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The spatial alignment of time: Differences in alignment of deictic and sequence time along the sagittal and lateral axes

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ABSTRACT

People use space in a variety of ways to structure their thoughts about time. The present report focuses on the different ways that space is employed when reasoning about deictic (past/future relationships) and sequence (earlier/later relationships) time. In the first study, we show that deictic and sequence time are aligned along the lateral axis in a manner consistent with previous work, with past and earlier events associated with left space and future and later events associated with right space. However, the alignment of time with space is different along the sagittal axis. Participants associated future events and earlier events—not later events—with the space in front of their body and past and later events with the space behind, consistent with the sagittal spatial terms (e.g., ahead, in front of) that we use to talk about deictic and sequence time. In the second study, we show that these associations between sequence time and sagittal space are sensitive to person-perspective. This suggests that the particular space-time associations observed in English speakers are influenced by a variety of different spatial properties, including spatial location and perspective.

1. Introduction

Space and time are intricately linked in the human mind. Systematic associations between time and space regularly show up not only in how we talk about time (e.g., *I'm looking* ***forward*** *to the weekend*), but also in co-speech gesture (Cooperrider & Núñez, 2009), in a variety of cultural artifacts (e.g., calendars, timelines), and even in how we reason about time (e.g., Boroditsky, 2000). These associations are complex and multifaceted, as both space and time are rich concepts (for a review, see Núñez & Cooperrider, 2013). Dimensions of spatial cognition include extent, perspective, and motion. And similarly, temporal cognition includes duration, past and future, and sequential order. While we know that space and time tend to be associated, less is known about the particulars of how (and whether) different spatial concepts are associated with how we think about time.

The present paper will focus on two different types of *relationships* between temporal events (Núñez & Cooperrider, 2013). The first, *deictic time*, captures temporal relationships that are referenced relative to the present moment, reflecting past/future relationships. The second, *sequence time*, captures temporal relationships that are referenced relative to another moment in time, reflecting earlier/later relationships, regardless of the present moment. For instance, whether the discovery of Mars happened *earlier* or *later* than the discovery of Jupiter (Evans, 2003; Moore, 2006; Tenbrink, 2011; Traugott, 1978; Núñez & Cooperrider, 2013). While both refer to a series of temporal events, they differ in that deictic time is always anchored to a deictic center (e.g., the present), while sequence time does not rely on this deictic center (i.e., there is not necessarily a "past" or "future" in sequence time). Both deictic and sequence time are spatialized in systematic ways in speech, gesture, and thought, as documented in a variety of data from linguistics (e.g., Traugott, 1978; Evans, 2003), gesture research (Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012), and cognitive psychology (e.g., Torralbo, Santiago, & Lupiáñez, 2006; Weger & Pratt, 2008; Fuhrman & Boroditsky, 2010).

One prominent way that people in many Western cultures spatialize both deictic and sequence time is along a lateral (left-right) spatial axis. Across a variety of studies that vary in response mode, type of stimulus, and language of study, it has been demonstrated that people who read and write from left to right associate past and earlier events with the left side of space and future and later events with the right side of space (e.g., Torralbo et al., 2006; Santiago, Lupáñez, Pérez, & Funes, 2007; Weger & Pratt, 2008; Ulrich & Maienborn, 2010; Ouellet, Santiago, Funes, & Lupiánez, 2010; Fuhrman & Boroditsky, 2010). This pattern is reversed for those who read and write from right to left (e.g., Tversky, Kugelmass, & Winter, 1991; Fuhrman & Boroditsky, 2010). Furthermore, when talking about various events in time, English speakers often gesture along a left to right "timeline", with leftward gestures co-produced with speech about past or earlier events and rightward

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gestures co-produced with speech about future or later events (Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012; Walker & Cooperrider, 2016). Such patterns are likely shaped by a lifetime of cultural experiences, including reading and writing in a particular direction (e.g., Tversky et al., 1991; Bergen & Lau, 2012; Winter, Matlock, Shaki, & Fischer, 2015).

An additional way that deictic and sequence time are spatialized is apparent in how we talk about time. English speakers often employ *sagittal* (front-back) language to talk about deictic time (e.g., The future *ahead* looks bright) and sequence time (e.g., Christmas always falls *ahead* of New Years). For deictic time, future times lie *ahead* of the speaker with past times lying *behind* the speaker; while for sequence time, earlier times lie *ahead* of later times. A closer look at these linguistic examples reveals that deictic and sequence time are aligned along the sagittal axis in a different manner than how they are aligned along the lateral axis, which is not used in the English language to talk about time. That is, in language, future and earlier events, rather than future and later events, are aligned with the front while past and later events, rather than past and earlier events, are aligned with the back. For example, we conducted a brief analysis of 100 randomly sampled instances of the word "ahead" from the Corpus of Contemporary American English (COCA) (Davies, 2008). These tokens contained 32 examples of the word "ahead" used temporally. Eight of those instances were used to communicate an earlier time in a sequence (e.g., "On Wednesday investors turned cautious *ahead* of next week's Fed meeting") and 24 were used to talk about future times (e.g. "And I think we're going to build on that in the weeks *ahead*"). Not a single example was used to talk about a later time in a sequence or about a time in the past.

This alignment of future with earlier contrasts with behavioral and gestural evidence of how deictic and sequence time are aligned along the lateral axis, where future and later events are aligned with right space and past and earlier events are aligned with left space. What implications do these differences in alignment have for how people think about these temporal concepts? Are these differences simply due to the use of different tasks for the different axes (e.g., comparing linguistic patterns with behavioral and gestural tasks along the lateral axis)? If so, are the patterns used in language simply conventions that people use to talk about time, or do they reflect something deeper about how people might associate deictic and sequence time with the sagittal axis?

Research using a variety of different methods suggests that people reliably associate deictic time with the sagittal axis (Sell & Kaschak, 2011; Kranjec & McDonough, 2011; Miles, Nind, & Macrae, 2010; Miles, Karpinska, Lumsden, Macrae & Gilbert, 2010; Hartmann & Mast, 2012; Koch, Glawe, & Holt, 2011; Sullivan & Barth, 2012; Eikmeier, Schröter, Maienborn, Alex-Ruf, & Ulrich, 2013). For instance, Hartmann and Mast (2012) found that future events were categorized more quickly when the participants were physically displaced forwards in a moving chair rather than backwards. However, few psychological studies have examined the association between *sequence* time and the sagittal axis, and the ones that do often fail to find effects (e.g., Kranjec & McDonough, 2011; Fuhrman et al., 2011; Casasanto & Jasmin, 2012). Thus, perhaps people simply do not associate sequence time with the sagittal axis. However, an alternate explanation is that previous experiments may not have been designed in a way that would capture any associations that might exist. For instance, Kranjec and McDonough (2011) did not present related stimuli in sequential order (e.g., a series of pictures of a caterpillar transforming into a butterfly would be intermixed with a variety of unrelated images). This may have made it difficult for participants to interpret the events as part of a sequence. However, if people could associate sequence time with the sagittal axis, what would such associations look like?

One possibility is that deictic and sequence time will be aligned along the sagittal axis much like they are aligned along the lateral axis, where past and earlier events are associated with the left and future and later events are associated with the right. As we know that people associate future events (i.e., events that are *later than now*) with the space in front of them, under this "polarity correspondence" hypothesis (Proctor & Cho, 2006), one would expect later events in a sequence to also be associated with the space in front of the speaker while both past and earlier events would be associated with the space behind the speaker. The "polarity correspondence" hypothesis (Proctor & Cho, 2006) aims to account for many of the observed compatibility effects across a variety of domains (e.g., time, number, valence). It proposes that for binary classification tasks, the stimuli and response alternatives are both coded in terms of positive or negative polarity and when the two polarities match, response selection is faster. In the present case, as deictic events, events in a sequence, and the sagittal and lateral axes each can be categorized in terms of two poles (earlier vs later, past vs future, front vs back, left vs right), responses may be the most efficient when the poles of the different categories are aligned (Proctor & Cho, 2006). We know how the poles are likely to be aligned based on the results along the lateral axis (where for English speakers, earlier and past align with left space and later and future align with right space). So, the polarity correspondence hypothesis predicts that we should see similar patterns of alignment along the sagittal axis. In contrast, associations between deictic and sequence time and sagittal space could be based on the words we use to talk about them. Under this "lexical association" hypothesis, while past events lie behind the speaker and future events ahead of the speaker, earlier events should lie ahead of, or in front of, later events, consistent with linguistic patterns.

Recent findings provide support for this latter hypothesis. Walker, Bergen, and Núñez (2014) had participants listen to stimuli presented auditorily either along the sagittal axis (from speakers placed in front of or behind their body) or along the lateral axis (from speakers to the left or to the right of the body). Participants then, reporting verbally, made either deictic judgments (e.g., Is high school graduation in the past or in the future?) or sequence judgments (e.g., Is high school graduation earlier or later than college graduation?). While the expected effects emerged for deictic and sequence judgments along the lateral axis (participants were faster to make "past" and "earlier" judgments presented to the left and "future" and "later" events presented to the right), results along the sagittal axis were mixed. For sequence judgments, they found that participants were faster to make "later" judgments when the stimuli were presented *behind* the participant and "earlier" judgments when the stimuli were presented *in front of the* participant. This pattern of compatibility effects mirrors how English speakers talk about temporal sequences, where earlier events lie in front of later events. However, with this paradigm they found no evidence of an association between deictic time and the sagittal axis. This pattern of results was unexpected because typically, if any space-time associations are observed along the sagittal axis, they are for deictic judgments, with future events associated with the space in front of the body and past events behind the body (e.g., Kranjec & McDonough, 2011).

These findings are seemingly at odds with a series of studies conducted by Eikmeier and colleagues (Eikmeier et al., 2013; Eikmeier, Alex-Ruf, Maienborn, & Ulrich, 2015). They found stronger associations between space and time for deictic judgments along the sagittal axis (Eikmeier et al., 2013) than along the lateral axis (Eikmeier et al., 2015). As a result, they propose that the left-right axis is more weakly represented than the front-back axis, and that the sagittal axis "may have a privileged cognitive status when people think about past and future" (Eikmeier et al., 2015, p. 5). However, a closer look at their experimental design suggests that there are nuanced (yet important) differences between their paradigm and the one used by Walker et al. (2014). Eikmeier et al. measured whether simple tones presented in different spatial locations (in front of or behind the participant, Eikmeier et al., 2013; or to the left or to the right of the participant, Eikmeier et al., 2015) primed participants to vocally respond "past" or "future". They found that while tones presented along the sagittal axis led to congruency effects (e.g., participants were faster to say "future" to a tone presented in front of them than behind them, Eikmeier et al., 2013), no such effects were seen for the lateral axis (Eikmeier et al., 2015). However, in Walker et al. (2014), participants heard particular *temporal events* (rather than tones) presented in different spatial locations and responded with "past" or "future'. Thus, participants had to also process the *meaning* of the temporal content before responding. As a result, the studies presented by Eikmeier and colleagues focused on examining associations between two polarized categories (front/back or left/right and past/future) while Walker et al. (2014) focused on *construals* of particular events in time and the relationships between them. There is reason to believe these differences may matter.

One reason is that when presented with a tone, participants might first verbally translate the tone into its spatial location "front" or "back" and then use that to determine whether it should be associated with "past" or "future". If this is the case, then the pattern of results observed by Eikmeier et al. is not surprising. Indeed, a similar pattern is seen in Casasanto and Jasmin (2012) (as well as in Walker & Cooperrider, 2016) when participants were *explicitly* asked to gesture about the past or the future. In that case, participants may be more likely to think about how they would *talk* about these concepts (e.g., "the future lies ahead, the past behind"), resulting in more sagittal than lateral gestures, as we often use sagittal language to talk about deictic time (while lateral language is never used). However, when gestures were *implicitly* measured, sagittal gestures were few, and lateral gestures made up the majority of gestures produced.

It is also possible, however, that the pattern of results observed by Walker et al. (2014) was influenced by the use of a novel auditory paradigm that was not sensitive enough to capture such an effect. The results could also be due to the particular stimuli that were used, as the stimuli used in the deictic and sequence judgments were different from one another in a small but systematic way. While the deictic stimuli often included the pronoun "your" (e.g., "your high school graduation"), the sequence stimuli included the pronoun "her" instead (e.g., "her high school graduation"). This confounds type of time with person perspective. And there's reason to believe that this might matter.

A variety of studies have demonstrated that the use of second versus third person pronouns influences the spatial perspective from which one mentally simulates an action or scene (Brunyé, Ditman, Mahoney, Augustyn, & Taylor, 2009; Beveridge & Pickering, 2013). Second-person pronouns, such as "your", encourage a listener or reader to take a first-person, or internal, perspective, while third-person pronouns, such as "her", encourage a third-person, or external, perspective (e.g., Brunyé et al., 2009). Therefore, if we use spatial representations to think about time, then the use of different pronouns for judgments about deictic and sequence time in Walker et al. (2014) might have influenced the perspective from which participants interpreted the events. To wit, deictic reasoning usually involves adopting an internal perspective, anchored to the thinker's "now," while sequence time is by default construed externally, as it is not tied to any particular place in time or space (see Núñez & Cooperrider, 2013 for a review). For instance, while speakers often gesture along a body-centered sagittal axis for deictic time, with the speaker's body anchoring the present moment, speakers are much more likely to gesture along a lateral axis for sequence time, which is not anchored to the speaker in the same way (Casasanto & Jasmin, 2012). Thus, coupling the first-person pronoun "your" with deictic judgments and the third-person pronoun "her" with sequence judgments presents participants with a situation where the perspective induced by a particular pronoun is aligned with the typical perspective one may take when construing deictic or sequence time. This makes it difficult to tell whether differences in spatial construal are due to type of time or pronoun-induced perspective. Thus, it is unclear whether the results observed by Walker et al. (2014) are due to the use of a novel auditory paradigm, differences in stimuli across the conditions, or some combination of the two.

The present report seeks to clarify our understanding of the nature of space-time associations and how space is associated with different types of temporal reasoning. In addition to conceptually replicating Walker et al. (2014) by using visual presentation and manual responses, Experiment 1 aims to test the "polarity correspondence" and "lexical association" hypotheses mentioned above. It also pursues the idea that sagittal construals of deictic and sequence time may be perspective-driven, by manipulating the perspective from which the temporal events are described and asking whether this influences the pattern of space-time associations observed along the sagittal axis (Experiment 2).

2. Experiment 1

In Experiment 1, participants made either deictic or sequence judgments by manually responding along either the lateral or sagittal axis. Along the lateral axis, participants should associate both past and earlier events with left space and future and later events with right space, consistent with the reading and writing direction of English. Along the sagittal axis, if participants simply align deictic and sequence time with the sagittal axis in a manner consistent with how they are associated with the lateral axis, then they should associate past and earlier events with the space behind them and future and later events with the space ahead of them. This would provide support for the "polarity correspondence" hypothesis. However, if participants associate deictic and sequence time with the sagittal axis in a manner that reflects the sagittal patterns used to describe deictic and sequence relationships in language, participants should associate past events with the space behind them and future events with the space ahead of them but associate earlier events with the space ahead of them and later events with the space behind them, in accord with the "lexical association" hypothesis.

Why should deictic-free *sequences* of events be associated with the space in front of or behind a participant? What we refer to as sequence time is consistent with the idea of Time-RP metaphors (Núñez, Motz, & Teuscher, 2006), where the focus is on "*posteriority* (reference to one time as being later in a sequence than another)…and *anteriority* (reference to one time as earlier in a sequence than another)" (p. 144) rather than on *past* and *future*. Thus, as a body-centered sagittal axis is used in this paradigm, participants may use their body to anchor the first event they hear. Then, after aligning their fronts and backs with the metaphorically oriented sequence of events, they may place the second event either in front of them (earlier) or behind them (later).

2.1. Methods

2.1.1. Participants

Seventy-two undergraduates (17 male; mean age = 20.01 years, SD = 2.01, range = 18–30) at the University of California, San Diego participated for partial course credit. Due to a computer error in counterbalancing, where participants were always given the same order of space-time mappings (congruent first, incongruent second) in the deictic condition, sixteen participants were randomly replaced by sixteen new participants in the appropriate counterbalanced condition so that there were an equal number of participants in each counterbalanced condition. Four participants in the sequence judgment condition were removed due to low levels of accuracy (< 75%), leaving 68 participants for analysis (32 sequence, accuracy = 94%; 36 deictic, accuracy = 95%).

2.1.2. Design and materials

The experiment was built using E-Prime (Psychology Software Tools, Pittsburgh, PA, USA). Deictic stimuli consisted of forty typical life events (Table 1). These were designed so that, for a typical undergraduate student in the United States, half would have occurred in the past relative to the time of the experiment (e.g., "your high

Table 1
List of stimuli used in the deictic condition of Experiment 1. Sequence stimuli were generated by combining pairs of deictic stimuli and replacing the pronoun "your" with the pronoun "her". These studies took place at the beginning of the year 2013, so the future events were indeed in the future at that time.

Past events		Future events	
2010	Getting your baby teeth	2015	Being a senior citizen
Getting your driver's permit	Learning to tie your shoes	Getting your first gray hair	Having your first child
Reading your first book	Speaking your first words	Having your first grandchild	Starting your first career
Starting to crawl	Taking your first steps	Starting your medicare	Taking your last college exam
Taking your SATs	Yesterday	Tomorrow	Writing your will
Your birth	Your first crush	Your fiftieth anniversary	Your first mortgage
Your first day in college	Your first day in elementary school	Your forty-fifth birthday	Your high school reunion
Your first day in high school	Your first haircut	Your mid-life crisis	Your retirement
Your first time shaving	Your twelfth birthday	Your wedding	Your college graduation
Your high school graduation	Your first day in sixth grade	Your 80th birthday	Being middle aged

school graduation"), and half would occur in the future (e.g., "your college graduation"). Sequence stimuli consisted of forty pairs of these life events (e.g., "her high school graduation", "her college graduation"). Twenty of these pairs required "earlier" responses while twenty required "later" responses. When possible, deictic stimuli included the pronoun "your" while sequence stimuli included the pronoun "her", in order to replicate the stimuli used by Walker et al. (2014).

2.1.3. Procedure

Participants held two computer mice, one in each hand, with each thumb placed over a single mouse button. In order to avoid referring to the response locations by name (e.g., left or right), different colored stickers were placed on each mouse (red and yellow) and all response instructions referred only to the colors and not to the hand. To collect responses along the lateral axis, we had participants hold one mouse with their left hand on their left side and the other mouse in their right hand on their right side (see Fig. 1a). For the sagittal axis, participants held one mouse directly in front of their body and the other mouse behind their back (see Fig. 1b). We counterbalanced which hand was held in front of the body (right or left) across participants.

Before each block, participants were presented with instructions that explained the stimulus-response mappings they would use for that block. The stimulus-response mappings were changed after each block.

For deictic judgments, participants were instructed to judge whether the event presented on the screen happened to them in the past or is likely to happen to them in the future and to indicate their decision by pressing either the yellow or red mouse, as indicated in the instructions. When making sequence judgments, they were asked to decide whether the second event they saw in a sequence was earlier or later than the first event by pressing either the yellow or red mouse. For both types of judgments, participants were told to complete the judgments as quickly and accurately as possible. Participants then completed four practice trials, followed by forty randomly ordered experimental trials.

On all trials, participants were presented with a fixation cross for 1000 ms, followed by a life event. For deictic judgments, this event remained on the screen until the participants responded, up to 5000 ms. For sequence judgments, the first event remained on the screen for 2000 ms. A white screen was then presented for 500 ms and the second event was then presented and remained on the screen until the participants responded, up to 5000 ms. Response times were measured from the onset of the critical event (the first and only event in deictic judgments, the second event in sequence judgments). Participants received new instructions before each block.

Each participant completed a total of four blocks of forty trials of either deictic or sequence judgments. Participants completed two blocks of trials along each axis (one block for each response mapping along each axis). Response mappings and axis order were counterbalanced across participants.

2.1.4. Analyses

All analyses were conducted in *R* (R Core Team, 2014). Incorrect trials or trials with no response (5.8% sequence; 4.5% deictic) were excluded from analysis, as well as trials that were 3 standard deviations from each subject or item's mean (2.3% sequence; 3.8% deictic). We first conducted an omnibus ANOVA that included the following factors: type of time (deictic vs. sequence), axis (sagittal vs. lateral), temporal reference (past/earlier vs. future/later) and location (left/back vs right/

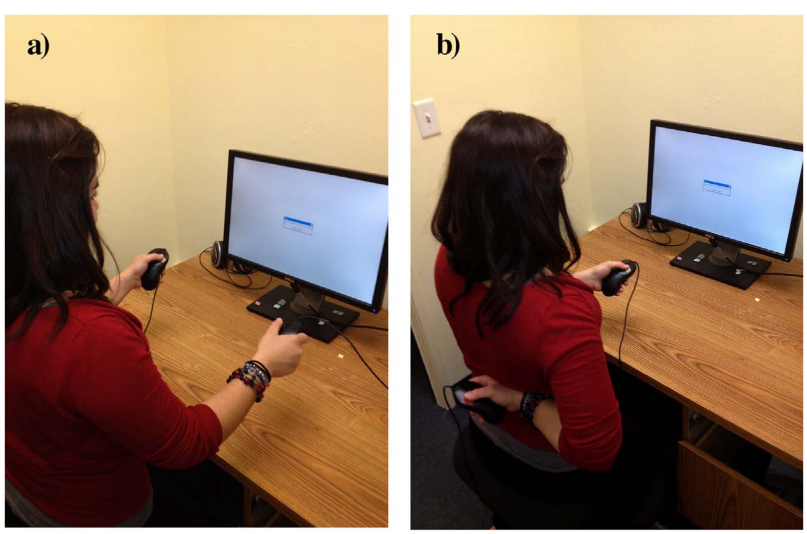

Fig. 1. The position of the computer mice when making judgments along the lateral axis (a) or along the sagittal axis (b).

front). We also included which hand (left or right) we assigned the participant to hold in front of their body during the sagittal judgments to assess whether it interacted with any of the other factors. Both by-subject (F_1) and by-items (F_2) analyses are reported. In order to include temporal reference as a factor across deictic and sequence judgments, past and earlier judgments were aligned and future and later judgments were aligned, based on known alignment of those categories along the lateral axis. Furthermore, left and back locations were aligned and right and front locations were aligned in order to include location as a factor across all conditions.

2.2. Results

The omnibus ANOVA revealed a main effect of type of time, as participants were consistently faster to make deictic than sequence judgments $F_1(1,64) = 27.704$, MSE = 729.562, $\eta_p = 0.30$, $p < 0.001$, $F_2(1,76) = 105.173$, MSE = 222.464, $\eta_p = 0.58$, $p < 0.001$. It also revealed a four way interaction between type of time, temporal reference, location, and spatial axis, $F_1(1,64) = 9.746$, MSE = 43.556, $\eta_p = 0.13$, $p = 0.003$, $F_2(1,76) = 38.09$, MSE = 8555, $\eta_p = 0.33$, $p < 0.001$. Which hand was in front during the sagittal judgments had no effect on response times ($p = 0.434$), nor did it interact with any other factors (all $ps > 0.16$)

To better interpret this four-way ANOVA, we compared deictic to sequence time along each axis (sagittal and lateral), with temporal reference (past/earlier or future/later), location (left or right for the lateral axis, front or back for the sagittal axis), and type of time (deictic/sequence) as factors. We first report analyses along the sagittal axis, and then the lateral axis (see Fig. 2 for a graphical summary of results).

2.2.1. Sagittal axis

Overall, participants were faster to make deictic than sequence judgments, $F_1(1,66) = 21.98$, $\eta_p = 0.25$, $p < 0.001$, $F_2(1,76) = 80.45$, $\eta_p = 0.51$, $p < 0.001$. The only other effect that reached significance was a three way interaction between type of time, temporal reference, and response location, $F_1(1,66) = 11.51$, $\eta_p = 0.14$, $p = 0.001$, $F_2(1,76) = 50.22$, $\eta_p = 0.40$, $p < 0.001$, revealing different patterns of alignment along the sagittal axis for sequence and deictic time than what is typically observed along the lateral axis.

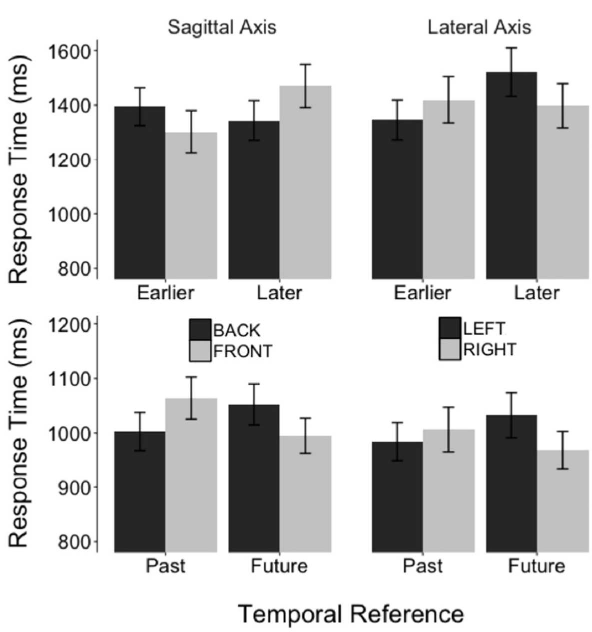

Fig. 2. Mean response times to sequence (top row) and deictic (bottom row) judgments along the sagittal (first column) and lateral (second column) axes in Experiment 1. Error bars indicate standard error.

To further examine how each type of time (deictic/sequence) was associated with the sagittal axis, we conducted separate ANOVAs along each axis for the deictic and sequence judgments, with temporal reference and location as factors. For sequence time, there was a significant interaction between temporal reference and response location, $F_1(1,31) = 4.73$, $\eta_p = 0.13$, $p = 0.037$, $F_2(1,38) = 23.32$, $\eta_p = 0.38$, $p < 0.001$. Pairwise *t*-tests revealed that participants were faster to make later judgments when responding *behind* their body than when responding *in front*, $t_1(31) = 2.32$, $p = 0.027$, $t_2(19) = 4.93$, $p < 0.001$. By contrast, participants were faster to respond to earlier events responding *in front* of the body than behind, $t_1(31) = 1.76$, $p = 0.09$, $t_2(19) = 2.29$, $p = 0.034$.

For deictic time, there also was a two-way interaction between temporal reference and location, $F_1(1,35) = 16.82$, $\eta_p = 0.32$, $p < 0.001$, $F_2(1,38) = 35.1$, $\eta_p = 0.48$, $p < 0.001$. Pairwise *t*-tests indicated that participants were faster to respond to past events when responding behind than in front ($t_1(35) = 3.88$, $p < 0.001$, $t_2(19) = 3.85$, $p = 0.001$) but were faster to respond to future events in front than behind ($t_1(35) = 2.55$, $p = 0.015$, $t_2(19) = 4.58$, $p < 0.001$). No main effects were observed.

2.2.2. Lateral axis

Overall, participants were again faster to make deictic than sequence judgments, $F_1(1,66) = 26.78$, $\eta_p = 0.29$, $p < 0.001$, $F_2(1,76) = 121.36$, $\eta_p = 0.61$, $p < 0.001$. Contrary to the sagittal axis, there was no three way interaction between type of time, temporal reference, and response location, $p_1 = 0.25$, $p_2 = 0.19$. There was, however, a two-way interaction between temporal reference and response location, $F_1(1,66) = 8.38$, $\eta_p = 0.11$, $p = 0.005$, $F_2(1,76) = 36.8$, $\eta_p = 0.33$, $p < 0.001$, suggesting that sequence and deictic time are aligned along the lateral axis in the manner initially predicted. Indeed, the two-way interaction between temporal reference and location is significant for both sequence time, $F_1(1,31) = 4.77$, $\eta_p = 0.13$, $p = 0.037$, $F_2(1,38) = 16.68$, $\eta_p = 0.31$, $p < 0.001$ and deictic time, $F_1(1,35) = 4.31$, $\eta_p = 0.11$, $p = 0.045$, $F_2(1,38) = 31.32$, $\eta_p = 0.45$, $p < 0.001$.

2.3. Discussion

Consistent with a large body of past work that examined deictic and sequence associations with the lateral axis in speakers of languages that are written left-to-right (e.g., Torralbo et al., 2006; Santiago et al., 2007; Weger & Pratt, 2008, Ulrich & Maienborn, 2010; Ouellet et al., 2010; Fuhrman & Boroditsky, 2010), past and earlier events were associated with the left, while future and later events were associated with the right. Along the sagittal axis, however, sequence and deictic judgments elicited patterns of spatialization that were not aligned in a manner consistent with the lateral axis. For sequence judgments, participants associated earlier events with the space in front of the body and later events with the space behind the body. This pattern of results from sequence judgments along the sagittal axis replicates Walker et al. (2014) and suggests that their original findings were not simply the product of a novel paradigm, as we observed the same pattern using a different modality of stimulus presentation and a different response modality.

Though Experiment 1 largely replicated the findings observed by Walker et al. (2014), one main difference in the results was observed: the previous study observed no compatibility effects for deictic time along the sagittal axis, but the present study revealed an association between deictic judgments and the sagittal axis. The present findings are consistent with a variety of other studies that observed similar sagittal associations using an array of different methods (e.g., Kranjec & McDonough, 2011; Eikmeier et al., 2013). Thus, one possibility is that the acoustic/vocal paradigm employed by Walker et al. (2014)

weakened the effect for deictic judgments.

For deictic judgments, we found that participants associated future events with the space in front of the body and past events with the space behind. Together, these results for deictic and sequence judgments are most consistent with the "lexical association" hypothesis discussed in the Introduction. That is, deictic and sequence time are spatially construed along the sagittal axis in ways that reflect patterns observed in language. This finding is in line with work in linguistics (Bender & Beller, 2014; Moore, 2011; Traugott, 1978). Past events are talked about as located in the space behind the speaker, the present moment is co-located with the speaker, and future events lie in the space in front of the speaker. In contrast to deictic time, earlier events in a sequence tend to be described as lying *in front* of another event while later events lie *behind* the referenced event (Moore, 2006, 2011). That is, each event is described as located in front or behind another event, as in "Polls showed a widening lead *ahead* of last month's elections" (Moore, 2011), where in this case, *ahead* means "before last month's elections" (at an earlier time).

However, an alternate possibility is that the alignment of deictic and sequence time along the sagittal axis differs from the alignment along the lateral axis because the stimuli are systematically different for the two types of judgments. In Experiment 1, all of the deictic stimuli included the pronoun "your" while all of the sequence stimuli included the pronoun "her", in order to replicate the stimuli used by Walker et al. (2014). Yet, as discussed in the Introduction, the use of different pronouns may encourage participants to construe the events from different perspectives. Experiment 2 controls for this possibility by asking whether the use of *different* pronouns influences how individuals spatialize sequence time. Experiment 2 addresses this question by manipulating, within participants, the perspective from which temporal sequences are described.

3. Experiment 2

Experiment 2 examines whether the use of different pronouns ("her", "your") leads participants to interpret temporal sequences from different perspectives and therefore leads to differences in how individuals map temporal sequences onto sagittal space. The pronoun "your" may be more likely to elicit an internal perspective (Brunyé et al., 2009), as it may prime thoughts about one's own location in time. While an internal perspective is often taken when reasoning about deictic time, it is less common when thinking about sequence time. However, introducing the pronoun "your" in temporal sequences could result in deictic-like associations along the sagittal axis for sequence time, where participants anchor themselves at the first event and then think about the second event in terms of the *past* or the *future* relative to the first event. In this case, "later" events would be construed as lying in front of the participant and "earlier" events would be construed as lying behind.

On the other hand, the pronoun "her" may elicit an external perspective. In this case, participants may again use their body to anchor the first event, but earlier events would be placed ahead of the body and later events behind the body, consistent with how sequence time is discussed in language, as observed in Experiment 1. However, based on the "lexical association" hypothesis, one would expect a different pattern of results. If it's the case that earlier events are systematically interpreted as lying ahead of later events, consistent with the language we use to talk about sequences, then we should see the same pattern of results across the two pronouns.

3.1. Methods

3.1.1. Participants

Forty-two undergraduates at the University of California, San Diego participated for partial course credit. Eight participants were removed due to low levels of accuracy (< 75%), leaving 36 participants for analysis.

3.1.2. Materials

The materials were identical to those used for sequence judgments in Experiment 1, with stimuli including either the pronoun "her" (e.g., "her high school graduation", "her college graduation") or the pronoun "your" (e.g., "your high school graduation", "your college graduation"), depending on the condition.

3.1.3. Procedure

The procedure was almost identical to that used in Experiment 1, except that participants made only sequence judgments along the sagittal axis. Each participant completed a total of four blocks of forty trials of sequence judgments. During two of the blocks, events included the pronoun "her", and during the other two blocks, events included the pronoun "your". Participants completed two blocks of trials (one block for each response mapping) with each pronoun, followed by another two blocks of trials using the other pronoun. There were a total of 160 trials (four blocks of 40 trials) and 16 practice trials (four practice trials per block). Response mappings and pronoun order were counterbalanced across participants.

3.1.4. Analyses

All analyses were conducted in *R* (R Core Team, 2014). To investigate whether the different pronouns elicited different spatial construals of temporal sequences along the sagittal axis, a four-way repeated measures analyses of variance (ANOVA) was performed on response times with pronoun (her, your), response location (back, front), and temporal reference (earlier, later) as within-subjects factors. We also included which hand (left or right) we assigned the participant to hold in front of their body as a between-subjects factor to assess whether it interacted with any of the other factors. Both by-subject (F_1) and by-items (F_2) analyses are reported. As needed, appropriate follow-up tests were conducted.

3.2. Results

The omnibus ANOVA revealed a two-way interaction between temporal reference and response location, $F_1(1,34) = 5.21$, $\eta_p = 0.13$, $p = 0.029$, $F_2(1,38) = 34.20$, $\eta_p = 0.47$, $p < 0.001$. Follow-up *t*-tests indicated that overall, participants responded faster to later events when responding on the mouse located behind them than the mouse in front of them ($t_1(35) = 2.22$, $p = 0.033$), $t_2(19) = 4.65$, $p < 0.001$) and to earlier events when responding in front than in back ($t_1(35) = 2.10$, $p = 0.042$, $t_2(19) = 3.87$, $p = 0.001$). Critically, there was also a three-way interaction between pronoun, temporal reference, and response location, $F_1(1,34) = 4.28$, $\eta_p = 0.11$, $p = 0.046$, $F_2(1,38) = 6.51$, $\eta_p = 0.15$, $p = 0.015$. Follow-up analyses indicated that this interaction was driven by a strong interaction between temporal reference and response location on trials using the pronoun "her", $F_1(1,35) = 10.03$, $\eta_p = 0.22$, $p = 0.003$, $F_2(1,38) = 42.70$, $\eta_p = 0.53$, $p < 0.001$. This interaction was not reliably significant for the pronoun "your", $p_1 = 0.43$, $p_2 = 0.055$ (see Fig. 3).

3.3. Discussion

We investigated whether the use of different pronouns ("her", "your") would lead participants to interpret temporal sequences from different perspectives and therefore lead to differences in how individuals mapped temporal sequences onto sagittal space. If participants simply systematically map sequences of events onto the sagittal axis in a manner consistent with patterns in language (earlier-in-front/later-in-back), the use of different pronouns should have no effect on the space-time mappings used by the participants. However, we observed a three-way interaction between pronoun, response location, and temporal reference: space-time mappings recruited for temporal sequences

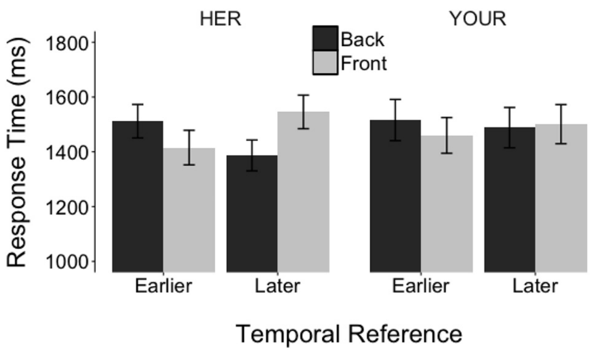

Fig. 3. Mean response times for earlier and later judgments along the sagittal axis. The left graph displays the results for the pronoun "her", and the right graph displays the results for the pronoun "your". Error bars represent standard error.

involving "her" were different than those recruited for the pronoun "your", suggesting that space-time associations are sensitive to person-perspective.

4. General discussion

In Experiment 1, deictic and sequence time were aligned along the sagittal axis differently from how they are aligned along the lateral axis. Along the lateral axis, past and earlier events were associated with left space and future and later events were associated with right space. These findings are consistent with a variety of other studies (e.g., Santiago et al., 2007; Weger & Pratt, 2008) and suggest that space-time associations along the lateral axis are robust to linguistic framing and modality of presentation and response. Thus, the lateral axis appears to be a particularly stable way of spatializing time, which is likely due to systematic patterns in reading and writing direction (e.g., Fuhrman & Boroditsky, 2010; Bergen & Lau, 2012). This is in stark contrast to the space-time associations observed along the sagittal axis, which seem to depend on the type of temporal judgment being made, as well as the perspective from which the events in time are described.

Along the sagittal axis, our participants associated the future with the space in front of their body and the past with the space behind their body, consistent with how we talk about deictic time. For sequence judgments, however, participants associated earlier events with the space in front of their body and later events with the space behind their body, replicating the results of Walker et al. (2014). Such a pattern is consistent with the "lexical association" hypothesis outlined above and is predicted by Moore's (2011) description of how deictically neutral temporal sequences are discussed in language, whereby earlier events lie ahead of, or in front of, later events. However, in Experiment 2, when we directly manipulated the perspective from which different temporal sequences were described, space-time mappings recruited for temporal sequences involving "her" were different than those recruited for the pronoun "your". This suggests that the particular perspective from which a person interprets an event in time influences how he or she will construe sequence time along the sagittal axis. But why should pronouns have any influence on how we spatialize time?

The use of pronouns has been shown to influence the perspective from which readers simulate actions in space that are described in narratives (Brunyé et al., 2009). When participants read sentences such as "You are cutting the tomato" versus "He is cutting the tomato", they are faster to judge that the picture depicts the described scenario if the perspective implied by the pronoun matches the spatial perspective from which the picture was taken (e.g., the pronoun "he" along with a picture of hands cutting a tomato from a third-person perspective). As such, how one spatializes described actions appears to be sensitive to the person-perspective from which those actions are described. If spatial thinking about time works similarly, then pronouns may also influence the spatial perspective one takes when thinking about events in *time*.

While we observed a three-way interaction between pronoun, temporal reference, and response location, we did not observe *a reversal* of associations across the two pronouns. Though participants recruited an "earlier-in-front, later-in-back" mapping for the pronoun "her", this mapping did not reverse when using the pronoun "your". What might explain the lack of an interaction between response location and temporal reference for the "your" stimuli? One possibility may be the fact that the pronoun "you" in English can be interpreted in two ways: either as the second person "you", referring to the interlocutor, or as the indefinite pronoun "you", which refers to a generic person (or people), as in "exercise is good for you". Thus, while some participants may be interpreting the sequence "your high school graduation, your college graduation" relative to their own lives, others may interpret it from a third person perspective, similar to "her high school graduation, her college graduation". Any effects for the pronoun "your" would then be masked by averaging and thus no interaction would emerge.

One factor that could have pushed participants to adopt either a personal or an indefinite interpretation of "your" is the order in which they completed the blocks in the experiment. Participants who started the experiment by making judgments about events that include the pronoun "her" might have been primed by that experience to subsequently interpret the sequences using "your" as not pertaining to themselves, but rather to be indefinite. By contrast, participants who started by making judgments that included "your" might have been more likely to adopt a personal second person interpretation. Exploratory analyses suggest that when the data are divided by which pronoun participants received first, as described above, hints of this particular pattern of results emerge. Participants who received "her" first demonstrated an earlier-in-front/later-in-back mapping for events containing both "her" and "your". On the other hand, no consistent space-time mapping was observed for "your" events by participants who received "your" first while the earlier-in-front/later-in-back was again demonstrated for the "her" events.[1] Though these analyses are exploratory and must be interpreted with caution, they provide preliminary evidence that the pronoun that is presented first influences the pattern of space-time mappings for subsequent pronouns in a manner consistent with the explanation offered above.

One question that remains from this pattern of results is why, even when "your" is presented first, the pronoun "your" does not reveal space-time mappings consistent with an ego-perspective. If "your" can be interpreted from these two different perspectives *and* can be primed by the pronoun "her", as the data above suggests, then it is plausible that no clear effect emerged because participants are interpreting "your" in different ways from the beginning. In future work, adding a small narrative in the instructions that puts the usage of "your" in context may help clarify this issue, as this has been shown to influence the perspective from which ambiguous pronouns, such as "you" or "I", are interpreted (Brunyé et al., 2009).

Another possibility for why no effect emerged for the pronoun "your" stems from a variety of priming experiments by Boroditsky and Ramscar (2002). They demonstrated that manipulating how one thinks about motion space affects how one subsequently thinks about "moving

[1] For participants that were presented with the pronoun "her" first, the same three-way interaction above does not appear (*ps* > 0.36). However, an interaction between temporal reference and location remains, $F_1(1,16) = 9.52$, MSE = 46.970, $p = 0.007$; $F_2(1,38) = 25.51$, MSE = 24.248, $p < 0.001$, and the earlier-in-front/later-in-back mapping is revealed for both "her" ($F_1(1,16) = 8.33$, MSE = 39.508, $p = 0.011$; $F_2(1,38) = 23.18$, MSE = 16.065, $p < 0.001$) and "your" ($F_1(1,16) = 4.63$, MSE = 29.989, $p = 0.047$; $F_2(1,38) = 8.82$, MSE = 28.587, $p = 0.0051$). On the other hand, participants who were tested with the pronoun "your" first demonstrated a three-way interaction between pronoun, temporal reference, and location, $F_1(1,18) = 4.39$, MSE = 45.223, $p = 0.05$; $F_2(1,38) = 8.29$, MSE = 20.678, $p = 0.0065$. While the earlier-in-front/later-in-back pattern remains for the pronoun "her", $F_1(1,18) = 4.68$, MSE = 55.156, $p = 0.044$; $F_2(1,38) = 10.64$, MSE = 20.696, $p = 0.0023$, no clear pattern emerges for the pronoun "your", *ps* > 0.31.

through time." This suggests that, consistent with the present findings, one's spatial perspective is intimately tied to the perspective from which one thinks about time. In the context of the present study, if one adopts an internal perspective when presented with the pronoun "your", either an ego-moving perspective *or* a time-moving perspective, which both involve the ego, could be recruited. As outlined in Boroditsky and Ramscar (2002), these two perspectives directly conflict in terms of how earlier versus later times are laid out in space and thus provides a potential explanation for why no clear effect emerged in the "your" condition. However, in order to better understand the nature of these mappings, future work must tease apart 1) whether "your" is interpreted from second person as opposed to the indefinite and 2) whether sequences involving "your", if assumed to be second person, are interpreted from an internal (which involves the ego) versus an external (which does not include the ego) perspective.

If pronouns are responsible for manipulating the perspective from which individuals spatialize deictic and sequence time, why are such effects only observed along the sagittal, but not the lateral axis? One possibility is that the two axes have different properties that make one more amenable to perspective shifts than the other. Núñez and Cooperrider (2013) distinguish between internal and external perspectives of time and point out that these are largely linked with the use of different axes. For instance, while the entire lateral axis can be laid out in front of the speaker (external), the sagittal axis used for deictic time is often body-centered and closely tied to the speaker's body (internal). External representations of time, such as those along the lateral axis are heavily regimented by writing practices and therefore are less influenced by changes in person perspective than internal representations of time, which are inherently connected to the perspective that the speaker is currently taking.

In sum, spatial cognition is a powerful resource for helping humans structure not only how they interact with the material world, but also for structuring our thoughts about the immaterial. Furthermore, just as there are many different aspects of temporal experience that are captured by different types of temporal concepts (deictic, sequence, duration), spatial experience is equally diverse, drawing on location, perspective, motion, etc. As such, by carefully breaking down the different aspects of our everyday spatial experience, we may be better able to understand the multiple ways that space can be recruited to reason about the abstract concept of time. The present studies support this idea and demonstrate that two different aspects of space, spatial location and perspective, shape how we reason about deictic and sequence time.

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