axis. Although this difference suggests that the front–back axis is cognitively more prominent when we think about time, future research is required to examine whether the two axes also differ in their cognitive function.

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