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Place, Movement, Perspective: How space shapes and constrains our thoughts about time

A dissertation submitted in partial satisfaction of the requirements for the degree

Doctor of Philosophy

in

Cognitive Science

by

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The Dissertation of Esther Jane Walker is approved, and it is acceptable

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ABSTRACT OF THE DISSERTATION

Place, Movement, Perspective: How space shapes and constrains our thoughts about time

by

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Time is fundamental to human experience: it plays a central role in our everyday lives; yet, we cannot feel it, touch it or hear it. How are we able to make sense of such an abstract concept? Lakoff and Johnson (1980) proposed that our concrete experience of being embodied within and moving through space lays the foundation for how we think about abstract concepts, such as time. This idea has driven much research in the field of Cognitive Science, and dozens of studies have since demonstrated that how we think about time appears to be intimately linked with how we think about space. However, at any given moment, people have numerous spatial resources available to them, in what ways are these resources deployed to structure our thoughts about time?

The studies presented in this dissertation investigate the variety of ways that space is used to structure our thoughts about time (at least in the minds of English speakers). I start with the question: *how are different types of temporal relationships associated with space?* I then tease apart the use of different spatial axes by deictic and sequence time, using auditory stimuli and vocal responses. These effects are then replicated using visual presentation and manual responses. From there, I ask: *what particular aspects of spatial experience are used to structure our thoughts about time?* Here, I explore how spatial perspective and bodily motion through space influence how we spatialize time. Next, I examine the role that space plays in reasoning about time by employing a dual-task paradigm designed to interfere with people's spatial resources during a temporal reasoning task. Finally, I look at what co-speech gesture reveals about how space is used in real time when thinking about time. Together, the psychological experiments and studies of co-speech gesture presented here reveal the flexibility, as well as the limits, of how we use space to structure our thoughts about time. This body of work hopes to draw attention to the richness with which space structures time and to illuminate some possible mechanisms that are responsible for our associations of time with space.

CHAPTER 1: Introduction

Time is fundamental to human experience. We structure our lives around it, always trying to arrive *on time* or get things done *ahead of the deadline.* But, time itself is a very abstract concept. We cannot feel it, touch it or hear it; yet, it plays a central role in our everyday lives. How are we able to make sense of such an abstract concept? To address this question, Lakoff and Johnson (1980) proposed that our concrete experience of being embodied within and moving through space structures our understanding of abstract concepts including time. In support of this idea, in many of the world's languages, people talk about time using spatial terms, as in the English expressions: *Way* ***back*** *in the 1950s...* or *I'm looking* ***forward*** *to the weekend.* Though the exact nature of these patterns is quite diverse and varies across languages, the language used to talk about time is often shared with the language used to talk about space. Furthermore, psychological research suggests that such patterns do not merely reflect how we *talk* about time, but reflect something deeper: our experience of acting within and moving through space structures how we *think* about time. This idea has driven much research in the field of Cognitive Science, and dozens of behavioral studies have since demonstrated that how we think about time appears to be intimately linked with how we think about space (e.g. Boroditsky, 2000; Santiago et al., 2007).

Time is an extremely multi-faceted concept and can refer to our perception of the passage of time, as well as our conceptualization of time, which allows us to think about whether an event happened in the past or will happen in the future or whether World War II happened before or after World War I. While the diverse nature of temporal concepts is highlighted in linguistics, it has been treated as somewhat of a monolith in the psychological literature, with studies on the perception of duration, judgments about the past and the future, and judgments about earlier and later events in a sequence all placed under an all-encompassing concept of “time”. Treating these all as the same type of time can lead to misleading conclusions about the nature of our conceptualization of time (Núñez and Cooperrider, 2013).

In this Chapter, I first review findings from three areas of research (linguistics, gesture studies, and cognitive psychology) that use different methods to document the use of spatial language when talking about time and the role that this language, as well as spatial experience, plays in structuring our thoughts about time. Each of these areas provides a unique perspective that allows one to uncover different yet complementary patterns of how space and time are linked in the mind. These findings are then synthesized into open research questions that I will address in subsequent chapters.

Spatial construals of time in linguistics

Linguists have documented the use of spatial language to talk about time in an overwhelming number of the world’s languages. These patterns are readily observable in the English language: everyday, we may hear people say things like, “I’m really looking *forward* to the weekend” or “Do you remember how people used to dress *back* in the 80s?” However, not all languages talk about time using space in the same way. Rather, by creating detailed taxonomies of lexicons, analyzing tense systems, and decomposing the word structure of various languages, linguists have demonstrated that though many regularities exist, there is remarkable variation in the ways that time is spatialized in languages across the world.

Linguists have described two main ways that temporal relationships are captured in language based on distinctions put forth by the philosopher John McTaggart (1908) a century ago. These distinctions capture the idea that temporal relationships can be referenced relative to the present moment, indexing past/future relationships, or to another moment in time, indexing earlier/later relationships, regardless of the present moment (Evans, 2003; Moore, 2006; Tenbrink, 2011; Traugott, 1978). The former is referred to as deictic time, and is seen in expressions such as "*Back* in my childhood...". The latter is referred to as sequence time, which describes expressions such as "Monday *follows* Sunday". Within deictic time, a further distinction can be made between whether speakers talk about time as moving toward or away from their location in space, as in "Spring break is quickly approaching" or whether they talk about moving through time, as in "We are quickly approaching Spring break" and are referred to as Moving-Time and Moving-Ego, respectively (Clark, 1973). While each of these distinctions have appeared under different names and in different forms in the literature, with small nuances separating one from the other (see Bender and Beller, 2014, for a review), they have provided a basis for comparison of how different languages use spatial terms to talk about time. This dissertation will focus only on the deictic/sequence distinction.

English speakers often talk about deictic time in terms of a sagittal axis that runs from the space behind the speaker to the space in front of the speaker. 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. This pattern is also observed in many other Western languages (e.g. French: *Le passé est* ***derrière*** *nous*; *Nous avons l'avenir* ***devant*** *nous*. Spanish: *Hemos dejado* ***atrás*** *el pasado; Tenemos todo* *el tiempo por* ***delante****.* German: *Ich hoffe dennoch, wir können die Vergangenheit* ***hinter*** *uns lassen und nach* ***vorn*** *schauen*.). For sequence time, there is no mandatory reference to the present moment, and thus even though sagittal language can be used to talk about sequences of temporal events, it does not map onto the speaker's body as it does in deictic time. In contrast to deictic time, earlier events in a non-deictic sequence tend to lie *in front* of the reference event while later events lie *behind* the reference 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). This can be contrasted with the use of *ahead* in deictic language, as in "The days *ahead* look bright", where *ahead* means "ahead of now" (in the future). Indeed, a brief analysis of 100 randomly sampled instances of the word "ahead" from the Corpus of Contemporary American English (COCA) **(**Davies, 2008) reveals a similar pattern. 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 pattern has also been documented in Wolof (a West African language), as well as in Japanese (Moore, 2006, 2011, but see Shinohara and Pardeshi, 2011). Thus, in a variety of languages, it is clear that how the sagittal axis is associated with deictic time contrasts with how it is associated with sequence time.

Not all languages share this particular pattern of spatialization of time in language, however. While many Western languages draw on front-back (sagittal) language with the future in front and the past behind, it is not universal. For example, by combining gestural data with linguistic analysis, Núñez and Sweetser (2006) observed that the Aymara of the Andes talk about the future as lying *behind* them and about the past as *in front* of them. Furthermore, sagittal space is not the only spatial axis that people use to talk about time. In Mandarin, vertical (up/down) metaphors can be employed when talking about time, where earlier events, such as "last year", are "up" and later events, such as "next year" are "down" (Chun, 2002).

The systematic observation of spatial terms used to describe temporal relationships has led scholars to claim that these patterns are not simply a linguistic phenomenon, but are reflective of the idea that our very conceptualization of time is structured by our concrete spatial experience (Lakoff and Johnson, 1980). Lakoff and Johnson (1980) proposed that we take advantage of the mental representations that we have built up from concrete experience, such as navigating through the world, and use that structure to shape our representations of more abstract concepts, such as time. While the systematic use of space to talk about time supports this claim, studying patterns in language alone does not put researchers in a position to make strong claims about *conceptual* structure. One needs evidence beyond linguistic examples alone, otherwise, as Murphy (1996) points out, the argument becomes circular: "linguistic data are used to identify metaphors, but the main concrete predictions the theory makes are about similar linguistic and psycholinguistic data" (p. 200). Furthermore, linguistic data alone cannot tell us whether talking about time using spatial terms actually means that our thoughts about time are structured by our thoughts about space. For instance, it may be the case that the linguistic expressions we use to talk about time are simply learned conventions and do not overlap with spatial thinking at all. Thus, while linguistic analyses have been a rich source of hypotheses about the nature of our conceptualization of time, using linguistic data alone to make claims about conceptual structure assumes that how we talk about time is a direct reflection of its conceptual structure. This is a strong assumption. Indeed, as we will see below, it has become clear, through the use of alternative methods such as gesture analysis, that people do not always think about time in the same ways that they talk about it.

In sum, work in linguistics has been particularly useful in documenting regularities in patterns of how space is used to talk about time within and across languages, as well as highlighting cases where they differ. Furthermore, such work provides insight into the possible nature of the structure of our conceptual systems and provides a rich array of hypotheses that can be tested using complementary methods. However, as we will see, basing one's conclusions about the nature of spatial construals of time on linguistic data alone would be premature for multiple reasons. First, it assumes that language is the only way that time gets spatialized and thus masks additional ways that space may be used to structure our thoughts about time. Second, it leads to questions about cases where time does not appear to be spatialized in a particular language. For instance, does this mean that speakers of that language simply do not (or cannot) use space to structure time? In both of these cases, the use of complementary methods such as the analysis of co-speech gesture and psychological experiments has revealed that time is spatialized in rich and nuanced manners that sometimes, but not always, coincide with patterns in language.

Spatial construals of time in gesture

One method that has been used to supplement purely linguistic data is the analysis of co-speech gesture. When people speak, they often gesture. These gestures can range from simple beat movements that may co-occur with an emphasized word in speech to intricate iconic movements that mimic one's interaction with a particular object. Such gestures are largely unconscious and can portray information that is not observed in speech alone (e.g. McNeill, 1992). In the context of space and time, speakers do not have to explicitly mention spatial language in order to produce a temporal gesture (e.g. Cooperrider and Núñez, 2009). Rather, the gesture often complements the content of the speech. For example, when saying "I finished reading that book a long time ago", a speaker may sweep their hand over their shoulder, mapping the space behind them onto the past, even though they do not mention anything about the past being behind them. As such, researchers have used gesture as an additional tool to examine possible metaphoric structure that has previously been observed in language alone (e.g, Núñez and Sweetser, 2006; Cooperrider and Núñez, 2009).

The use of gestural methods has led to a variety of interesting findings regarding spatial construals of time. First, speakers of many of Western languages including French (Calbris, 1990), Italian (De Jorio, 2000), Spanish (Núñez and Sweetser, 2006), and English (Casasanto and Jasmin, 2012) often gesture to the front when talking about the future, point to the ground they are standing on when talking about the present, or sweep a hand over their shoulder when talking about the past, consistent with how speakers talk about the future, the present, and the past. Furthermore, Gu, Mol, Hoetjes, and Swerts (2013) found that Mandarin-English bilinguals gestured along a vertical axis when talking about temporal events in Mandarin, with past events lying above future events, consistent with the vertical spatial metaphors used in Mandarin. However, patterns in language are not always the best predictors of how speakers use space to gesture about time. Indeed, speakers often gesture about time in ways that are *not* captured in language (Calbris, 1990; Cienki, 1998; Cooperrider and Núñez, 2009; Casasanto and Jasmin, 2012; Núñez, Cooperrider, Doan, and Wassmann, 2012). For example, English speakers often gesture along a left-right lateral axis: they may place one hand to the left when talking about the past or sweep their hand to the right when talking about the future (Cooperrider and Núñez, 2009), even though we never hear things like "I'm looking *rightward* to the weekend". Such patterns appear to be the result of our repeated interactions with a variety of cultural technologies such as writing direction, timelines, and calendars (Cooperrider and Núñez, 2009).

Gesture research has also revealed a rich cross-cultural diversity in how individuals spatialize time that would not be evident from looking at linguistic patterns alone (e.g. Núñez and Sweetser, 2006; Núñez et al., 2012; Levinson and Majid, 2013; Le Guen and Balam, 2013). For example, by supplementing their linguistic analyses with gestural data, Núñez and Sweetser (2006) observed that the Aymara of the Andes gesture along a sagittal axis in a unique way: while they point straight downwards when talking about the present (deictic center), they point in front of their body when talking about the past and point over their shoulder when talking about the future. Furthermore, the Yupno people of the Finisterre Range of Papua New Guinea display an even more striking pattern. Rather than gesturing along a linear, ego-based trajectory when talking about the past and the future, the Yupno gesture in an allocentric manner that maps onto the local terrain. When talking about the present, like the Aymara and most cultures around the world, they also gesture straight downwards, but when talking about the past they gesture downhill, while when talking about the future, they gesture uphill, regardless of their bodily orientation. Thus the resulting 'time line' is not a straight line with future and past in opposite directions, but a broken line that reflects the topographic properties of the terrain (Núñez et al., 2012).

The study of co-speech gesture has also provided further evidence for the idea that deictic and sequence time are distinct types of temporal concepts. In their second study, Casasanto and Jasmin (2012) observed that speakers gesture along the lateral and sagittal spatial axes in different proportions depending on the type of temporal relationship (deictic or sequence) being discussed. Speakers used more sagittal gestures when talking about deictic time, but gestured more often along the lateral axis when talking about sequence time. This observation is consistent with the idea that while deictic time includes a deictic center that is co-located with the speaker's body, and thus may more easily lend itself to the front-back structure of the sagittal axis, sequence time does not. On the other hand, temporal sequences are often portrayed from left-to-right on timelines, calendars and other cultural artifacts, which may lead to an increased use of the lateral axis for sequence time. However, this interpretation is at the moment speculative and must be further explored through both gesture studies as well as psychological experiments.

Studying the production of spontaneous co-speech gesture provides a window into how space and time are connected in the mind. As spontaneously produced gesture goes largely unnoticed by the speaker, it acts as a highly revealing yet ecologically valid way to examine conceptual structure and has revealed novel ways in which people use space to structure their thoughts about time. However, while linguistic and gestural data provide great insight into the various ways the people actually use space when talking and thinking about time, there are limits to the types of questions about the nature of spatial construals of time that can be answered by such methods. For instance, analysis of co-speech gesture alone may not be the ideal method for examining the functional role that space plays in structuring our thoughts about time. Furthermore, if one is interested in examining patterns of spatialization of time in language that do not regularly appear in gesture, one may need to look to additional methods, such as the use of controlled psychological experiments.

Spatial construals of time in psychological experiments

In recent years, researchers have conducted an increasing number of psychological experiments that examine spatial construals of time. The majority of this work employs adaptations of more classic paradigms from cognitive psychology. Though many different paradigms have been used, the present section will focus on findings that were obtained from response compatibility studies, as these will be employed in many of the studies in this dissertation.

Response compatibility studies

A common approach used in psychology to examine spatial construals of time is to look for evidence of associations between space and time using reaction time as a dependent measure. The assumptions behind such experiments are relatively straightforward: reaction time is often used as a measure to infer speed of cognitive processing. Critically, any difference in reaction time observed across conditions is taken as evidence of difference in cognitive processing across those conditions. Generally, faster response times reflect easier judgments while slower response times are the result of more difficult judgments. Thus, if time and space share cognitive resources, then participants should be faster to respond when the spatial location and temporal event are presented in a manner that is consistent with patterns in language and gesture, for instance, as it should be easier to respond to congruent mappings than incongruent mappings. This is, for the most part, exactly what researchers find. However, there are exceptions and the findings do not always mirror patterns found in language.

Within such paradigms, researchers have manipulated a variety of variables in order to examine what factors contribute to particular spatial construals of time. For example, experiments vary in how participants are asked to respond when making a judgment about time (or space), with the majority of experiments using manual button presses (Torralbo, Santiago and Lupiáñez 2006; Santiago, Lupiáñez, Pérez, and Funes 2007; Weger and Pratt 2008; Ouellet, Santiago, Israeli, and Gabay 2010; Ulrich et al. 2010; Ulrich et al. 2012; Sell and Kaschak 2011) while others have used vocal responses (Torralbo, Santiago and Lupiáñez 2006; Walker, Bergen, and Núñez 2014; Eikmeier, Schröter, Maienborn, Alex-Ruf and Ulrich 2013). The modality of stimulus presentation also differs across experiments, with visual presentation being the most prevalent (Torralbo et al. 2007; Santiago et al. 2007; Weger and Pratt 2008; Ulrich and Maienborn 2010; Ulrich et al. 2012; Sell and Kaschak 2011), but auditory stimuli have also been used (Ouellet et al. 2010; Walker et al., 2014; Eikmeier et al. 2013). Furthermore, the type of stimulus has also been extensively manipulated, with researchers presenting participants with full sentences that include temporal content (e.g. Sell and Kaschak 2011), single temporal words like "past" or "yesterday" (e.g. Weger and Pratt 2008), single words written in the past or future tense (e.g. Torralbo et al. 2006), short phrases that reflect specific events in time (e.g. "high school graduation", Walker et al. 2013) as well as series of images that index a temporal sequence (e.g. Weger and Pratt 2008). Studies also vary on other factors such as whether the judgments are *explicitly* temporal (e.g. "is this word categorized as *past* or *future*?", Torralbo et al. 2006) or not (e.g., "is this sentence sensible?", Ulrich et al. 2012), what language the participants speak (Spanish: Torralbo et al. 2006; Hebrew: Ouellet et al. 2010; Fuhrman and Boroditsky 2010; English: Sell and Kaschak 2011; German: Ulrich and Maienborn 2010, Ulrich et al. 2012), and the reading direction the participants use (e.g. left-to-right vs. right-to-left: Fuhrman and Boroditsky 2010; mirror reading *within* a language: Casasanto and Bottini 2010).

It is evident from the list above that response compatibility studies using reaction time as a dependent measure have generated a large body of psychological research on the topic of spatial construals of time. However, one open question regarding the results of such studies is what exactly the presence (or absence) of compatibility effects reveals about the nature of spatial construals of time. For instance, perhaps space is *necessary* for reasoning about higher-level temporal concepts like deictic and sequence time, which leads to the systematic observation of compatibility effects in these studies. That is, perhaps space plays a functional role in how we conceptualize time. Alternatively, maybe the link between space and time is epiphenomenal. Perhaps space just happens to be a particularly useful tool for helping people reason about the temporal relationship between events, but this doesn't mean that space is necessary for the conceptualization of deictic and sequence time. Indeed, the observed compatibility effects may reflect learned associations between space and time due to the repeated use of particular linguistic patterns and interaction with cultural artifacts that solidify these associations in one's mind. Currently, the state of the literature cannot distinguish between these and other possible explanations of such effects and this question will be further explored in Chapter 5.

Findings from psychological experiments

This large body of psychological work has provided a strong foundation for examining the role that space (and spatial language) plays in structuring our thoughts about time. There are (at least) three main conclusions that have arisen out of this literature that lead to potentially fruitful avenues for future research. First, space-time mappings can be influenced by factors beyond patterns in spoken language. For instance, writing direction is a strong indicator of how people map time onto lateral space (e.g. Tversky, Kugelmass, and Winter 1991; Ouellet et al. 2010; Fuhrman and Boroditsky 2010). People who read and write from left-to-right, such as English speakers, not only systematically arrange events in time from left to right (with earlier events on the left and later events on the right), they also respond faster to earlier (and past) events on their left and later (and future) events on their right. On the other hand, people who read and write from right-to-left, such as Hebrew and Arabic speakers, show the opposite pattern (Tversky, Kugelmass, and Winter 1991; Fuhrman and Boroditsky 2010). This pattern, which, as discussed above, shows up strongly in gesture and in a variety of psychological experiments, is not evident in our language use and points to the role that our everyday interactions with cultural artifacts such as timelines, comic strips, and calendars play in our thoughts about time. Beyond writing direction, other factors have also been proposed to influence the directionality of space-time mappings. For example, de la Fuente, Santiago, Román, Dumitrache, and Casasanto (2014) proposed that whether one's temporal focus lies on the future or on the past influences how they are likely to place past and future events along a sagittal axis, with those focused on the future placing the future in front and those focused on the past placing the past in front.

Second, the majority of studies that report an association between sagittal space and deictic time have included motion in part of their experimental design, whether it was produced by participants at the response level (Sell and Kaschak 2011; Ulrich et al. 2012; Kranjec and McDonough 2011; Miles, Nind, and Macrae 2010; Rinaldi et al 2016) or it was manipulated as an independent variable (Miles, Karpinska, Lumsden and Macrae 2010; Hartmann and Mast 2012; Koch, Glawe, and Holt, 2011; Sullivan and Barth 2012). Interestingly, a closer look at patterns in language reveals that deictic construals often invoke motion (or potential motion) through space. When we talk about deictic time, we often employ language about motion through space as demonstrated in the phrases: *approaching a deadline* or *coming up on the weekend*. This leads to an intriguing proposal: if particular aspects of spatial experience, such as moving through space, are picked up by language, then maybe this aspect of space also plays a key role in how we conceptualize deictic time. If this is the case, then if stimuli are presented in static locations and participants do not have to move to respond, compatibility effects should not be expected to emerge. In line with this idea, Sell and Kaschak (2011) manipulated whether participants had to move their hand or not to respond to visually-presented sentences about the past or the future. They found that compatibility effects were only observed when movement was required, which suggests that movement may play an important role in representing past and future concepts. However, at the moment this hypothesis is speculative and further experiments are needed in order to better understand the role motion plays in our representation of deictic time. For example, is self-initiated movement through space more likely to elicit stronger deictic construals along the sagittal axis than passive, or even imagined, movement through space? This topic will be explored in Chapter 4.

Finally, deictic time and sequence time appear to be aligned in different manners along the lateral axis and the sagittal axis. Along the lateral axis, “past” and “earlier” events are aligned with left space, while “future” and “later” events are aligned with right space, consistent with cultural conventions. Along the sagittal axis, however, the linguistic findings discussed above suggest that 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. Furthermore, gestural findings discussed above suggest that talking about deictic relationships elicits sagittal gestures while this is less common when talking about sequential relationships, but both types of time lead to gestures along the lateral axis (Casasanto & Jasmin, 2012). However, few psychological studies have sought to tease apart deictic from sequence time or have examined differences in effects along the sagittal and lateral axes (Kranjec & McDonough, 2011; Casasanto & Jasmin, 2012). Yet, these distinctions are important for a variety of reasons. First, the results observed along one axis may not be generalizable to the other axis, as the two different axes have different affordances. For instance, while the entire lateral axis can be laid out in front of the speaker, the sagittal axis used for deictic time is often body-centered and closely tied to the speaker's body. Furthermore, the two axes may have different experiential bases. While associations with the sagittal axis may be more strongly driven by linguistic patterns and embodied experience in the world, lateral axis associations may be more driven by writing and other cultural practices. Similarly, associations between space and deictic time may not be generalizable to sequence time, as both linguistic and gestural evidence suggests that these are type very different temporal concepts. Chapters 2 and 3 investigate this issue.

Outline of Chapters

In this dissertation, I developed and tested novel experimental tools to investigate the nuanced ways that space is used to structure our thoughts about time (or, at least those of English speakers). Chapters 2 and 3 start with the question: *how are different types of temporal relationships associated with space?* In Chapter 2, I tease apart the use of different spatial axes by deictic and sequence time, using auditory stimuli and vocal responses. Chapter 3 serves to replicate the results of Chapter 2 using visual presentation and manual response. Furthermore, Chapter 3 extends these findings and, along with chapter 4, examines *what particular aspects of spatial experience are used to structure* *our thoughts about time?* In these chapters, I explore the role that person perspective and bodily motion play in how we spatialize time. In Chapter 5, I examine the role that space plays in reasoning about time, using a dual-task paradigm to occupy spatial resources while participants reason about time. Finally, in Chapter 6, I move beyond spatial compatibility effects and look at what gesture reveals about how space is used in real time when thinking about time. Together, this body of work hopes to draw attention to the richness with which space structures time and to illuminate some possible mechanisms that are responsible for our associations of time with space.

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CHAPTER 2: Disentangling spatial metaphors for time using non-spatial responses and auditory stimuli

Introduction

Around the world, people talk about time using spatial terms (Clark, 1973; Haspelmath, 1997) as in the English expression *"I'm looking forward to tomorrow."* This spatialization of time also shows up in co-speech gesture, as when one points in front of the body when talking about the upcoming weekend (Núñez & Sweetser, 2006). These patterns have led to the proposal that our concrete experience of being embodied within and moving through space structures our understanding of abstract concepts including time (Lakoff & Johnson, 1980).

However, time is a multi-faceted concept. We can talk about the relationship between events in time and the present—such as whether an event happened in the *past* or will occur in the *future*. Or we can discuss the relative timing of events—whether the discovery of Mars happened *earlier* or *later* than the discovery of Jupiter. These examples capture two different types of temporal reasoning, deictic and sequential, a distinction that has been commented on by both philosophers (McTaggart, 1908) and linguists (Evans, 2003; Moore, 2006; Traugott, 1978). Deictic time describes past and future relationships relative to the present moment (e.g., *"The week ahead of us looks busy"*), while sequential time captures earlier and later relationships relative to another moment in time (e.g., *"The incumbent was in a strong position ahead of the elections"*). But this distinction has been largely overlooked by psychologists, and the particular methods that are often employed to investigate spatial construals of time also tend to mask this distinction. The present study introduces and evaluates a novel paradigm that uses auditory stimuli and vocal responses to investigate the psychological reality of these different spatial construals of time.

The paradigm we used is based on a common method that examines the psychological reality of space-time associations: measuring compatibility effects between the domains of space and time. If time and space share cognitive resources, then participants should be faster to respond when the time and spatial location of an event are presented in a manner that is consistent with patterns in language and gesture (e.g., the past *behind*). Such studies have examined compatibility effects along three different spatial axes: left-right (transversal), front-back (sagittal), and up- down (vertical). The present study will focus on the transversal and sagittal axes, as English was used as the language of study and it, like many other languages, does not use the vertical axis in a systematic way.

Past research using compatibility effects has demonstrated that even though English speakers do not talk about time using the transversal axis, this axis is associated with both deictic and sequential time in a manner consistent with cultural technologies, most notably, writing (e.g., Ouellet, Santiago, Israeli, & Gabay, 2010; Santiago, Lupiáñez, Perez, & Funes, 2007; Weger & Pratt, 2008). English speakers are faster to respond to past events on their left and future events on their right, but this pattern is reversed for speakers of languages such as Hebrew, which is written and read from right to left (Fuhrman & Boroditsky, 2010). In addition to associating past events with the left and future events with the right, English speakers also associate earlier events with the left and later events with the right (e.g., Weger & Pratt, 2008). Thus, if one only examines the patterns of space-time associations along the transversal axis, it may appear as though deictic and sequential time are spatialized in the same manner.

The sagittal axis, on the other hand, is used in both language and gesture. In English, linguistic and gestural data reveal that for deictic time, the future is often portrayed as lying in front of the speaker (*"The future ahead looks bright"*), the past behind the speaker (*"When I look back on my past . . ."*), and the present moment co-located with the speaker (*"The weekend is finally here")*. However, the same sagittal spatial terms can be used in different ways depending on whether one is talking about deictic or sequential time. For instance, the spatial term *ahead* used deictically refers to a time in the *future,* relative to the present (e.g., *"Sunny days lie ahead"*). For sequential time, however, the same term refers to a point *earlier* in time relative to another event (e.g., *"It is two minutes ahead of the hour"*; Moore, 2006, 2011). Thus, in contrast to the transversal axis, these two types of time appear to be spatially construed in different ways on the sagittal axis, at least in language.

While systematic associations between the sagittal axis and sequential time have not been observed experimentally (Casasanto & Jasmin, 2012; Fuhrman et al., 2011; Kranjec & McDonough, 2011), a variety of studies using different methods have found associations between deictic time and the sagittal axis, with future in front and the past behind (Eikmeier, Schröter, Maienborn, Alex-Ruf, & Ulrich, 2013; Hartmann & Mast, 2012; Koch, Glawe, & Holt; 2011; Kranjec & McDonough, 2011; Miles, Karpinska, Lumsden, & Macrae, 2010; Miles, Nind, & Macrae, 2010; Sell & Kashak, 2011; Sullivan & Barth, 2012; Ulrich et al., 2012). However, a closer look reveals that the space-time associations observed in these studies may depend on the particulars of the experimental paradigm used.

First, the majority of such studies require participants to produce manual spatial responses (Koch et al., 2011; Kranjec & McDonough, 2011; Sell & Kashak, 2011; Ulrich et al., 2012). This may serve to prime participants to behave in a way that is consistent with how they often gesture in space when talking about the past or the future, for example. Second, many paradigms include motion as part of the experimental design, either in the presentation of stimuli (e.g., Hartmann & Mast, 2012; Sullivan & Barth, 2012) or in the response (e.g., Koch et al., 2011; Miles, Nind, et al., 2010; Ulrich et al., 2012). This may not only make space particularly salient for the participants, but also confounds motion with spatial location, which makes it unclear whether the results are due to associations with particular locations or to movement (actual or imagined) to that location. Finally, many studies present participants with a sagittal axis that does not capture how sagittal space is used in language. That is, instead of using the space in front of and behind the body, experimenters often provide participants with responses that lie solely in the space in front of the body (e.g., Sell & Kashak, 2011; Ulrich et al., 2012). While space-time associations for deictic judgments have been observed using a frontal sagittal axis, such a design requires participants to displace the deictic center from their body to an external location and thus may reflect a different construal than internal deictic time, which uses sagittal space that surrounds the body (Núñez & Cooperrider, 2013). Furthermore, in the case of sequential time, where a deictic center is not necessary and thus the body isn't necessarily yoked to the axis, the use of a sagittal axis that lies completely in front of the participant may lead to ambiguities in where the "front" and the “back” of the axis is located. Indeed, it has been shown that for objects that do not have a salient front/back distinction, people can interpret the front and the back of that object from different perspectives, and they can be primed to use one interpretation over another (e.g., Boroditsky, 2000). This may explain why Fuhrman et al. (2011), who had participants make judgments about sequential time using a button box placed sagittally in front of the participants, found no compatibility effects between sequential judgments and location on the sagittal axis.

The present paradigm aims to address these concerns and investigates, via compatibility effects, the link between body-centered sagittal and transversal space and deictic and sequential time. We use auditory stimuli and vocal responses, which allow for non-spatial responses and presentation of stimuli along a body-centered sagittal axis, which resolves any ambiguities regarding what is assumed to be the “front” and what is assumed to be the “back” of the sagittal axis. As a result, the use of this novel paradigm allows us to investigate the following three questions.

First, are the previously observed space-time compatibility effects the product of the particular constraints of experimental settings? Past research has often used a forced spatialization of responses (e.g., left and right response keys) and the salient visual presentation of stimuli in particular spatial locations on a computer screen. Such an experimental set-up may compel participants to respond in a manner consistent with learned external representations of time (e.g., timelines). In the present paradigm, responses are not spatialized and auditory stimuli are used and therefore it remains an open question whether the previously documented compatibility effects are still observed when responses are not overtly spatial and the stimuli are not visually presented.

Second, does the use of a body-centered sagittal axis lead to different patterns of space-time associations than an axis that lies completely in front of the body? As discussed above, for deictic judgments, a body-centered axis does not require the deictic center to be displaced away from the body and thus may capture different patterns of associations than a solely frontal axis, which may encourage a more allocentric construal (e.g., events as static positions on an external timeline). In the case of sequential judgments, a body-centered sagittal axis may remove any ambiguities as to what the front and back of the axis is, as the body's front-back asymmetry can serve as a particularly salient cue (e.g., Clark, 1973).

Third, what is the psychological reality of spatial construals of deictic and sequential time, particularly along the sagittal axis? Few studies have sought to tease apart these types of time (with two exceptions: Casasanto & Jasmin, 2012; and Kranjec & McDonough, 2011). The use of this novel paradigm, which separates deictic from sequential time, as well as the transversal from the sagittal axis, is particularly well-suited to shed some light on this question. If deictic and sequential time are not meaningfully different from one another, as is assumed in much of the psychological literature, then they should be associated with space in similar ways. Specifically, not only should deictic and sequential judgments use the transversal axis in the same ways, as is often observed, but they should also use the sagittal axis in a similar manner, with past and earlier judgments faster when presented behind the participant, and future and later judgments faster when presented in front of the participant. However, if they are spatialized in different ways, as reflected in linguistic patterns, then the associations observed between deictic and sequential time and the sagittal axis should reflect this difference.

Methods

Participants were presented with a series of linguistic phrases referring to typical life events and performed one of two tasks. They were asked to vocally report either whether each event occurred in the past or will occur in the future (deictic judgment) or whether one event occurred earlier or later than another event (sequential judgment) by saying the appropriate word aloud into a microphone ("past" or "future" for deictic judgments, "earlier" or "later" for sequential judgments). The stimuli were presented from one of four speakers—in front of, behind, to the left, or to the right of the participant (see Figure 2.1).

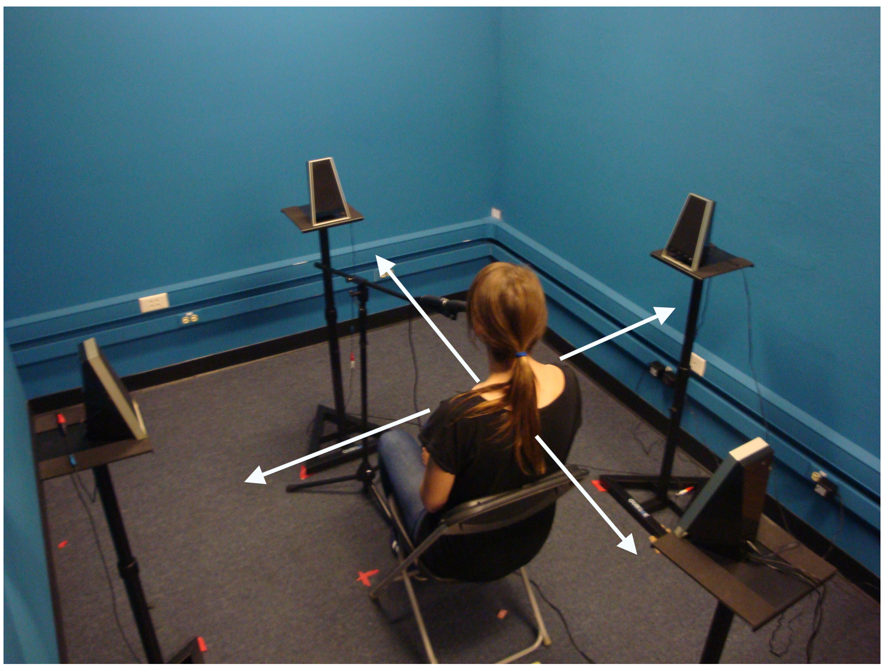

Figure 2.1: Experimental set-up to investigate deictic and sequential judgments along the sagittal (front-back) and transversal (left-right) axes.

Participants

Sixty-four participants from the University of California, San Diego received partial course credit for participating in the study. Thirty-two participants were randomly assigned to make deictic judgments, with the rest making sequential judgments. In the debriefing questionnaire, thirteen subjects reported that even though they were able to hear the stimuli, they were not able to localize sound from at least one of the four speakers and were thus excluded from analysis. This was largely due to front-back confusions, where participants perceived the sound presented from the back speaker as coming from the front speaker. This phenomenon is common in such laboratory set-ups, with front-back confusion rates as high as 50%, as in more natural environments, individuals often move their heads to localize sounds along this axis, but often are not encouraged to do so in the laboratory (Wightman & Kistler, 1999). Two other participants were excluded due to low levels of accuracy (< 80%). Additional participants were recruited to return the number of participants to 32 in each condition.

Materials

For the deictic judgments, we generated 40 life events likely to have happened in the past (e.g., "your birth") or the future (e.g., "your retirement") for an undergraduate student in the United States (see Table 2.1). Past stimuli did not differ from future stimuli in word length (in syllables), $p = .35$, nor in auditory presentation length (in milliseconds), $p = .31$**.** The sequential stimuli were composed of 40 pairs of the life events used for the deictic judgments. Events in the sequential task were preceded with the pronoun "her" rather than "your" (e.g., "her high school graduation," "her college graduation").

Table 2.1: Deictic stimuli belonging to the categories “past” or “future”. Sequential stimuli were composed of pairs of these events but included the pronoun “her” instead of “your”.

Past Events		**Future Events**	
Your birth	Speaking your first word	Your death	Your first mortgage
Your prom	Having your first crush	Your wedding	Starting your first career
Taking your SATs	Your first day in high school	Starting on medicare	Having a child
Starting kindergarten	Your first time shaving	Your child's baby shower	Getting your first gray hair
Getting your baby teeth	Your first part time job	Having a mid-life crisis	Paying off your loans
Getting your driver's permit	Starting to crawl	Your high school reunion	Being middle-aged
Learning to walk	Getting chicken pox	Writing your will	Taking your last college exam
Learning to read	Starting elementary school	Having grandchildren	Being a senior citizen
Starting college	Being in sixth grade	Getting dentures	Your forty-fifth birthday
Taking gym class	Your twelfth birthday	Your retirement	Getting promoted

Design

The experiment was run using a Mac Pro computer and was programmed in MATLAB (2009) using Psychtoolbox (Brainard, 1997). Stimuli were presented via one of four computer speakers. Each participant only made one type of temporal judgment (either deictic or sequential), but all participants heard stimuli along both spatial axes (transversal and sagittal). Vocal response times were measured from the offset of the auditory stimulus.

Participants were each presented with 5 practice trials, followed by two blocks of 80 randomly presented experimental trials. Over the course of the experiment, each subject heard each stimulus once from each of the four speaker locations. In each block, subjects only made judgments along either the transversal or sagittal axis. Axis order (sagittal or transversal first) and type of judgment (deictic or sequential) were counterbalanced across participants. Each trial began with either a short tone (for deictic judgments) or another life event (for sequential judgments) that was simultaneously presented from both speakers along the axis being tested (e.g. from both the left and right speakers for the transversal axis). Participants then heard the critical stimulus from a single speaker along that axis (e.g., the left speaker) and made the corresponding judgment.

After the experiment, participants completed two questionnaires. The first questionnaire listed all of the life events stimuli and participants listed whether each event happened for them in the past or is likely to happen to them in the future. The data from this questionnaire was then used to calculate their accuracy on the deictic judgments. The second questionnaire asked participants what they thought the purpose of the experiment was and to report from which speakers they perceived sound played during the course of the experiment.

Analyses

All analyses were carried out in R (R Development Core Team, 2005). Trials that were not picked up by the microphone, that were spoiled (e.g., coughing, laughing), were incorrect based on questionnaire responses, or were 2.5 standard deviations from each subject's or item's mean were excluded from analysis (deictic: 5.7%; sequential: 6.8%). To compare deictic to sequential judgments along each axis, a separate ANOVA was conducted on vocal response times for each axis with type of time (deictic or sequential), location (left or right for the transversal axis, front or back for the sagittal axis) and temporal reference (earlier or past; later or future) included as independent variables. Furthermore, to examine how each temporal concept was associated with each spatial axis, planned by-subject and by-items ANOVAs were conducted separately along each axis for the deictic and sequential judgments with temporal reference (past/earlier or future/later) and location (left or right for the transversal axis, front or back for the sagittal axis) as the independent variables (see Table 2.2).

Table 2.2: Mean reaction times and standard deviations (in ms).

		Sagittal Axis		Transversal Axis	
		Front	Back	Left	Right
Deictic Judgment	Past	421 (216)	422 (199)	395 (192)	413 (191)
	Future	521 (264)	534 (218)	506 (213)	488 (195)
Sequential Judgment	Earlier	591 (241)	612 (260)	558 (207)	568 (213)
	Later	582 (229)	559 (208)	554 (209)	525 (177)

Results

Sagittal Axis

Results are summarized in Figure 2.2. Overall, participants were faster to make deictic judgments (471 ms) than sequential judgments (588 ms) along the sagittal axis, $F(1, 62) = 4.32$, $p = .042$, $\eta_p^2 = .07$. A two-way interaction between type of temporal judgment and temporal reference also emerged, $F(1, 62) = 60.72$, $p < .001$, $\eta_p^2 = .49$. While past judgments were faster than future judgments for deictic time, $p = .05$, $\eta^2 = .06$, earlier judgments were not significantly faster than later judgments for sequential time, $p = .60$, $\eta^2 = .004$. Critically, there was also a three-way interaction between type of temporal judgment, location, and temporal reference, $F(1, 62) = 4.45$, $p = .039$, $\eta_p^2 = .07$. This interaction was driven by different patterns of space- time compatibility effects for the two types of temporal judgments. For deictic time, contrary to predictions from language and gesture that there are systematic future-in-front and past-behind construals, our paradigm did not find an interaction between temporal reference and speaker location along the sagittal axis, $p_1 = .46$, $\eta_p^2 = .02$, $p_2 = .60$, $\eta_p^2 = .02$.There was a main effect of temporal reference, $F_1(1, 31) = 41.28$, $p < .001$, $\eta_p^2 = .68$; $F_2(1, 38) = 18.27$, $p < .001$, $\eta_p^2 = .34$, as participants were faster to make judgments about past events (421 ms) than future events (528 ms). No main effect of location was observed ($p_1 = .97$, $\eta_p^2 = .01$, $p_2 = .96$, $\eta_p^2 = 0$). Sequential judgments, however, revealed an unexpected interaction along the sagittal axis between temporal reference and location, $F_1(1, 31) = 5.42$, $p = .027$, $\eta_p^2 = .15$; $F_2(1, 38) = 5.32$, $p = .027$, $\eta_p^2 = .12$**.** Follow-up pairwise *t*-tests indicated that participants were faster to make later than earlier judgments presented behind them, $t_1(31) = 3.29$, $p_1 = .003$, $\eta_p^2 = .26$; $t_2(38) = 1.98$, $p_2 = .055$, $\eta_p^2 = .09$. There was no significant difference for stimuli presented in front of the participants, $p_1 = .53$, $\eta_p^2 = .01$, $p_2 = .70$, $\eta_p^2 = .004$.

Transversal Axis

Once again, participants were faster to make deictic (459 ms) than sequential judgments (556 ms) along the transversal axis, $F(1, 62) = 4.06$, $p = .048$, $\eta_p^2 = .06$. However, there was no three- way interaction between type of time, location, and temporal reference, $p = .64$, $\eta_p^2 = .004$. Participants produced similar space-time compatibility effects along the transversal axis for both deictic and sequential time. Planned comparisons for each type of time revealed that there was an interaction between temporal reference and location for deictic, $F_1(1, 31) = 4.28$, $p = .047$, $\eta_p^2 = .12$; $F_2(1, 38) = 6.77$, $p = .012$, $\eta_p^2 = .10$; as well as a marginal interaction for sequential judgments, $F_1(1, 31) = 3.51$, $p = .07$, $\eta_p^2 = .10$; $F_2(1, 38) = 4.72$, $p = .036$, $\eta_p^2 = .11$; replicating previous work.

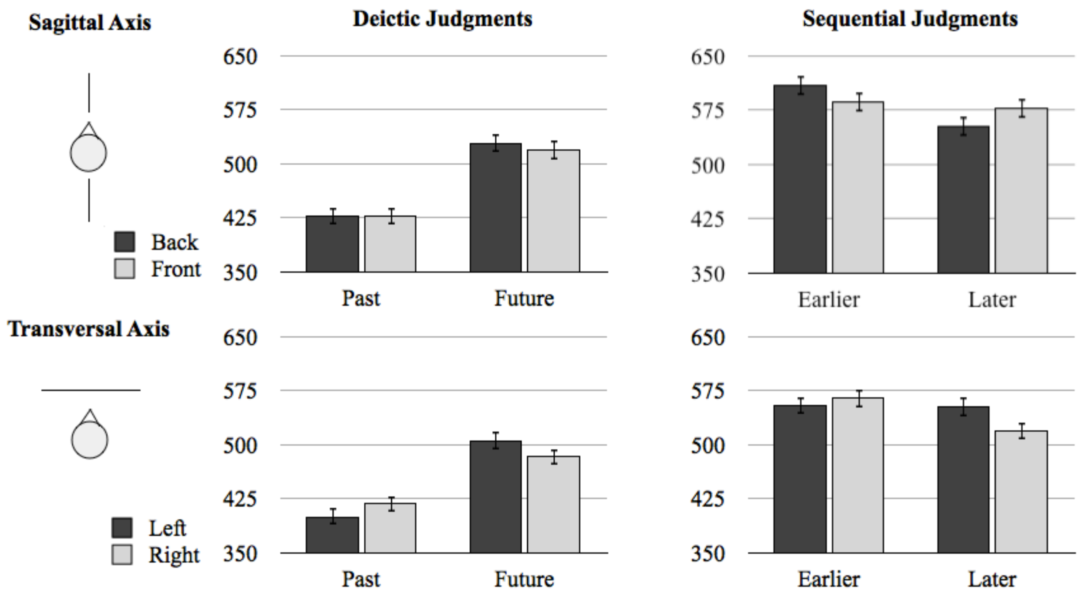

Figure 2.2: Reaction times to deictic and sequential judgments (columns) along the sagittal and transversal axes (rows). Error bars indicate standard error.

Discussion

We introduced and tested a new paradigm that uses auditory stimuli and vocal responses to investigate the psychological reality of different spatial construals of time. Along the transversal axis, we found the typically observed space-time associations for both deictic and sequential time, which squares with previous work (e.g., Santiago et al., 2007; Weger & Pratt, 2008). Importantly, the present results make the novel contribution of showing that these transversal effects are independent of stimulus modality and response mode, which points to the transversal axis as a stable and robust candidate for the spatialization of time. Furthermore, not only did we replicate previous work involving the transversal axis, but we also observed novel and interesting results using a body-centered sagittal axis. While no compatibility effects were observed for deictic judgments on the sagittal axis, there was a clear association between sequential judgments and location on this axis. To our knowledge, this is the first experimental evidence of such an associa- tion. Together, these results highlight the importance of separating deictic and sequential time in future work, as they appear to be two different types of temporal concept (Núñez & Cooperrider, 2013).

In the present study, the difference between deictic and sequential time was reflected in two distinct ways. First, participants were much faster to make deictic judgments than sequential judgments, which is likely due to a difference in difficulty in the two tasks, as participants found it more challenging to compare one event in time relative to another event in time than comparing one event to the present moment. This difference also highlights the very nature of the distinction we are making here—deictic and sequential time capture very different types of relationships, which is reflected in the time it takes people to reason about each of them. Second, deictic and sequential judgments recruited space in fundamentally different ways. While both temporal concepts recruited the transversal axis as expected—likely due to cultural conventions (Cooperrider & Núñez, 2009)—deictic and sequential time displayed different patterns along the sagittal axis. Compatibility effects were *not* observed for deictic judgments, but *were* observed for sequential judgments.

At first, the lack of a deictic space-time compatibility effect appears inconsistent with much of the literature investigating spatial construals of deictic time, as many studies have reported compatibility effects between past and future judgments and the sagittal axis (e.g., Hartmann & Mast, 2012; Koch et al., 2011; Sell & Kashak, 2011; Ulrich et al., 2012). For instance, using a similar set-up (auditory presentation and vocal responses) but a different type of task, Eikmeier et al. (2013) found a compatibility effect using tones presented in front of or behind the participant and whether they responded to that tone by saying "past" or "future". Thus, one possibility is that the present paradigm simply was not sensitive enough to capture such an effect. While this is possible, it seems unlikely given that compatibility effects were observed not only along the transversal axis for both types of time, but also along the sagittal axis for sequential judgments. Additionally, as Eikmeier et al. (2013) were mainly interested in measuring dimensional overlap between time and space, they only had participants make simple associations between the location of a tone and categorizing the tone's location as "past" or "future" whereas the present study required participants to actively construe a particular event as having happened in the past or in the future. As such, an alternative possibility is that the present paradigm, by removing spatialized responses, failed to highlight properties of spatial experience, such as motion, that are often involved in deictic construals.

When we talk about deictic time, we often use motion language, as in *"The weekend is fast approaching."* Interestingly, the majority of studies of the relationship between deictic time and the sagittal axis involve imagined or actual motion in space as part of their design (e.g., Sell & Kashak, 2011; Ulrich et al., 2012). For instance, Miles, Karpinska, et al. (2010) found that illusory forward self-motion through space induced more daydreams about the future while illusory backward self-motion induced more daydreams about the past. Thus, maybe *motion*—and not just location—is key to the representation of past/future relationships along the sagittal axis (Boroditsky & Ramscar, 2002; Sell & Kaschak, 2011). Our results are consistent with this idea, as we found that non-spatialized responses failed to elicit a clear sagittal deictic association. Future work must carefully investigate this speculative hypothesis and examine to what extent and in what ways the motor system or other particular types of spatialized responses may be involved in bringing forth spatial construals of deictic time when using a body-centered sagittal axis. Whether this is due to patterns in language (e.g., is deictic time described more often using motion terms than static spatial locations?), contingencies in how we interact with the world (e.g., motion forward in space co-occurs with passing through time towards the future), or a combination of the two needs to be further explored.

While no deictic sagittal effect was observed, a space-time compatibility effect emerged for sequential judgments on the sagittal axis, with participants associating earlier events with the space in front of them and later events with the space behind them. This aspect of our results may appear surprising for a variety of reasons. For example, previous studies have failed to find evidence of an association between sequential time and the sagittal axis (Casasanto & Jasmin, 2012; Fuhrman et al., 2011; Kranjec & McDonough, 2011). A closer look at these studies, however, suggests that these studies may represent absence of evidence rather than evidence of an absence, as there are limitations to each. For example, in Kranjec and McDonough (2011), the sequential stimuli were not presented in a sequence, but were separated by other images, which may have prevented subjects from realizing they were part of a sequence. Furthermore, Casasanto and Jasmin (2012) found that individuals do not gesture along the sagittal axis when talking about sequential time. However, people may typically gesture along the transversal axis for sequential time for particular reasons. For instance, when comparing events in time, as is often the case with sequences, it may simply be easier to lay things out along the transversal axis, rather than use the space in front of and behind the body.

This does not necessarily mean that individuals do not associate sequential time with sagittal space.

The pattern of associations we observed for sequential judgments on the sagittal axis might also appear counterintuitive: shouldn't *earlier* events be associated with the space *behind* the participant and *later* events associated with the space in *front*? However, that particular pattern describes the case for *deictic* time, where events that are earlier than the present, or past events, are behind and events that are later than the present, or future events, are ahead. Rather, the observed results are consistent with a deictically neutral field-based perspective of sequences in language (Moore, 2011), evidenced in expressions like *"The incumbent was in a strong position ahead of the elections,"* where earlier events are placed *in front* of later events. Given the use of a body-centered sagittal axis in this paradigm, participants may have used their body to anchor the first event they heard. Then, after aligning their fronts and backs with the metaphorically oriented sequence of events, they may have placed the second event either in front of them (earlier) or behind them (later). Future research may more closely examine the nature of this association and the differences between deictic and sequential time.

While the present paradigm proved to be a useful method of investigating spatial construals of deictic and sequential time along multiple spatial axes, it is important to consider its limitations. For instance, future implementations of a similar paradigm may want to consider further investigating the nature of the front-back sound confusions our participants experienced and how they may best be avoided. In addition, we explicitly sought to eliminate the use of spatial responding in the present study. Though compatibility effects were still observed along the transversal axis, no such effects were observed for deictic judgments along the sagittal axis, which conflicts with previous findings. However, it is unclear whether this is due to a lack of sensitivity of our paradigm or whether spatial construals of deictic time rely on particular aspects of space that weren't highlighted in the present paradigm. A potentially fruitful area of future research would be to more closely examine what particular aspects of space and spatial experience are important for bringing forth such spatial construals of time.

In sum, we developed a novel paradigm that can be used to tease apart the use of different spatial axes by different types of temporal concepts. The results obtained by this paradigm replicated previous work along the transversal axis, but also revealed previously unobserved findings along the sagittal axis. These results highlight the importance of disentangling the various elements involved in the realization of spatial construals of time and suggest that time is a multifarious concept that recruits spatial properties in nuanced, context-dependent ways.

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CHAPTER 3: The spatial alignment of time: Differences in alignment of deictic and sequence time along the sagittal and lateral axes

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). And how space gets associated with temporal thought is complex and multifaceted, as both space and time are rich concepts (for a review, see Núñez and 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, which allow for complex coordination and planning across individuals (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 (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 having such an anchor (i.e., there is no "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), 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 et al., 2007; Weger & Pratt, 2008, Ulrich & Maienborn, 2010; Ouellet et al., 2010; Fuhrman & Boroditsky, 2010). This pattern is reversed for those who read and write from right to left (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 gestures co-produced with speech about future or later events (Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012). Such patterns are likely shaped by a lifetime of cultural experiences, including reading and writing in a particular direction (e.g., Winter, Matlock, Shaki, & Fischer, 2015).

An additional way that deictic and sequence time get spatialized is revealed through how we talk about time. English speakers often employ *sagittal* (front-back) language to talk about deictic time (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 a 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 in a different manner than how they are aligned along the lateral axis, which is not typically used in language. 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 an 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.

The linguistic 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 & Kashak, 2011; Kranjec & McDonough, 2011; Miles, Nind, & Macrae, 2010; Miles, Karpinska, Lumsden. & Macrae, 2010; Hartmann & Mast, 2012; Koch, Glawe, & Holt; 2011; Sullivan & Barth, 2012). 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 (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 a sequential order (e.g., a series of pictures of a caterpillar transforming into a butterfly would be intermixed with images from a variety of other series). 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 "temporal alignment" hypothesis, 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. Indeed, this account is similar to the "polarity correspondence" hypothesis (Proctor & Cho, 2006) that aims to account for many of the observed compatibility effects across a variety of domains (e.g., time, number, valence). 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 some 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?). For sequence judgments, they found that participants were faster to make later judgments when the stimuli were presented behind their body and earlier judgments when the stimuli were presented in front of the body. 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).

It is possible, however, that the pattern of results observed by Walker et al. (2014) was due to the particulars of the paradigm that was used. The majority of studies that report associations between deictic judgments and the sagittal axis include motion, which is either produced at the response level (Sell & Kashak, 2011; Ulrich et al., 2012; Kranjec & McDonough, 2011; Miles, Nind, & Macrae, 2010) or is manipulated as an independent variable (Miles, Karpinska, Lumsden. & Macrae, 2010; Hartmann & Mast, 2012; Koch, Glawe, & Holt; 2011; Sullivan & Barth, 2012). However, the paradigm used by Walker et al. (2014) does not foreground motion through, or action in space as a result of the particular mode of stimulus presentation and response modality used. By requiring participants to respond vocally (i.e., non-spatially), the sagittal axis may have become less salient than had they been required to respond manually, resulting in their observed null effect for deictic judgments. In addition, the sagittal effect Walker et al. (2014) observed for sequence judgments, where earlier events were associated with the space in front of the participant and later events with the space behind the participant, could 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 always included the pronoun “your” (e.g., “your high school graduation”), the sequence stimuli always included the pronoun “her” (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 et al., 2012; 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., 2012). 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 (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, testing the "temporal alignment" and "lexical association" hypotheses (Experiments 1 and 2) 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 3).

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. 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.

Methods

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 who made sequence judgments were removed due to low levels of accuracy (< 75%), leaving 68 participants for analysis (32 sequence, accuracy = 94%; 36 deictic, accuracy = 95%).

Design and Materials

The experiment was programmed using E-Prime (Psychology Software Tools, Pittsburgh, PA, USA). Deictic stimuli consisted of forty typical life events (Table 3.1). 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 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. Deictic stimuli always included the pronoun "your" while sequence stimuli always included the pronoun "her", in order to replicate the stimuli used by Walker et al. (2014).

Table 3.1: 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 80^{th} birthday	Being middle aged

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 Figure 3.1a). For the sagittal axis, participants held one mouse directly in front of their body and the other mouse behind their back (see Figure 3.1b). We counterbalanced which hand was held in front of the body (right or left) across participants.

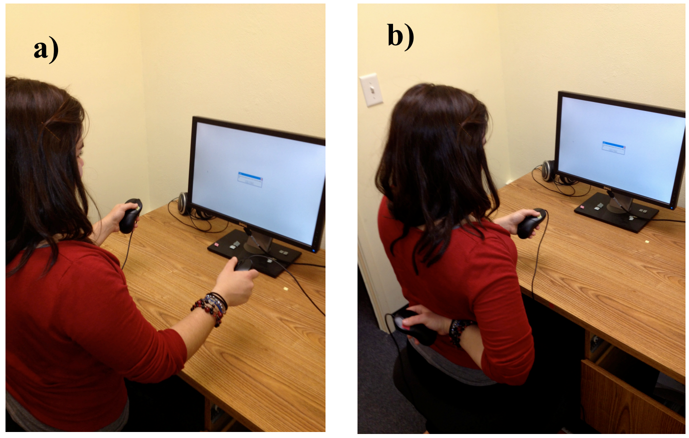

Figure 3.1: The position of the computer mice when making judgments along the lateral axis (a) or along the sagittal axis (b).

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 1000ms, followed by a life event. For deictic judgments, this event remained on the screen until the participants responded, up to 5000ms. For sequence judgments, the first event remained on the screen for 2000ms. A white screen was then presented for 500ms and the second event was then presented and remained on the screen until the participants responded, up to 5000ms. Reaction 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.

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). First, we compared deictic to sequence time along each axis (sagittal and lateral) using by-subject (F_1) and by-items (F_2) ANOVAs, 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 then examined how each type of time (deictic/sequence) was associated with each spatial axis by conducting separate ANOVAs along each axis for the deictic and sequence judgments, with temporal reference and location as factors. 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.

Results

We first report analyses along the sagittal axis, and then the lateral axis (see figure 3.2 for a graphical summary of results).

Sagittal Axis

Overall, participants were faster to make deictic than sequence judgments, F_1 (1,66) = 21.98, η_p = .25, p < .001, F_2(1,76) = 80.45, η_p = .51, p < .001. There was also a main effect of temporal reference whereby participants were faster to make past and earlier judgments than future and later judgments in the by-subject analysis, F_1(1,31) = 11.85, η_p = .28, *p* = .002, but not by-items, *p* = .38. 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, η_p = .14, p = .001, F_2(1,76) = 50.22, η_p = .40, *p* < .001, revealing different patterns of alignment along the sagittal axis for sequence and deictic time than what is typically observed along the lateral axis. For sequence time, there was a significant interaction between temporal reference and response location, F_1(1,31) = 4.73, η_p = .13, *p* = .037, F_2(1,38) = 23.32, η_p = .38, *p* < .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* = .027, t_2(19) = 4.93, *p* < .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* = .09, t_2(19) = 2.29, *p* = .034.

For deictic time, there also was a two-way interaction between temporal reference and location, F_1(1,35) = 16.82, η_p = .32, *p* < .001, F_2(1,38) = 35.1, η_p = .48, *p* < .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* < .001, t_2(19) = 3.85, *p* = .001) but were faster to respond to future events in front than behind ($t_1(35) = 2.55$, $p = .015$, $t_2(19) = 4.58$, $p < .001$). No main effects were observed.

Lateral Axis

Overall, participants were again faster to make deictic than sequence judgments, $F_1(1,66) = 26.78$, $\eta_p = .29$, $p < .001$, $F_2(1,76) = 121.36$, $\eta_p = .61$, $p < .001$. Participants were also faster overall to make earlier than later judgments, $F_1(1,31) = 11.81$, $\eta_p = .28$, $p = .002$ in the by-subjects analysis, but not by-items, p=.17. Contrary to the sagittal axis, there was no three way interaction between type of time, temporal reference, and response location, $p_1 = .25$, $p_2 = .19$. There was, however, a two-way interaction between temporal reference and response location, $F_1(1,66) = 8.38$, $\eta_p = .11$, $p = .005$, $F_2(1,76) = 36.8$, $\eta_p = .33$, $p < .001$, suggesting that sequence and deictic time are aligned along the lateral axis in the manner initially predicted. .

For sequence time, there was a significant interaction between temporal reference and location, $F_1(1,31) = 4.77$, $\eta_p = .13$, $p = .037$, $F_2(1,38) = 16.68$, $\eta_p = .31$, $p < .001$. Pairwise t-tests revealed participants were faster to make later judgments by pressing the right mouse than the left mouse ($t_1(31) = 2.47$, $p = .019$; $t_2(19) = 3.40$, $p = .003$). Earlier judgments were faster using the left mouse than the right mouse, but this was only reliable by items ($p_1 = .18$, $t_2(19) = 2.33$, p=.03).

There was also an interaction between temporal reference and location for deictic time, $F_1(1,35) = 4.31$, $\eta_p = .11$, $p = .045$, $F_2(1,38) = 31.32$, $\eta_p = .45$, $p < .001$. Pairwise t-tests revealed that for future judgments, participants were faster to respond using the mouse on their right than on their left, $t_1(35) = 2.61$, $p = .013$, $t_2(19) = 4.65$, $p < .001$. Past judgments were reliably faster on the left, but only in the by-items analysis, $p_1 = .34$, $t_2(19) = 3.12$, $p_2 = .006$.

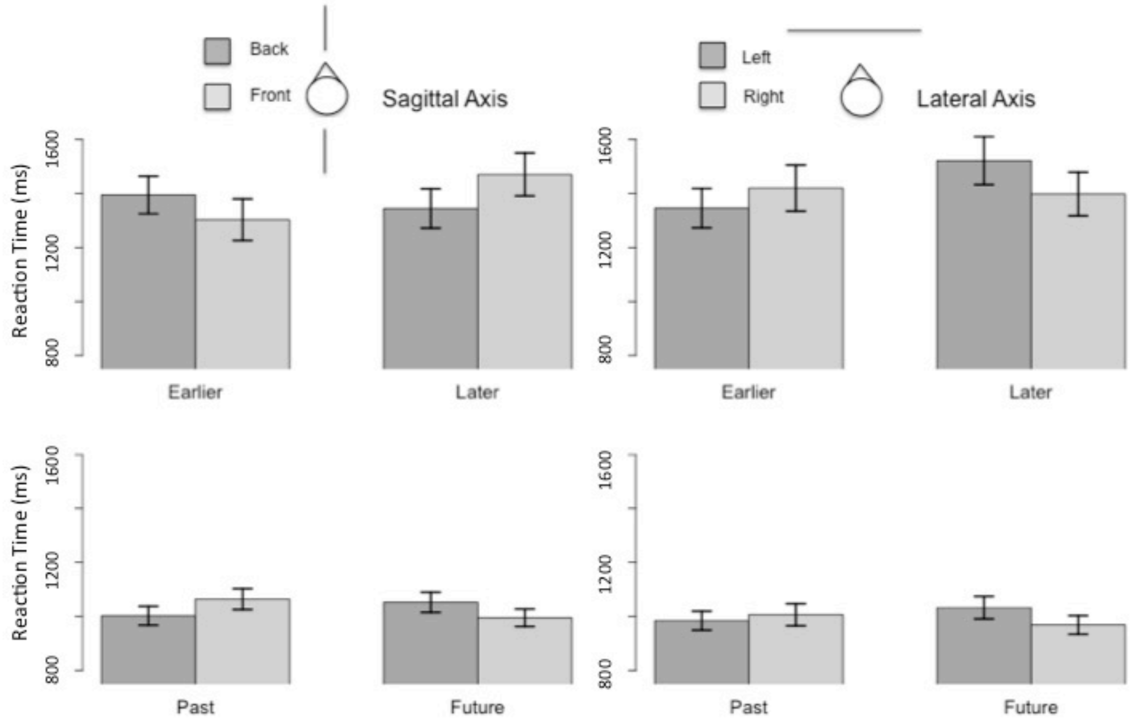

Figure 3.2: Mean reaction times to sequence (top row) and deictic (bottom row) judgments along the sagittal (first column) and lateral (second column) axes in Experiment 1. Error bars indicate standard error.

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., 2007; 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. 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 eliminating the presence of pronouns in the stimuli.

Experiment 2

Experiment 2 examined whether the differences in alignment along the sagittal axis observed in Experiment 1 were due to differences in the use of pronouns across the two types of temporal judgments. In order to make the deictic and sequence stimuli as similar as possible, all pronouns were removed from the stimuli. If the “lexical association” hypothesis was responsible for the pattern of results observed in Experiment 1, then we should observe the same pattern of results, even when the pronouns are removed. However, if the use of different pronouns was responsible for producing differences in alignment along the sagittal axis for deictic and sequence time, then by eliminating the difference across the two types of judgments, we should no longer observe different patterns of alignment along the *sagittal* axis for the two types of judgments. Critically, however, results along the lateral axis should remain unchanged. The lateral axis is often used to represent deictic and sequence relationships, where changes in perspective do not influence the relative positions of past and future or earlier and later events: past events are to the left of the present and future events are to the right of the present while earlier events are to the left of later events.

Methods

Participants

Sixty-four undergraduates (21 males, mean age = 19.7 years, SD = 1.41, range = 18-24)) at the University of California, San Diego participated for partial course credit. Participants were randomly assigned to make either deictic or sequence judgments. One participant who made sequence judgments was excluded from analysis due to very low levels of accuracy (51%; average sequence accuracy = 94%) and one deictic participant was excluded due to high levels of not responding (only completed 62% of trials; average deictic accuracy = 95%).

Materials

The materials were similar to those used in Experiment 1 except that all pronouns were removed from the stimuli (Table 3.2). If the removal of a pronoun made the stimulus unclear or difficult to understand, the stimulus was either edited or removed and additional events were added to return the number of stimuli to 20 in each condition.

Table 3.2: List of deictic stimuli used in Experiment 2. Sequence stimuli were generated by combining pairs of deictic stimuli. 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	Twelfth birthday	2014	Mid-life crisis
Birth	Getting a driver's permit	Halloween 2013	Taking last college exam
Learning to walk	First time shaving	Having a child	Christmas 2013
Learning to read	Taking the SATs	Starting first career	Wedding
Elementary school	Starting to crawl	Being a senior citizen	Being middle aged
Spring break 2012	Starting to talk	Tomorrow	First mortgage
Valentine's day 2012	Starting college	Having grandchildren	Thanksgiving 2013
First day in high school	Easter 2012	Fall quarter 2013	Writing a will
First crush	Being in sixth grade	High school reunion	Retirement
Yesterday	Spring quarter 2012	Forty-fifth birthday	Starting medicare

Procedure

The procedure was identical to Experiment 1. Participants received four blocks of trials (two blocks along each axis) and made either deictic (past/future) or sequence (earlier/later) judgments by clicking one of two computer mouses.

Analyses

Analyses followed the analyses in Experiment 1. Incorrect trials or trials with no response (6.3% sequence; 3.3% deictic) were excluded from analysis, as well as trials that were 3 standard deviations from each subject's or item's mean (2.5% sequence; 2.0% deictic).

Results

Sagittal Axis

Overall, participants were faster to make deictic than sequence judgments, $F_1(1,58) = 10.52$, $\eta_p = .15$, $p = .002$, $F_2(1,76) = 34.86$, $\eta_p = .31$, $p < .001$ (see Figure 3.3 for a summary of results). No three way interaction between type of time, temporal reference and response location was observed, $p_1 = .75$, $p_2 = .40$. Interactions were not observed between temporal reference and response location for either sequence ($p_1 = .75$, $p_2 = .12$) or deictic judgments ($p_1 = .64$, $p_2 = .42$).

Lateral Axis

Overall, participants were faster to make deictic than sequence judgments, $F_1(1,59) = 16.87$, $\eta_p = .22$, $p < .001$, $F_2(1,76) = 45.2$, $\eta_p = .37$, $p < .001$. There was a marginal three way interaction between type of time, temporal reference, and response location, $F_1(1,59) = 3.71$, $\eta_p = .06$, $p = .059$, $F_2(1,76) = 20.7$, $\eta_p = .21$, $p < .001$. This interaction is largely driven by the difference in the sizes of the compatibility effects observed for sequence and deictic judgments, as the same pattern of effects was observed for both types of time. Indeed, there was an overall two-way interaction between temporal reference and response location, $F_1(1,59) = 9.28$, $\eta_p = .14$, $p = .003$, $F_2(1,76) = 53.8$, $\eta_p = .41$, $p < .001$.

For sequence judgments, there was an interaction between temporal reference and response location, $F_1(1,30) = 6.39$, $\eta_p = .19$, $p = .017$, $F_2(1,38) = 46.2$, $\eta_p = .55$, $p < .001$. Participants were faster to make later judgments on their right than on their left, $t_1(30) = 3.38$, $p = .002$, $t_2(19) = 7.12$, $p < .001$. They were also faster to make earlier judgments on their left than on their right, but this was only reliable by-items, $t_1(30) = 1.64$, $p = .11$, $t_2(19) = 3.19$, $p=.005$.

A similar interaction was observed for deictic judgments, $F_1(1,30) = 4.67$, $\eta_p = .13$, $p = .039$, $F_2(1,38) = 8.20$, $\eta_p = .18$, $p = .007$. Participants were faster to make past judgments on their left than on their right, $t_1(30) = 2.27$, $p = .031$, $t_2(19) = 2.40$, $p = .027$. They were no faster at making future judgments on their left or on their right ($p_1 = .19$, $p_2 = .12$).

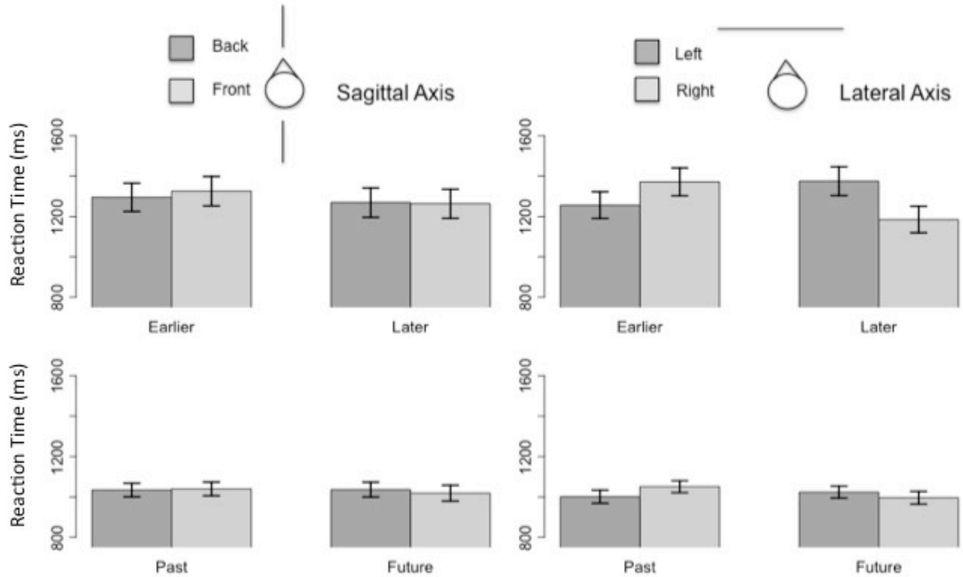

Figure 3.3: Mean reaction times to sequence (top row) and deictic (bottom row) judgments along the sagittal (first column) and lateral (second column) axes in Experiment 2. Error bars indicate standard error.

Discussion

Experiment 2 examined whether the use of different pronouns in Experiment 1 was driving the previously observed results for deictic and sequence judgments by removing all pronouns from the stimuli. Results along the lateral axis remained largely unchanged, suggesting that deictic and sequence time are associated with the lateral axis in a way that is robust to differences in linguistic framing. However, the removal of pronouns from the stimuli affected results along the sagittal axis more dramatically. Compatibility effects were no longer observed for either deictic or sequence judgments, contrary to what was observed in Experiment 1.

Perhaps compatibility effects were no longer observed along the sagittal axis in Experiment 2 because the stimuli became less clear and more difficult to interpret once the pronouns were removed. However, if this were the case, then one would not expect to see any compatibility effects along the lateral axis, as the same stimuli were used. Yet, the exclusion of pronouns only affected the presence of compatibility effects along the sagittal axis, suggesting that this is likely not the case.

Why might the absence of pronouns affect compatibility effects along the sagittal axis? It is possible that the removal of pronouns in Experiment 2 leaves out an important linguistic cue, person, that participants might otherwise use to interpret the perspective from which the event ought to be represented along the sagittal axis. We know that in the absence of person cues to perspective, perspective effects disappear. For instance, findings by Sato and Bergen (2013) suggest that when a sentence only implies person (because it omits a pronoun), individuals show no aggregate preference for spatial perspective in mentally construing the sentence content. As a result, when, as in Experiment 2, no perspective is described in sentences about time (by virtue of there being no pronoun), then listeners might 1) simply not adopt a particular perspective, 2) adopt multiple different perspectives simultaneously, or 3) adopt one perspective or another, which may differ across items or participants (or both). As a result, any potential space-time compatibility effects may be washed away. Experiment 2 cannot differentiate between these possibilities.

While the present study removed the presence of pronouns as a proxy for controlling for perspective, it leaves the question open of whether the use of *different* pronouns influences how individuals spatialize deictic and sequence time. Experiment 3 addresses this question by manipulating, within participants, the perspective from which temporal sequences are described.

Experiment 3

Experiment 3 examines whether the use of different pronouns ("her", "your") leads participants to interpret temporal sequences from different perspectives and therefore lead to differences in how individuals mapped temporal sequences onto space. The pronoun "your" may be more likely to elicit an internal perspective (Brunyé et al., 2009), which is often used for deictic time, but not for sequence time. As a result, the use of the pronoun "your" may automatically prime thoughts about one's own location in time. This 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.

Methods

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 (<80%), leaving 36 participants for analysis.

Materials

The materials were identical to those used in Experiment 1, with each stimulus including either the pronoun "her" or the pronoun "your", depending on the condition.

Procedure

The procedure was almost identical to that used in Experiment 1, except that participants made only sequence judgments. Each participant completed a total of four blocks of forty trials of sequence judgments. During two of the blocks, each event was preceded with the pronoun "her" and during the other two blocks, events were preceded with "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.

Analyses

All analyses were conducted in *R* (R Development Core Team, 2005). To investigate whether the different pronouns elicited different spatial construals of temporal sequences, a three-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 (reported as F_1). By-items (F_2) analyses are also reported with pronoun and response location as within-items factors and temporal reference as a between-items factor. As needed, appropriate follow-up tests were conducted.

Results

The omnibus ANOVA revealed a two-way interaction between temporal reference and response location, $F_1(1,35)=5.36$, $\eta_p = .13$, p=.027, $F_2(1,38)=36.40$, $\eta_p = .49$, p<.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=.033), $t_2(19)=4.65$, p<.001) and to earlier events when responding in front than in back ($t_1(35)=2.02$, p=.051, $t_2(19)=3.87$, p=.001). Critically, there was also a three-way interaction between pronoun, temporal reference, and response location, $F_1(1,35)=4.38$, $\eta_p = .11$, p=.044, $F_2(1,38)=8.01$, $\eta_p = .17$, p=.007. 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", $F_1(1,35)=10.03$, $\eta_p = .22$, p=.003, $F_2(1,38)= 42.70$, $\eta_p = .53$, p<.001. This interaction was not reliably significant for the pronoun "your", $p_1=.43$, $p_2=.055$ (see Figure 3.4).

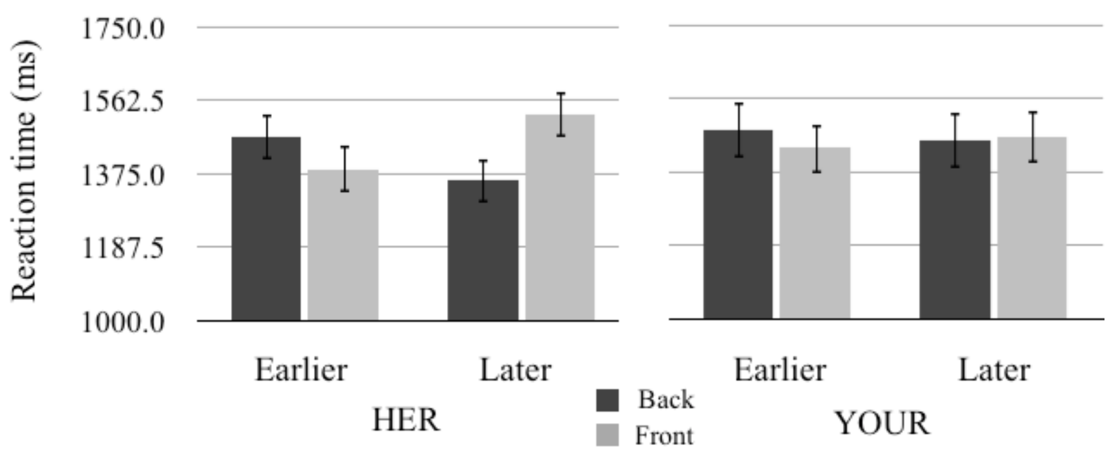

Figure 3.4: Mean response times for earlier and later judgments along the sagittal axis. The left graph displays the results for the pronoun "her". The interaction between response location and temporal reference is significant. The right graph displays the results for the pronoun "your". Error bars represent standard error.

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 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 involving “her” were different than those recruited for the pronoun “your”.

General Discussion

In the first two studies, we found that the presence or absence of pronouns modulates compatibility effects for deictic and sequence time along the sagittal, but not the lateral axis. Along the lateral axis, we observed similar patterns of space-time compatibility effects for both deictic (Experiment 1: η_p = .11, Experiment 2: η_p = .13) and sequence time (Experiment 1: η_p = .13, Experiment 2: η_p = .19), where 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 and the modality being tested (Walker et al., 2014), as well as the perspective from which the events in time are described.

In Experiment 1, deictic and sequence time were aligned along the sagittal axis differently from how they are aligned along the lateral 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, simply removing pronouns from the stimuli led to the disappearance of compatibility effects along the sagittal axis for both types of judgments. No such disappearance was observed for judgments made along the lateral axis. This suggests that the particular perspective from which one interprets an event in time influences how people construe deictic and sequence time along the sagittal, but not the lateral axis. Experiment 3 provided further support for this idea by directly manipulating 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". 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 predicted a three-way interaction between pronoun, temporal reference, and response location, we did not observe the interaction pattern we expected. Though participants recruited an "earlier-in-front, later-in-back" mapping for the pronoun "her", we did not see *a reversal* of this mapping when the stimuli were preceded with "your". What might explain the lack of an interaction between response location and temporal reference for the "your" stimuli? One possibility may be due to 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 potential factor that could have pushed participants to adopt either a personal or an indefinite interpretation of "your" could have been the order in which they completed the blocks in the experiment. Participants who started the experiment by making judgments to events that used 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 to "your" events might have been more likely to adopt a personal second person interpretation.

Exploratory analyses suggest that when the data were divided by which pronoun participants received first, as described above, this very pattern of results emerges. 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 was presented first influences the pattern of space-time mappings for each of the 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

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[1] For participants that were presented with the pronoun "her" first, the same three-way interaction above does not appear (ps>.36). However, an interaction between temporal reference and location remains, $F_1(1,16)=9.52$, MSE=46970, $p=.007$; $F_2(1,38)=25.51$, MSE=24248, $p<.001$, and the earlier-in-front/later-

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 the “your” in different manners 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 by influencing how one thinks about *physically moving* through space, how one thinks about “moving through time” is affected. 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 ego-perspective when presented with the pronoun “your”, an ego-moving perspective *or* time-moving perspective which both involve the ego, may be equally likely to be recruited. As each of these perspectives would predict opposite effects, this would explain why no clear effect emerged in the “your” condition. While this additional source of ambiguity regarding the pronoun “your” may *partly* explain why no effect was observed for that pronoun, our exploratory analyses argue that that interpretation cannot account for all of the present data. For example, it is unclear why the pronoun “her” would subsequently prime a time-moving (which involves the ego) instead of a field- based perspective for “your”. Indeed, a third-person pronoun priming such a perspective seems unlikely given the work investigating the relationship between perspective and pronouns (e.g., Brunyé et al., 2009). Thus, 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 ego-moving versus time- moving 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, may simply be 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.

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 observed large and consistent effects for deictic judgments along the sagittal axis in Experiment 1. 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 Walker et al.

(2014) simply failed to detect a real effect. However, another possibility is that the present study foregrounds different aspects of space as a result of the particular response modality used. By requiring participants to respond manually in the present studies, rather than vocally (i.e., non-spatially) as in Walker et al. (2014), the sagittal axis may become spatially more salient than simply listening to events presented in front of and behind the body and responding vocally. Furthermore, many of the previous studies that find sagittal deictic effects involve motion either at the response level or in the stimulus (e.g., Hartmann & Mast, 2012; Sullivan & Barth, 2012; Ulrich et al., 2012). In the present study, the use of manual responses may encourage people to think about *moving* and *acting* along that axis, which may be more likely to elicit thoughts about deictic time, as they are physically acting in space rather than responding vocally, which is a non-spatial response.

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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CHAPTER 4: Stepping through time: Sagittal construals of deictic and sequence time

Introduction

Even though we often talk and gesture about deictic time along the sagittal axis, Chapters 1 and 2 found that the space in front of and behind the speaker is not automatically associated with the deictic concepts of “past” and “future” in English speakers. Rather, a variety of factors seem to influence how individuals construe deictic time, including person perspective. For instance, in study 2 of Chapter 3, we saw that when the perspective from which temporal events were described was ambiguous (no pronoun was included in the description), participants did not associate past or future concepts with the sagittal axis in a systematic way. However, when the perspective was made explicit (via the pronoun “your” in Chapter 2 and study 1 of Chapter 3), participants systematically associated past events with the space behind them and future events with the space in front of them. There, I suggested that perhaps the pronoun “your” helps prime thoughts about the participant’s location in space and time, which may in turn prime the sagittal axis. However, when disambiguating perspective information is unavailable, what other factors, if any, influence the English speaker’s associations between the sagittal axis and deictic and sequence time?

One factor that may play an important role in how we think about deictic time is motion. Indeed, Clark (1973) proposed that self-locomotion through space may provide a particularly salient experience that easily lends itself to thinking about the past and the future. Locations in space we have passed are behind us both in space and in time (corresponding to the past) while locations in space we have not yet reached are in front of us in both space and time (corresponding to the future). Furthermore, a closer look at patterns in language reveals that deictic construals often invoke motion (or potential motion) through space. When English speakers talk about deictic time, they often employ language about *motion* through space (e.g., ***approaching*** *a deadline* or ***coming up*** *on the weekend*). This observation is important, as it leads to the idea that if particular aspects of spatial experience, such as moving through space, are picked up by language, then maybe this aspect of space also plays a key role in how we conceptualize deictic time. Indeed, action language has been shown to engage regions of the brain that are associated with motor actions. For example, Tettamanti et al. (2005) found that simply listening to action verbs activates the motor system. Furthermore, Filimon, Nelson, Hagler, and Sereno (2007) demonstrated that even just imagining motion activates motor and premotor cortex. Thus, it is plausible that thinking about the past and the future, which is often associated with motion language in English, activates the motor system as well. In line with this idea, many studies that do report an association between sagittal space and deictic time have included motion in part of their experimental design, whether it was produced by participants at the response level (Sell and Kaschak 2011; Ulrich et al. 2012; Kranjec and McDonough 2011; Miles, Nind, and Macrae 2010; Rinaldi et al 2016) or it was manipulated as an independent variable (Miles, Karpinska, Lumsden and Macrae 2010; Hartmann and Mast 2012; Koch, Glawe, and Holt; 2011; Sullivan and Barth 2012).

The present study examines whether self-motion through space leads individuals to associate deictic events that are described from an ambiguous perspective with the sagittal axis. Participants made either deictic or sequence time judgments by moving their foot to a particular target in front of or behind their body. If motion plays a key role in how English speakers conceptualize deictic events, we should observe a systematic association between moving along the sagittal axis and deictic time, even when the events do not specify person perspective, as self-motion should elicit an internal perspective in and of itself. Specifically, participants should respond faster to future events when asked to step forward, rather than backward, and with participants should respond faster to past events when asked to step backward, rather than forward. However, while the predictions for deictic judgments are clear, what should we predict in the case of sequence judgments?

As with deictic judgments, sequence events that were described from an ambiguous perspective were not associated with the sagittal axis in a systematic way in Chapter 3. Should the introduction of bodily-self motion also affect sequence judgments? There are at least three distinct possibilities. First, as sequences in English are non-deictic and are not tied to the body, bodily motion should not affect how individuals associate sequences with the sagittal axis. Thus, we would expect similar findings to Experiment 2 in Chapter 3, where no pronoun was used in the stimuli. In that case, people did not systematically associate sequence time with the sagittal axis. Another possibility is that motion simply makes the front/back distinction more salient than static manual responses. As sequences are talked about in English such that earlier events lie in front of later events, the body may simply serve as an anchor, with the front of the body mapped onto earlier events and the back of the body mapped onto later events, as observed in the case where pronouns are included in the stimuli. Finally, a third possibility is that having to move one's body through space may change the frame of reference from which an individual thinks about sequence time. That is, it may highlight our everyday experience of walking, where typically moving towards something co-occurs with "moving" later in time. Thus, later events, even though they are deictically neutral, should now be associated with the space in front of the participant rather than the space behind.

Methods

Participants

80 participants (40 deictic, 40 sequence) participated (32 male, mean age: 20.62 years). Four participants were removed due to low accuracy (<50%) and two were removed due to foot pedal malfunctions. This resulted in a total of 40 participants making deictic judgments and 34 participants making sequence judgments.

Design and Materials

The experiment was programmed using E-Prime (Psychology Software Tools, Pittsburgh, PA, USA). Deictic stimuli consisted of forty life events that typically will have happened (or will happen) to an undergraduate student in the United States. Half of these events were designed to have happened in the past (e.g., “high school graduation”) for a typical undergraduate student, while the other half would likely occur in the future (e.g., “college graduation”). The sequence stimuli were made of pairs of the deictic stimuli (“high school graduation”, “college graduation”). No pronouns were included in the stimuli.

Procedure

Participants stood in the center of the experiment room with their dominant foot placed on a foot pedal connected to a serial response box (Psychology Software Tools, Pittsburgh, PA, USA) (see Figure 4.1). Stimuli were presented in black font on a white background on computer screen located approximately 48 inches from the center of the participant's body. Participants first saw the image of a shoe on the screen, indicating that they should press down on the foot pedal and hold it there until they want to respond. They then saw a fixation cross 1000ms. For deictic judgments, the fixation cross was followed by a single stimulus and participants then indicated whether the event happened in the past or will likely happen in the future for them by moving their foot to a target placed either in front of or behind them. For sequence judgments, participants saw one stimulus presented on the screen, followed by a second stimulus. They were then asked to determine whether the second event they saw (e.g., high school graduation) happened earlier or later relative to the first event they saw (e.g., college graduation). Reaction time was recorded using a foot pedal that was triggered when the participant released their foot from a center location to move to a target that was either in front of them or behind them. For each trial, the experimenter recorded whether the participant stepped to the front target or the back target using an external button box, as the actual targets on the floor were made of masking tape and did not record any data.

Figure 4.1: Set-up of the foot pedal device and response targets.

On half of the trials, participants had to step forward to a red target on the floor to respond to a particular type of event (e.g. earlier or future) and to step backward to a yellow target on the floor to respond to the other type of event (e.g., later or past). For the other half of the trials, this pattern was reversed. The order of stimulus-response mapping was counterbalanced across participants. Each participant completed a total of two blocks of either deictic or sequence judgments. Each block began with 4 practice trials, followed by 40 experimental trials, for a total of 88 trials (8 practice, 80 experimental).

Analyses

All analyses were conducted in *R* (R Core Team, 2014). Incorrect trials or trials with no response (7.9% deictic, 10.3% sequence) were excluded from analysis. Trials that were 3 standard deviations or more from each subject's mean were also removed (3.1% deictic; 2.8% sequence). Results are reported separately for deictic and sequence time.

Results

Deictic Judgments

There was a three-way interaction between target location, temporal reference, and block order, $F(1,38)=22.06$, $p<.001$. When participants received congruent mappings first (future-front, past-behind), there was no two-way interaction between temporal reference and location, $p=.16$. When participants received incongruent mappings first (future-back, past-behind), the two way-interaction between temporal reference and location was significant, $F(1,19)=23.86$, $p<.001$. Participants were faster to make past judgments by stepping backward (1012 ms) than by stepping forward (1112 ms), t(19)=3.59, p<.001. Participants were also faster to make future judgments by stepping forward (1009 ms) than by stepping backward (1162 ms), t(19)=5.19, p<.001.

Overall, there was also a two-way interaction between location and temporal reference, F(1,38)=7.85, p=.008. Future judgments were faster when stepping forward (t(39)=2.41, p=.021) than backward. Past judgments were marginally faster when stepping backward than forward, t(39)=1.74, p=.09. There was also a main effect of temporal reference, F(1,38)=6.10, p=.018, as participants were faster to make past judgments (1066 ms) than future (1087 ms) judgments. There was also a main effect of location, F(1,32)=4.32, p=.046, with participants responding faster by moving forward (1317 ms) than by moving backward (1348 ms). Results are summarized in Figure 4.2.

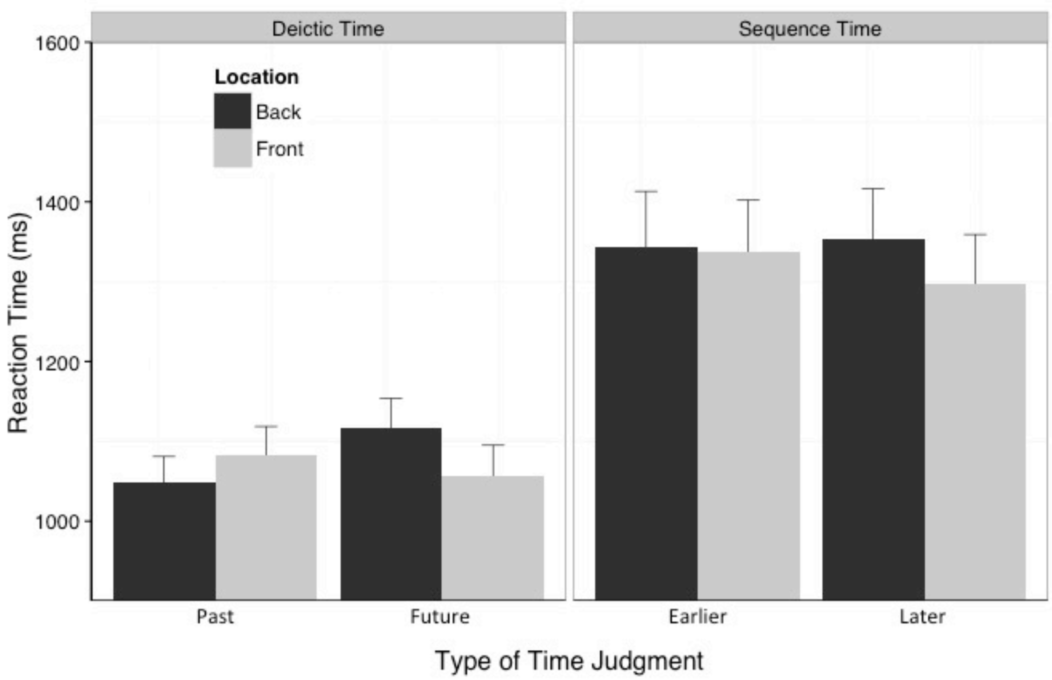

Figure 4.2: Mean reaction times to deictic (left) and sequence (right) judgments. Error bars indicate standard error.

Sequence Judgments

For sequence judgments, there was also a three way interaction between location, temporal reference, and block order, $F(1,32)=26.29$, $p<.001$. This was due to a reversal of the two-way interaction between location and temporal reference across the two different block orders. When participants received the earlier-in-back, later-in-front mappings first, there was a two way interaction between location and temporal reference, $F(1,16)=7.76$, $p=.013$. Participants were faster to make later judgments by moving their foot backward (1235 ms) than forward (1348 ms), $t(16)=2.51$, $p=.023$, and participants were faster to make earlier judgments by moving their foot forward (1222 ms) than backward (1379 ms), $t(16)=2.74$, $p=.015$. When participants received the earlier-in-front, later-in-back mapping first, there was a two way interaction between location and temporal reference, $F(1,16)=22.27$, $p<.001$. Participants were faster to make later judgments by moving their foot forward (1246 ms) than backward (1470 ms), $t(16)=4.92$, $p<.001$, and participants were faster to make earlier judgments by moving their foot backward (1308 ms) than forward (1453 ms), $t(16)=3.15$, $p=.006$. No other effects were significant.

Discussion

In this study, individuals physically stepped forward or backward to a target in space in response to either deictic (past/future) or sequence (earlier/later) time judgments. Stepping through space affected deictic judgments: participants were faster to step forward when making future judgments than when making past judgments and were faster to step backward when making past judgments than when making future judgments. However, stepping through space did not systematically influence sequence judgments. Together, these findings suggest that bodily motion through space influences how we process deictic, but not sequence time.

In English speakers, deictic time is not consistently and automatically associated with the sagittal axis. What factors are responsible for these inconsistencies? Whether or not the design includes motion seems to play an important role. Studies that include motion in part of their experimental design often observe compatibility effects where participants associate the past with the space behind them and the future with the space in front of them (Ulrich et al. 2012; Kranjec and McDonough 2011; Miles, Nind, and Macrae 2010; Rinaldi et al 2016). However, studies that do not include motion in the design have mixed results. Sell and Kaschak (2011) found an association between deictic judgments and sagittal space, but only when the participants had to move their hands to respond (as opposed to responding in a static location). In Chapter 3, associations between deictic time and the sagittal axis were observed using static responses when the perspective from which the events were described was made explicit (e.g., “your high school graduation”), but not when the perspective was ambiguous (pronouns were absent from the stimuli; e.g., “high school graduation”). In the present study, when participants responded to events portrayed from an ambiguous perspective, yet had to move through space to respond, clear associations between deictic time and the sagittal axis emerged. Thus, bodily self-motion through space appears to prime deictic thinking, even when perspective information is unavailable. Sequence judgments, on the other hand, did not benefit from bodily motion in the same way. Consistent with findings in Chapter 3, no clear associations between sequence time and the sagittal axis emerged when no perspective information was available.

Why are deictic and sequence time differentially affected by bodily motion? One reason may be that the two types of temporal relations are associated with (bodily) motion in different ways. As discussed in the introduction, language about deictic time often includes bodily motion through sagittal space (e.g, "We're quickly *approaching* the weekend"), with the present moment co-located with the body, forward motion towards the future, and backwards motion towards the past. While motion can also be used to describe temporal sequences (e.g, "Monday *follows* Sunday"), the motion is not yoked to the body as with deictic time, and thus it is not as clear whether forward motion should map on to earlier or later times. The present study highlights motion that is consistent with deictic conceptualizations of time, but not with sequence time.

For both deictic and sequence judgments, there was a three way interaction between temporal reference, location, and block order. These effects have been observed in many studies that use a blocked compatibility effect design and likely reflect practice effects (e.g, Ulrich et al., 2012). In general, participants are faster to respond on their second time through the task than the first time through, resulting in the second set of mappings being faster than the first set of mappings. In the case of deictic time, however, one particular set of associations (back-past, future-forward) is much stronger, and thus an overall two-way interaction emerges, despite practice effects. For sequence time, no overall two-way interaction between temporal reference and location was observed, suggesting that one set of associations is not statistically stronger than the other. However, the magnitude of the congruency effects is on average numerically larger if an earlier-behind/later-in-front set of mappings is considered congruent (congruency effect: 184.5 ms) than when an earlier-in-front/later-behind set of mappings is considered congruent (congruency effect: 134.5 ms). As these results come from two different groups of participants, one cannot put too much weight on this observation, but it is interesting that the earlier-behind/later-in-front mappings resulted in a larger congruency effect. This is the reverse of what has previously been found, where earlier events are associated with the space in front of the body and later events are associated with the space behind the body (see Chapter 2, Chapter 3). Thus, it may be that actually moving through space leads to a more deictic-like construal of sequences, where typically moving towards something co-occurs with "moving" later in time. As a result, later events may now be associated with the space in front of the participant rather than the space behind. However, this is a very speculative interpretation and future studies must more closely examine the role that motion may play in how we associate sequences with the sagittal axis.

Conclusion

The present chapter builds on the idea that deictic and sequence time are distinct temporal concepts that are not only associated with space in different ways, but they also recruit different aspects of spatial experience. While bodily motion through space affected how deictic judgments were processed, it did not influence sequence judgments.

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CHAPTER 5: The effects of verbal and spatial interference on lateral representations of sequence time

Introduction

Humans are experts at drawing on space to enhance our interactions with the world around us, from organizing ingredients on a countertop before starting a complex recipe to grouping similarly shaped puzzle pieces together before assembling a puzzle (Kirsh, 1995). In addition to these concrete uses of space, space is also a powerful tool for structuring how we think about abstract concepts that we cannot directly perceive or interact with. For instance, Lakoff and Johnson (1980) suggest that properties of spatial structure get analogically projected onto abstract domains, serving to supply structure for that concept, which in turn allows us to think and reason about that concept just like anything else. One such abstract domain that is often spatialized is that of time. Systematic associations between time and space show up not only in how we talk about time (e.g., *I'm looking* ***forward*** *to the weekend*), but are also revealed in co-speech gesture (Cooperrider & Núñez, 2009) and even in how we reason about time (e.g., Boroditsky, 2000). However, what exactly do these associations between space and time reveal about the relationship between space and time in the mind?

A number of studies using a variety of methods highlight how temporal sequences are associated with a left-to-right spatial axis. People are faster to categorize an event as *earlier* than another event when the response button is on the left of the body and *later* when it is to the right than the reverse (Torralbo et al., 2006; Weger & Pratt, 2008). This effect was initially interpreted as suggesting that thinking about sequences of events in time affects visuospatial attention. Additionally, orienting people's attention to either the left or right side of space influences their temporal judgments (Frassinetti, Magnani &

Oliveri, 2009; Vicario, Caltagirone & Oliveri, 2007; Vicario, Pavone, Martino & Fuggetta, 2011). In line with these findings, Casasanto and Jasmin (2012) proposed, based on their work on temporal gestures, that when thinking about sequences of time, speakers adopt a "moving attention perspective", where a speaker's attention moves along an imagined left-to-right timeline, similar to how they would interact with an actual physical timeline. Although these studies suggest that our visuospatial attention is tightly linked with how we think about temporal sequences, what role do such spatial representations play in how we think about temporal sequences?

One possibility is that our spatial representations lay the foundation for temporal thought, with space playing a *necessary* role in temporal representations. In support of this idea, Saj, Fuhrman, Vuilleumier, and Boroditsky (2013) found that patients with left hemispatial neglect not only neglect the left side of space, but also have difficulty representing past events, which fall on the left side of the mental timeline. However, another possibility is that the space-time associations observed are epiphenomenal: perhaps space just happens to be a particularly useful tool for helping people reason about the temporal relationship between events, but this doesn't mean that space is necessary for the conceptualization of deictic and sequence time. Indeed, the compatibility effects observed in previous studies may reflect learned associations between space and time due to the repeated use of particular linguistic patterns and interaction with cultural artifacts that solidify these associations in one's mind, but this doesn't necessarily mean that people can't reason about time without thinking about space. While little work has examined the particular role space plays in how we conceptualize time, some evidence from a similar abstract domain, number, suggests that visuospatial working memory may play a key role in how we think about temporal sequences.

Mental timelines are often compared to mental number lines, as both express differences in magnitude along a lateral axis (Bonato et al., 2012). Indeed, a variety of research has suggested overlapping neural resources for space, time, and number, often centered in the parietal cortex (e.g., Walsh, 2003). Both spatial and verbal interference tasks have interfered with people's abilities to engage in different types of *numerical* cognition, shedding light on the working memory resources that are necessary to do those tasks. When completing a magnitude comparison of two numbers, participants are typically faster to say that a number is larger than another when doing so involves responding on the right sides of their bodies and to say that a number is smaller when the appropriate response is on the left side -- referred to as the spatial-numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993). The SNARC effect is drastically reduced, however, when participants engage in a dual-task in which the secondary task requires visuospatial working memory (van Dijck et al., 2009). This suggests that making magnitude comparisons requires spatial working memory in the moment.

Other numerical tasks are affected by dual-tasks that interfere with *verbal* working memory. Typically when people make parity (even/odd) decisions about a number, they are faster to make that decision for larger numbers when the response is on the right and for smaller numbers when the response is on left than when these response locations are reversed, even though they are not explicitly drawing on magnitude information. When they engage in a dual-task requiring them to maintain a string of consonants in memory while making parity judgments, however, the SNARC effect is eliminated (van Dijck et al., 2009). Similarly, people are unable to accurately count objects while undergoing this same type of verbal interference, suggesting that counting requires an internal linguistic routine (Frank et al., 2012).

Do temporal judgments similarly rely on visuospatial or verbal representations? That is, will spatial or verbal dual-tasks interfere with participants' representation of earlier events on the left and later events on the right, eliminating evidence of a left-right mental timeline? The present study employs a dual-task paradigm, modeled after van Dijck et al. (2009) to investigate this question. If our lateral representations of sequence time are grounded in how we think about space, we would expect spatial interference to interfere with people's ability to think of sequences in terms of lateral space, eliminating evidence of a left-right mental timeline. However, if the associations we observe between time and space are more epiphenomenal, undergoing spatial interference should not affect how people think about time.

Methods

Participants

72 undergraduate students at the University of California, San Diego participated for course credit. Participants were excluded if performance was below 20% on the visuospatial or verbal interference task (five participants) or below 50% on the time judgment task (seven participants). One additional participant was removed because the program crashed halfway through the experiment. This left a total of 58 participants for analysis (22 in the verbal interference condition, 18 in the control condition, and 18 in the

visuospatial interference condition). Only trials where participants responded accurately to the time judgments were included in the analysis (93.8% of trials). Furthermore, only reaction times that were within 3 standard deviations of each participant's cell mean (97.8% of correct trials) were included in analysis.

Procedure

The design of the experiment was modeled after van Dijck, Gevers, and Fias (2009), who conducted a similar dual-task experiment on the representation of number. Each participant was randomly assigned to one of three conditions: control (no interference), verbal interference, or visuospatial interference. First, a baseline measure of performance was taken for the time judgment task. Then, each participant's working memory span was measured using either a visuospatial or a verbal task. This span was then used to calibrate the final dual-task portion of the study.

Time Judgment Task

The time judgment task is the same as used in the lateral axis sequence condition in Chapter 3. Participants held two computer mouses, one in each hand, with each thumb placed over a single mouse button. Participants held one mouse with their left hand on their left side and the other mouse in their right hand on their right side. Before each block, participants were presented with instructions that explained the stimulus-response mappings (e.g., left response for earlier events, right response for later events) they would use for that block. The stimulus- response mappings were changed after each block. After the presentation of a fixation cross for 1000ms, participants read a reference life event written in the center of the computer screen (e.g., "high school graduation"), which remained on the screen for 2000ms. A white screen was then presented for 500ms and the text of a second life event (e.g., "college graduation") was presented and remained on the screen until the participants responded, up to 5000ms. Reaction times were measured from the onset of the second event. Participants received new instructions before each block. Participants completed four practice trials, followed by forty experimental trials during each of two blocks. Whether the participants received congruent (past-left, future-right) or incongruent (past-right, future-left) mappings during their first block was counterbalanced across participants.

Working Memory Measures

After the baseline time judgment task was completed, either the verbal or visuospatial working memory span of the participant was measured, depending on which condition they were randomly assigned to. For both the visuospatial and verbal working memory tasks, strings of items were presented in an increasing number (from three to eight items, with three strings of items per testing length). The participant's span was then defined as the highest sequence length where they recalled at least two of the three strings for that length.

The verbal working memory span was modeled after Szmalec and Vandierendonck (2007). Each trial started with a blank screen, followed by a string of single consonants, which were each separated by an empty screen. Participants were then asked to type their responses after all of the consonants were presented.

A computerized Corsi task was employed to measure visuospatial working memory. Nine white squares were presented on a black background. Each trial started with an image of the white squares, followed by a sequence of squares flashing blue, one at a time. When the sequence was over, all of the white squares remained on the screen and the participant had to reproduce the sequence by clicking on the squares in the order that they saw them flash.

Dual Task

To ensure the dual-task was challenging, but not too difficult, the participant's working memory span minus one was used to calibrate the dual task portion of the study. Participants in the dual task condition were first presented with either a verbal or visuospatial sequence to remember, depending on which condition they were initially assigned to. They then completed 2 sequence time judgment trials. Finally, they were asked to recall the verbal or visuospatial sequence. This cycle was repeated 20 times for each mapping (either incongruent or congruent), for a total of 80 temporal judgment trials and 40 span trials. Each participant completed two blocks of dual task trials, with each block using either congruent or incongruent stimulus-response mappings. Participants in the control condition simply completed the initial time judgment task once more, rather than completing the dual task version.

Results

Reaction Times

A 3 (type of interference group: control, verbal, visuospatial) x 2 (congruency: congruent or incongruent) x 2 (load type: baseline or under load, which includes the Control, Verbal, and Visuospatial Interference groups) ANOVA on reaction times revealed an overall congruency effect, $F(1,55)=25.62$, $p<.001$, where participants were faster to respond to congruent (1360 ms) than incongruent (1529 ms) trials. There was also a main effect of load type, $F(1,55)=5.88$, $p=.005$, where participants were faster under load (1345 ms) than at baseline (1544 ms). However, this doesn't imply that the "under load" condition was easier. Rather, the "under load" condition was also the second time they completed the time judgment task, so this effect likely reflects a practice effect. There was, however, an interaction between interference type and load condition, $F(2,55)=5.88$, $p=.005$. Follow-up tests revealed that while participants in the Control ($F(1,21)=30.51$, $p<.001$) and Verbal ($F(1,17)=21.42$, $p<.001$) interference conditions got faster the second time they completed the task, participants in the visuospatial interference condition showed no such improvement, $p=.62$.

There was no main effect of type of interference ($p=.66$), nor was there an interaction between interference condition and congruency ($p=.16$). There was also no interaction between congruency and load type, $p=.78$, suggesting that congruency effects did not change between baseline and when the load was introduced. Finally, no three way interaction emerged, $p=.62$. Reaction times for the different interference conditions are shown in Figure 5.1.

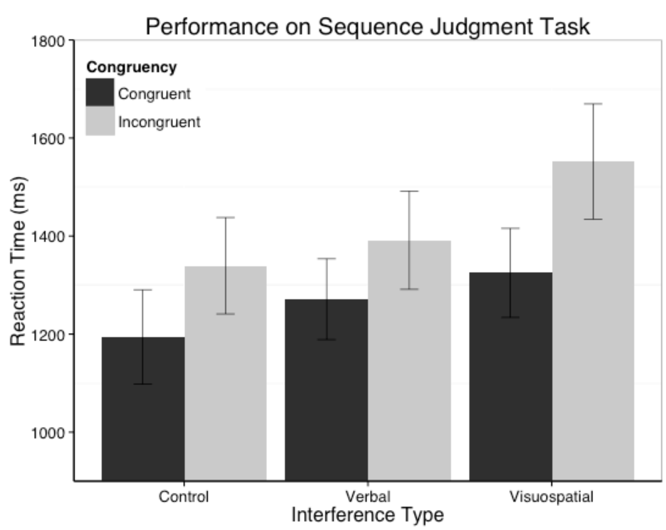

Figure 5.1: Average reaction times for congruent and incongruent sequence judgments. Error bars indicate standard error.

Time Judgment Accuracy

A 3 (type of interference: control, verbal, visuospatial) x 2 (congruency: congruent or incongruent) x 2 (load type: baseline or under interference) ANOVA was also conducted on the accuracy of the time judgment trials. There was an overall main effect of congruency, $F(1,55)=7.87$, $p=.007$, where participants were more accurate on congruent (94.8%) than incongruent (92.7%) trials. There was also a main effect of load, $F(1,55)=7.24$, $p=.009$, again reflecting practice effects, as participants were more accurate the second time through the task (94.8%) than during baseline (92.7%). There was no main effect of interference type, $p=.26$, nor were there any interactions.

Interference Task Accuracy

Based on the working memory span calibration, there was no difference in the number of interference items assigned to participants in the verbal ($M=4.0$, $SD=1.195$) and visuospatial ($M=4.5$, $SD=1.0$) interference groups, $p=.15$.

Performance on the working memory interference tasks (visuospatial task or verbal task) was analyzed using a 2 (congruency: congruent/incongruent) x 2 (type of task: visuospatial or verbal) ANOVA on interference task accuracy. Participants were more accurate in the interference task on trials that occurred with congruent time judgment trials (63.9%) than those that occurred with incongruent time judgment trials (57.6%), $F(1,38) = 6.49$, $p=.015$. Participants also performed better on the verbal interference task (71.3%) than on the visuospatial interference task (47.9%), $F(1,38) = 12.91$, $p<.001$. When the different interference tasks were analyzed separately, post-hoc paired t-tests revealed that participants performed better in the visuospatial interference task when the temporal judgment trial was congruent (52.6%) than when the temporal judgment was incongruent (43.4%), t(17) = 2.45, p = .025. Such a congruency effect was not observed for the verbal interference task, p = .25. Secondary task accuracy for the different interference conditions is shown in Figure 5.2.

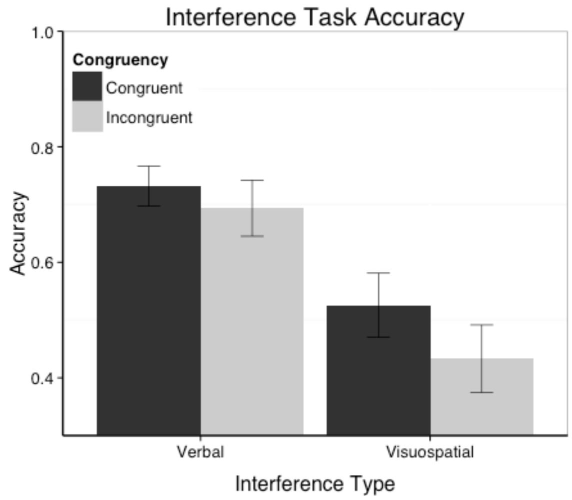

Figure 5.2: Average accuracy on the interference task during congruent or incongruent sequence judgments trials. Error bars indicate standard error.

Discussion

Our spatial experience is proposed to lay the foundation for how we think about more abstract concepts, such as time (e.g., Lakoff & Johnson, 1980). The present study aimed to exploit this spatial scaffolding by using a dual-task paradigm that was designed to interfere with people's spatial resources during a temporal reasoning task. Across three conditions, similar space-time congruency effects were observed, suggesting no effect of visuospatial or verbal interference on a left-right "mental timeline". However, interference can affect performance in a dual-task in multiple ways, and even though an effect of interference on sequence judgment reaction times was not observed, other hints of interference were present.

Subtle signatures of interference were observed both in the reaction times of the temporal judgment task, as well as in the performance on the secondary task. For example, as each participant completed the time judgment task twice (once as a baseline measure and once under interference), participants should improve the second time through the task due to practice, even if they're under interference. While this improvement was observed in the control and verbal interference conditions, it was not seen in the visuospatial interference condition. This suggests that participants in the visuospatial condition were more impacted by load than those in the verbal interference condition. Furthermore, the temporal task appeared to interfere with performance on the visuospatial working memory task. Participants performed worse on the visuospatial memory task during the incongruent blocks of the time judgment task than during the congruent blocks. This effect was not seen on the verbal memory task, and suggests that adding the visuospatial secondary task requires some of the same cognitive resources as the temporal judgment task, as performance on the secondary task likely suffered as a result of the extra mental load. However, as this last analysis was exploratory, strong conclusions cannot yet be drawn and future work must more carefully the nature of the overlap between the resources required to reason about space and time.

How does the present work fit into larger theories of how space and time interact in the human mind? While the particular role that space plays in how we think about time is still largely unknown, two very distinct theories have tried to account for the associations so commonly observed between space and time. The first, Walsh's (2003) "A Theory of Magnitude" (ATOM) is often used to explain associations between space, time, and number. ATOM proposes a domain-general representation of magnitude centered in the bilateral inferior parietal cortex (Walsh, 2003; Bueti & Walsh, 2009). Based on ATOM, spatial, temporal, and numerical magnitudes all rely on the same neural resources and cross-domain associations arise from this overlap. Thus, interfering with magnitude processing in one domain may affect magnitude processing in another domain. This interpretation is in line with van Dijck et al.'s (2009) findings, where the SNARC effect, which involves magnitude judgments, was eliminated when participants were faced with spatial interference. No such interference effect was observed in the present study. However, the temporal judgments participants made in the present task cannot be strictly classified as magnitude judgments. Rather, the judgments were about temporal relations, which are thought to reflect higher-level cognitive processes that emerge later in development than low-level magnitude and temporal *duration* processing (Winter, Marghetis, and Matlock, 2015). As such, it is unclear whether the predictions put forth by ATOM should scale up to higher order temporal relations, such as sequence judgments. Instead, ATOM would be more likely to predict effects of spatial interference on temporal *duration* rather than on temporal *conceptualization.*

Conceptual Metaphor Theory (CMT) (Lakoff & Johnson, 1980), on the other hand, is specifically designed to deal with explaining how higher-level cognitive relations are represented. CMT proposes that our representation of concrete domains, such as space, is used to structure more abstract domains, such as time. Under this theory, interfering with spatial resources should have downstream effects on our representations of time. However, just as time is not a monolithic concept (Núñez & Cooperrider, 2013), space is an incredibly multi-faceted domain and one must consider how exactly space is being used to structure time. That is, in the present task, "spatial resources" were operationalized as performance on the Corsi Block Task. Thus, the lack of an interference effect could be due to a true lack of a functional link between spatial and temporal thinking, but it could also reflect a failure to tap into the right kind of spatial resources involved in temporal thinking. Thus, future studies should investigate a wider range of spatial tasks to examine what aspects of spatial cognition, if any, are more likely to interfere with temporal reasoning.

Conclusion

The aim of the present study was to go beyond studying simple behavioral associations between space and time and to investigate the functional role (if any) that space plays in thinking about time. While we found no strong evidence that tying up spatial resources interferes with temporal reasoning, the present study cannot rule out the possibility that space (in some form or another) is necessary for temporal reasoning.

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CHAPTER 6: The continuity of metaphor: Evidence from temporal gesture

Introduction

Over the course of the last few decades, the view that metaphors are merely ornamental linguistic flourishes has been definitively turned on its head. Metaphors are now accepted as basic building blocks of everyday reasoning. In discourse across different domains—from talk about numbers and time, to discussions of political ideology and social status—metaphors are not only commonplace, they are inescapable. According to conceptual metaphor theory (CMT), metaphors are inescapable because human reasoning itself—not just language—is metaphorical (Lakoff & Johnson, 1980). In the framework of CMT, metaphors are conceptual mappings between a target domain concept—whatever it is we are actually talking or thinking about—and some source domain concept—whatever concept we draw on to understand the target. Consider, for example, Neil Armstrong's famous pronouncement that his first small steps on the moon constituted a "giant leap for mankind." In this case, the target concept is progress and the source concept he draws on is forward motion. Armstrong's pronouncement is hardly a one-off flourish. It is just one manifestation of a systematic and productive mapping between these domains, called a conceptual metaphor.

The PROGRESS IS FORWARD MOTION metaphor belongs to a large and much-studied subclass of metaphors, which Lakoff and Johnson (1980) termed "orientational metaphors." In an orientational metaphor, a spatial contrast is recruited to make sense of a contrast in a target domain that is not intrinsically spatial. In the example above, the contrast between forward and backward motion is recruited to construe the contrast between progress and regress. Interestingly, for many of our most foundational abstract concepts, such as time, number, and valence, there is more than one spatial source contrast available to construe the very same target contrast. In such cases, the competing metaphors involved appear to be cut from different cloth. Take the two predominant orientational metaphors for reasoning about past and future in English. On the one hand, there is evidence for a sagittal metaphor in which past times are mapped to the back and future times to the front. Such evidence comes primarily from everyday language use (Alverson, 1994; Clark, 1973). For example, people “think back” to past experiences and “look forward” to future ones. On the other hand, there is evidence for a lateral metaphor in which the past is mapped to the left and future to the right. This metaphor is not found in everyday language but reliably emerges in reaction time studies (Santiago et al., 2007) and in gesture (see Núñez & Cooperrider, 2013 for a review). Moreover, the sagittal and lateral temporal metaphors are often traced to different developmental sources, with the sagittal mapping most likely developing through linguistic experience and the lateral mapping through experience with graphical representations.

Given that these two temporal metaphors emerge in different kinds of behaviors and likely have different experiential sources, studies have endorsed the idea, at least implicitly, that they are distinct in online reasoning. Psychological studies have zoomed in on one metaphor at a time, for instance by having participants respond by pressing buttons on the left and right (Weger & Pratt, 2008) or front and back (Fuhrman et al., 2011; Sell & Kaschak, 2011), by having participants respond to stimuli that are displayed along the left-right axis (Torralbo, Santiago, & Lupiañez, 2006), or by isolating only one axis to measure from a continuous, multi-dimensional response (Miles, Nind, & Macrae, 2010). In those studies whose designs have allowed both sagittal and lateral temporal metaphors to be glimpsed within the same paradigm, researchers have kept the metaphors analytically distinct (Casasanto & Jasmin, 2012; Cooperrider & Núñez, 2009; Walker, Bergen, & Núñez, 2014). In sum, the consensus in current research is that these orientational metaphors for time are distinct mappings and that speakers will “use only one in a situation that allows both of them” (Torralbo et al., 2006, p. 748).

In the present studies, we challenge this consensus view. The seed of this challenge lies in observations of a ubiquitous, spontaneous, and everyday behavior—gesture. Across a wide range of topics and contexts, gesture has been shown to provide a “window” into the mind (Goldin-Meadow, 2003; McNeill, 1992), reflecting both concrete spatial imagery and metaphorical conceptualization (Cienki, 1998). For our purposes, a critical property of gestures is that they are three-dimensional spatial representations that unfold in time. As such, they have a richness that other behaviors used to study metaphorical reasoning, such as language use or button presses, cannot match. In gesture, not only are the pure forward, backward, leftward, and rightward directions available; in principle the entire space in front of the body is available, in a continuous fashion. Interestingly, informal observation of gestures accompanying talk about time turns up examples in which a single gesture appears to be consistent with both sagittal and lateral metaphors for time. Such gestures suggest that these two metaphors are simultaneously active in the speaker’s mind—in short, that they are co-activated. One way that this co-activation manifests is in the gesture’s directionality. Consider an example from a television interview in which a speaker says “looking to the future” while moving his right hand simultaneously forward and to the right (see Figure 6.1B). Another more subtle way that this co-activation manifests is in the selection of which hand to gesture with. For example, later in the interview, the same speaker uses his left hand to gesture backward while saying “where I had been,” referring to his past (see Figure 6.1A). Such examples from the wild are suggestive, but quantitative evidence is needed to distinguish what may be motor noise in gesture from the more interesting possibility of systematic co-activation of distinct temporal metaphors.

Here, we report two studies that test the possibility that English speakers systematically combine the sagittal and lateral metaphors for time in their gestures by looking for evidence of the two gestural signatures of co-activation described above: (a) gestural directionality and (b) hand selection. In a first study, we looked for these signatures of co-activation in people’s directly elicited gestures about time concepts; in a second study, we looked for these same signatures in people’s spontaneous temporal gestures. These two types of gesture data are complementary. Directly elicited gestures, though somewhat unnatural, allow more experimental control; spontaneous gestures, though more difficult to examine in a controlled way, are more naturalistic. What both types have in common is the critical property of gesture that makes it a useful window into the possible co-activation of metaphors: its three-dimensional, continuous character.

Study 1: Directly elicited temporal gestures

Methods

Participants

One hundred and four students (74 female; 10 left-handed) at the University of California, San Diego, participated in the study. All participants were native speakers of English.

Materials

To directly elicit temporal gestures, we used the same prompts developed by Casasanto and Jasmin (2012). The prompts consisted of four questions that explicitly asked participants how they would gesture about different temporal concepts. Two of the questions asked about deictic concepts (past, future), whereas the other two asked about sequential concepts (before, after). The order of the questions was counterbalanced across participants. The present analysis focuses only on gestures produced following the two deictic prompts (one past, one future, see Table 6.1) as the sequential prompts generated fewer gestures along the axes of interest. Some prompts used explicit directional language (e.g., far ahead in the future), whereas others used no directional language (e.g., in the distant future). This was counterbalanced across participants, but no differences across prompt types were found, consistent with Casasanto and Jasmin (2012).

Table 6.1: Prompts used to directly elicit gestures from participants in Study 1.

How would you gesture about things that will happen a long time from now, far ahead in the/in the distant future?
How would you gesture about things that happened a long time ago, way back in the/in the distant past?

Figure 6.1: Examples of gestures that combine sagittal (front-back) and lateral (left-right) metaphors for past and future. Gestures are taken from a television interview (A and B), from Study 1 (C and D), and from Study 2 (E and F).

Procedure

After having completed a separate task[2], each participant was seated on a stool and was explicitly asked four questions about how they would gesture about time. Participants were told their responses would be video-recorded.

[2] The first task was a reaction time experiment investigating spatial construals of time (Walker et al., 2014). No relationships were found between patterns of responses observed in the reaction time experiment and patterns observed in gesture.

Coding

Separate clips for each question for each participant were created. Two coders coded only the video (without audio) of each clip. For each gesture, they recorded the handedness of the gesture (left hand, right hand, or both hands) and the directionality of the gesture stroke (leftward, rightward, backward, forward, forward-leftward, forward-rightward, backward-leftward, backward-rightward, or other). All statistics reported are based on the annotations of the second coder, who was completely naïve regarding the hypotheses. After the coding was complete, gestures were then analyzed for congruency.

Congruency of the gestures was determined as follows. For gestures produced along the lateral axis, leftward past gestures and rightward future gestures were coded as congruent, in line with previous research on English speakers (e.g., Casasanto & Jasmin, 2012). Along the sagittal axis, backwards past gestures and forwards future gestures were considered congruent. Finally, gestures that combined the two axes (combined-axis gestures) were coded as incongruent, singly congruent, or doubly congruent. Gestures were singly congruent if the gesture was only congruent along one of the two axes (forward- leftward or backward-rightward past gestures or forward-leftward or backward-rightward future gestures). They were considered doubly congruent if the gesture's directionality was congruent for both of the axes involved (backward-leftward past gestures or forward- rightward future gestures). All other cases were considered incongruent.

Reliability

For a conservative measure of reliability, we calculated the absolute agreement of the directionality of the gesture stroke (nine categories: leftward, rightward, forward, backward, forward-leftward, forward-rightward, backward-leftward, backward-rightward, and other). Good agreement was achieved between the two coders: 77.4% agreement, Cohen's $\kappa = .72$. To better compare our reliability rates with those of similar studies that have used fewer categories (e.g., Casasanto & Jasmin, 2012 coded four categories), we also adopted a more relaxed criterion according to which two codes were considered to be in agreement if they were within 45 degrees of each other (e.g., coder 1 coded the stroke as leftward, whereas coder 2 coded the stroke as forward-leftward). Under this scheme, reliability was very good: 92.3% agreement, Cohen's $\kappa = .91$.

Analyses

To test the hypothesis that people combine metaphors when gesturing about time, we looked for two signatures of co-activation. First, we analyzed whether combined-axis gestures were more likely to be doubly congruent than singly congruent, which would suggest that participants systematically combine the two axes. Second, we examined whether, for congruent gestures produced along the sagittal axis, the hand used to produce the gesture was related to whether the participant was gesturing about the past or the future. For example, when someone produces a backward gesture about the past, does she also smuggle in a leftward component by gesturing with her left hand as opposed to their right? If so, this would suggest activation of the past-to-left mapping even when the primary axis used is front-back.

Results

The total number of gesture strokes produced by each hand (left, right, or both hands) for each temporal category (past, future) along each axis (lateral, sagittal, combined) was recorded. Though 208 gestures were recorded, 30 of the gestures had no clearly codable direction along the axes of interest and were excluded from further analysis. Of the 178 remaining gestures, 30 (17%) were produced along the lateral axis (16 leftward, 14 rightward), 119 (67%) along the sagittal axis (60 forward, 59 backward), and 29 (16%) gestures combined the two axes (10 backward-leftward, 4 backward-rightward, 2 forward- leftward, 13 forward-rightward) (see Figures 6.1C and 6.1D, for examples of combined-axis gestures). As for handedness, 39 of the 178 were produced with the left hand (22%), 124 with the right hand (70%), and 15 were produced bimanually (8%). The majority (96%) of gestures produced were congruent (26/30 lateral, 116/119 sagittal, and 29/29 combined-axis gestures were either singly or doubly congruent).

Double and single congruency

A binomial test revealed that gestures that combined axes were more likely to be doubly congruent (23 gestures, 79%) than singly congruent (6 gestures, 21%), N = 29, p = .002 (Figure 6.2). The 29 combined-axis gestures were produced by 25 different individuals, with 19 of those individuals producing at least one doubly congruent gesture (range: 1–2 doubly congruent gestures). The complete data table is viewable in the online supplementary tables as Table S1.

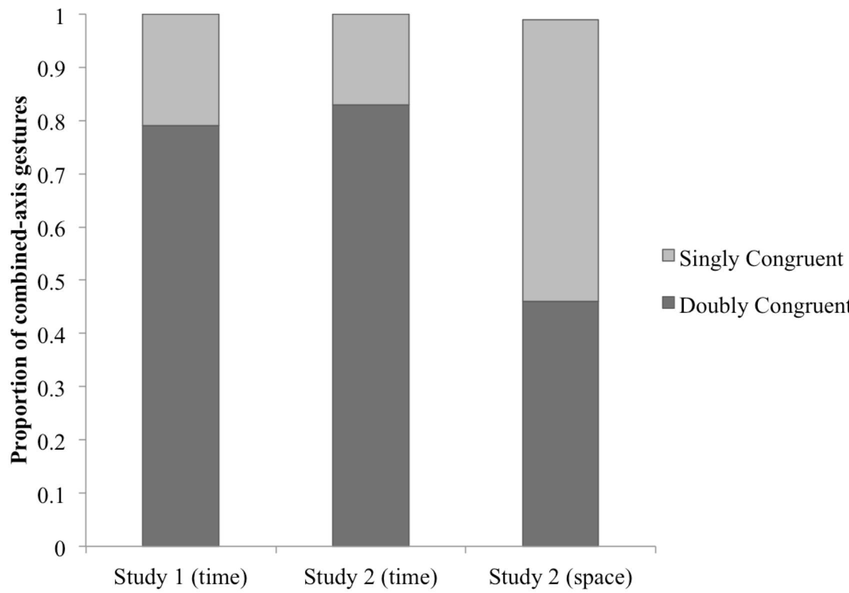

Figure 6.2: Proportions of doubly and singly congruent combined-axis gestures produced in Study 1 (time) and Study 2 (time, space).

Hand selection and temporal category

A chi-squared test on the 108 congruent, one-handed sagittal gestures (forward future gestures or backward past gestures) indicated that the use of the left or right hand was not independent of whether the participant was gesturing about the past or the future, $\chi^2(1, N = 108) = 12.15, p < .001$. There were only five instances of future gestures being produced with the left hand, whereas left-handed past gestures occurred 21 times. The right hand was used 50 times to produce future gestures compared to only 32 times to produce past gestures (Figure 6.3).

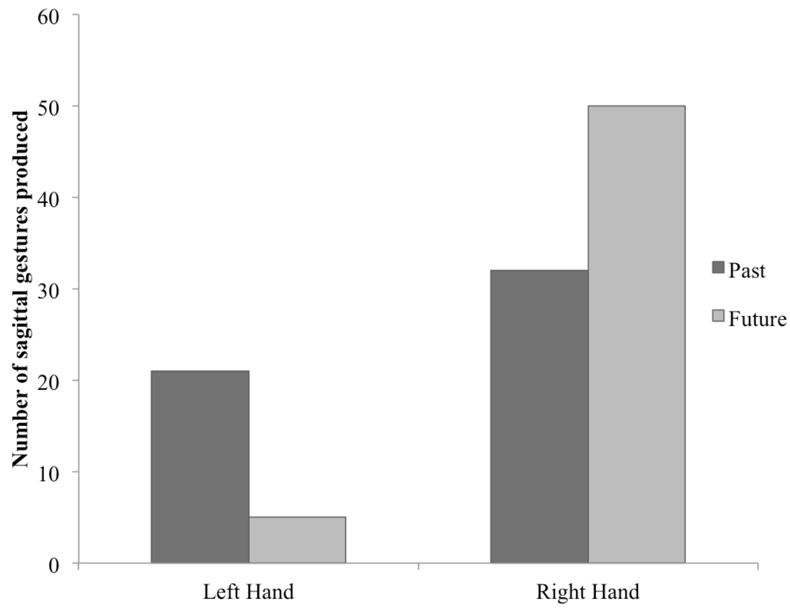

Figure 6.3: Number of past and future gestures produced along the sagittal axis by each hand in Study 1.

Discussion

In Study 1, we found two kinds of evidence that people combine sagittal and lateral metaphors for time in their gestures: (a) people were more likely to produce combined-axis gestures congruent with both metaphors than congruent with one but not the other, and (b) people used their left hand more often to gesture directly backwards about the past than they did to gesture directly forward about the future, and vice versa for the right hand. These results demonstrate that people can activate both front-back and left-right temporal metaphors either simultaneously or else in extremely rapid succession. In a situation in which both temporal metaphors are available to be expressed, in this case through a continuous manual motor response, English speakers do not always choose one or the other.

Directly elicited gestures are, of course, somewhat unnatural. Under ordinary circumstances speakers do not attend closely to their gestural movements (McNeill, 1992). And, indeed, several studies have reported differences between participants directly elicited and spontaneous gestures (Casasanto & Jasmin, 2012; Goldin-Meadow, McNeill, & Singleton, 1996). Thus, an interesting additional question is whether speakers also combine metaphors in these same ways in their spontaneous co-speech gestures. If so, this would provide evidence that, not only can people co-activate distinct metaphors in gesture, they do in more naturalistic and everyday behaviors. To address this question, in a second study we had people explain time concepts, as well as other concepts, as a way of eliciting temporal reasoning and spontaneous gestures. The task also involved explanation of a handful of concrete spatial concepts to test whether mere biomechanical preferences—rather than the combining of metaphors—might explain the patterns observed in the first study. Specifically, we wanted to address the possibility that for some purely biomechanical reason gestures tend to follow those directions—forward-rightward and backward-leftward—that happen to be doubly congruent with the two time metaphors in English.

Study 2: Spontaneous temporal gestures

Methods

Participants

Twenty-four students at the University of California, San Diego, were recruited to participate in exchange for course credit. All were native speakers of English. Six participants did not produce any gestures during the task and were thus not included, leaving 18 participants for analysis (11 female, 7 male; 2 left-handed, 1 ambidextrous).

Materials

We generated a list of 32 English words (Table 6.2) comprising three categories: eight time-related (e.g., past, future), eight space-related (e.g., left, right), and sixteen filler words (e.g., beauty, courage). The list was split into two randomized lists that each contained four time words, four space words, and eight filler words. Each participant received both lists and the order of the list presentation was counterbalanced.

Table 6.2: List of stimuli included in Study 2.

Time Words	Space Words	Filler Words	
Future	Below	Peace	Happiness
Now	Right	Cause	Success
Later	Back	Power	Hero
Earlier	Front	Remainder	Idea
Tomorrow	Far	Love	Summit
Today	Above	Courage	Anxiety
Past	Left	Beauty	Edge
Yesterday	Near	Fear	Faith

Procedure

Participants were seated on a stool and instructed that their task would be to define a series of English words as clearly as possible so that someone with a beginning level of English would be able to watch the video and understand the words. They were told that they would have 30 seconds to define each word and were asked to continue speaking for the full time. Words to be defined were presented on a large computer monitor that was placed off to the participant's left side on a table. After 30 seconds, the current word was automatically replaced on the screen by the next. Once participants had finished the first list, they took a brief break and then the experimenter started the second list. Finally, participants completed a debriefing questionnaire that asked them what they thought the purpose of the experiment was, as well as whether they were familiar with all of the words they were asked to define.

Coding

For each participant, separate clips were created for each of the eight time words and for the four space words that corresponded to the temporal axes of interest (front, back, right, left). Audio-only and video-only versions of each clip were created for coding purposes. Coding then proceeded in three steps. First, using ELAN annotation software (Max Planck Institute for Psycholinguistics, Available at: http://www.mpi.nl/tools/elan.html), a coder listened to the audio-only version of each clip and created an annotation whenever the participant produced one of a pre-determined set of target words. In addition to the eight time words listed in Table 6.2, target temporal words also included present, before, last/next (week, month, etc.), ago, after, and already. Target spatial words included front, back, left, right, forward, backward, leftward, rightward, and here. The annotated words were then cleared for the next set of coders, leaving only empty annotations time-locked to the moment when they were produced. Then, two coders watched the video-only clips and coded whether a gesture occurred during each of the previously made annotations. If a gesture was present either within the annotation window or started within 500 ms before the start of that annotation, then the coders recorded the handedness of the gesture and the directionality of the gesture stroke, as in Study 1. Again, statistics reported are based on the annotations of the second coder, who was completely naïve regarding the hypotheses and naïve about whether participants were providing definitions of temporal or spatial words. Finally, the audio and video coding were brought together and the congruency of each gesture was determined in the same manner as in Study 1.

Reliability

In addition to conducting the absolute and "45 degree" reliability analyses on stroke directionality conducted in Study 1, we also determined how consistent the coders were in determining whether a gesture was present during a particular speech annotation (due to the nature of the direct elicitation, this analysis was not needed in Study 1). Reliability was calculated separately for gestures produced during the temporal and spatial clips.

The two coders had good agreement about the presence of a gesture (temporal gestures: 92.6%, Cohen's $\kappa = .77$; spatial gestures: 91%, Cohen's $\kappa = .77$). When coding for directionality, the two coders also had good agreement, both for the conservative absolute analysis (temporal gestures: 89.4%, $j = .69$, spatial gestures: 85.3%, $j = .67$) and the more relaxed "45 degree" analysis (temporal gestures: 91.9%, $j = .77$, spatial gestures: 89.5%, $j = .76$).

Results for temporal gestures

Two hundred and thirty-three temporal gestures exhibited a clearly codable direction along the axes of interest and were included in the analysis. Of these gestures, 167 (72%) were produced along the lateral axis (93 leftward, 74 rightward), 40 (17%) along the sagittal axis (18 backward, 22 forward), and 26 (11%) combined axes (9 backward-leftward, 1 backward-rightward, 3 forward-leftward, 13 forward-rightward) (see Figures 6.1E and 6.1F, for examples of combined-axis gestures). As for handedness, 90 (39%) were produced with the left hand, 99 (42%) with the right hand, and 44 (19%) bimanually. The majority (86%) of gestures produced were congruent (148/167 lateral, 29/40 sagittal, and 24/26 combined-axis gestures were either singly or doubly congruent).

Double and single congruency

As in Study 1, a binomial test revealed that congruent combined-axis gestures were more likely to be doubly congruent (20 gestures, 83%) than singly congruent (4 gestures, 17%), $N = 24$, $p = .001$ (Fig. 2). Eleven of the 18 participants produced at least one combined-axis gesture, with nine producing at least one doubly congruent gesture (range: 1–4 doubly congruent gestures). The complete data table is viewable in the online supplementary tables as Table S2.

Hand selection and temporal category

There was a lower percentage of sagittal gestures produced in Study 2 (consistent with Casasanto & Jasmin, 2012 and discussed below) and fewer sagittal gestures overall (29 congruent sagittal gestures in Study 2, compared to 116 in Study 1). As a result, there are insufficient data to conclusively evaluate the relationship between hand selection and temporal category. While there were fewer left-handed future gestures (3) than for any other hand/temporal category combination (7 left-handed past; 6 right-handed future; 10 right-handed past), there is no strong evidence of an association between hand selection and temporal category.

Results for spatial gestures

One hundred and nineteen spatial gestures exhibited a clearly codable direction along the axes of interest and were included in the analysis. We observed 59 instances (50%) of lateral gestures (27 leftward, 32 rightward), 45 instances (38%) of sagittal gestures (21 backward, 24 forward), and 15 instances (13%) of combined-axis gestures (5 backward-leftward, 6 backward-rightward, 2 forward-leftward, 2 forward-rightward). Gestures were produced with the right hand 57 times, the left hand 48 times, and with both hands 14 times.

For spatial gestures, gestures were considered congruent if the gesture matched the speech content (e.g., a leftward gesture when saying "left," forward gesture when saying "front," etc.). Furthermore, to compare the patterns observed in the combined-axis temporal gestures to the combined-axis spatial gestures, we coded the spatial combined-axis gestures as "doubly congruent" if they were produced along the doubly congruent temporal axes (backward-leftward, forward-rightward) and "singly congruent" if they were produced along the singly congruent temporal axes (backward-rightward, forward-leftward). Overall, spatial gestures were congruent 75% of the time (38/59 lateral, 38/45 sagittal, and 13/15 combined-axis gestures were either singly or doubly congruent).

Double and single congruency

In contrast to the temporal gestures, congruent spatial combined-axis gestures were no more likely to be doubly congruent (six gestures) than singly congruent (seven gestures), as revealed by a binomial test, $N = 13$, $p = .46$ (Fig. 2).

Hand selection and temporal category

As in the temporal gestures, there were relatively few instances of purely sagittal spatial gestures (7 left-handed back gestures, 4 left-handed front gestures, 10 right-handed back gestures, 9 right-handed front gestures), but there is no strong evidence of an association between gesture directionality and hand selection.

Discussion

In their spontaneous temporal gestures participants in Study 2 were more likely to produce combined-axis gestures that were doubly congruent than combined-axis gestures that were singly congruent, mirroring the pattern found for directly elicited gestures in Study 1. Importantly, we found no evidence that the doubly congruent axes (backward-leftward and forward-rightward) are preferred in gesturing about concrete spatial concepts, suggesting the pattern is not driven by a quirk of biomechanics, but rather by the systematic combining of sagittal and lateral metaphors for time. Participants produced a lower percentage of sagittal gestures in their spontaneous gestures about time (17%) than in their directly elicited gestures (67%). Though perhaps striking, this overall pattern mirrors one found previously. In Casasanto and Jasmin (2012), English speakers produced a lower percentage of sagittal gestures in a spontaneous story-telling task (26%) than in a direct elicitation task (59%) (the same task used in our Study 1). The researchers note a likely source of this pattern: when directly asked to produce a gesture about the past or future, participants may consider how they would talk about these concepts. In English, linguistic metaphors for the past and future frequently involve front-back language but never left- right language (Casasanto & Jasmin, 2012). Thus, though our data are consistent with previous findings, the relative scarcity of sagittal gestures meant we had insufficient data in Study 2 to conclusively test for the presence of the other signature of metaphor combination, hand selection in front-back gestures.

General discussion

Across two studies we found evidence that people combine sagittal (past-behind, future-in-front) and lateral (past-to-left, future-to-right) metaphors for time in their hands, both in directly elicited (Study 1) and in spontaneous gestures (Study 2). Previous studies have reported that people spatialize time in gesture even when not explicitly using any spatial metaphor in speech (Cienki, 1998) and have highlighted that left-right temporal gestures are pervasive even though left-right temporal metaphors are entirely absent from language (Casasanto & Jasmin, 2012). In the present studies, we demonstrate yet another way that gesture sidesteps speech to provide distinctive insights into metaphorical reasoning: Though people may not combine metaphors for time in their words, they do so systematically in their hands.

It has been shown elsewhere that people "mix metaphors" in language more generally. How are our findings different? While it is clear that people sometimes switch between metaphors in discourse (e.g., Kimmel, 2010), it is less clear what we can infer about mental representation from such observations. For one, the presence of a metaphor in language is not necessarily evidence that a source domain is activated. Many linguistic metaphors may be frozen, conventional forms that are processed differently from novel forms (e.g., Bowdle & Gentner, 2005). Second, by virtue of its serial nature, language simply cannot express two metaphors at the same time—it can only express them one after the other, in sequential fashion. Gesture overcomes both of these limitations: In a single stroke it provides evidence, not only for source domain activation (e.g., Cienki, 1998), but also for the co-activation of two source domains within a very narrow time window. Our findings thus provide the strongest evidence yet that, counter to assumptions and occasional statements in the metaphor literature, people do not necessarily choose only one metaphor in a situation that allows more than one.

One reading of our data is that the phenomenon of combining metaphors in gesture is a somewhat marginal one, only exhibited in rare cases. This conclusion would be unwarranted. First, the rates of combined-axis gestures we observed were comparable to the rates of gestures produced along the less prominent of the two "pure" axes in each study (the lateral axis in Study 1, and the sagittal axis in Study 2). Furthermore, the rate of combined-axis gestures was not simply driven by one or two individuals. In Study 1, almost every instance of a combined-axis gesture was produced by a different individual, and, in Study 2, half of the participants produced at least one doubly congruent gesture. Second, our measures of combined metaphor use were relatively coarse-grained: Gestures were only coded as combining the front-back and left-right axes when they were closer to the 45 degree diagonal than to either of the "pure" lateral or sagittal axes. Many gestures were thus coded as purely lateral or purely sagittal when in fact they had subtle spatial properties not captured by our categorical measure. Future studies involving continuous measures of high-dimensional behaviors such as gestures or reaching movements will be required to shed further light on just how pervasive metaphor combination is in real-time behavior.

The above results provide initial empirical support for an emerging view that underscores the dynamic nature of metaphorical representation (Gibbs & Santa Cruz, 2012). According to this view, which we term the "continuity of metaphor" hypothesis, people do not have to choose one metaphor in a situation that allows more than one. Rather, in cases where more than one source domain is regularly mapped to a particular target domain, both sources may be activated in an apparently continuous fashion. Metaphorical representation, on this view, has the continuous character exhibited by other kinds of mental representation (Spivey, 2007), as seen, for example, in decision-making tasks involving motor responses (McKinstry, Dale, & Spivey, 2008; Song & Nakayama, 2009). Note that the continuity observed in temporal gestures might arise from different possible underlying processes. One possibility is that these metaphorical representations remain distinct but are sometimes activated in extremely rapid succession, for instance in the amount of time it takes to plan and execute a gesture. Another possibility is that these representations are not activated serially but rather are simultaneously active to different degrees whenever reasoning about time. Whether this co-activation is serial or simultaneous is an important question for further research, but answering it will require measures with fine-grained temporal resolution in addition to fine-grained spatial resolution.

Though the "continuity of metaphor" hypothesis is motivated by observations about the metaphorical construal of time, it extends straightforwardly to other bedrock abstract concepts. Reasoning about number and valence—like reasoning about time—has been shown to involve more than one orientational metaphor. Numerical magnitude can be either "higher" or further to the right on the mental number line (Núñez & Marghetis, 2015; Winter, Perlman, & Matlock, 2014), and the "continuity of metaphor" hypothesis predicts that these seemingly competing representations would in fact be co-active. Suggestive examples of this phenomenon have in fact already been described (Winter et al., 2015). Similarly, positive valence is mapped both with "up" (Meier & Robinson, 2011) and with the dominant hand side (Casasanto & Jasmin, 2010), and, again, the "continuity of metaphor" hypothesis predicts that these metaphors would be regularly combined in real-time behavior. Whether the continuity of metaphor extends beyond the orientational metaphors described here to other kinds of spatial metaphors, or even to metaphors that do not involve spatial source domains, is an important question. The use of mixed metaphors in formal writing is often considered a mark of muddy thinking and has long been reviled by English teachers and editors. But the use of mixed metaphors in everyday reasoning, much like the use of metaphor in the first place, may prove to be inescapable.

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Cognitive Science, 40, 481-495. The dissertation author was the primary investigator and author of this paper.

Supplementary table 1. Individual participant data for Study 1.

Congruent Sagittal	Congruent Lateral	Singly Congruent	Doubly Congruent	Incongruent	TOTAL
			2		2
					0
	2				2
2					2
				1	1
					0
1			1		2
2					2
1					1
					0
2					2
2					2
1				1	2
1				1	2
					0
	1				1
2					2
	2				2
					0
1					1
2					2
1			1		2
1				1	2
1			1		2
	2				2
2					2
2					2
1			1		2
1			1		2
	2				2
					0
1	1				2
	1		1		2
			1		1
1			1		2
	2				2
		2			2
1	1				2
	1		1		2
			1		1
2					2
1			1		2
2					2
2					2
2					2
1			1		2
		1		1	2
			1	1	2
2					2

Supplementary table 1. Individual participant data for Study 1, Continued.

	2					2
		1		1		2
2						2
	2					2
		2				2
		2				2
	2					2
	2					2
	1					1
						0
	2					2
	2					2
	2					2
	2					2
	2					2
	2					2
	2					2
	2					2
	2					2
	1					1
				1	1	2
	2					2
	2					2
	1	1				2
				2		2
	2					2
	2					2
	2					2
	1	1				2
						0
	1					1
						0
		1		1		2
		1		1		2
	1					1
	2					2
	2					2
	2					2
						0
	1		1			2
	2					2
	2					2
	2					2
	2					2
	1	1				2
	1	1				2
	1			1		2
	2					2
			2			2
	2					2

Supplementary table 1. Individual participant data for Study 1, Continued.

2		2
2		2
1	1	2
2		2
2		2
		178

Supplementary table 2. Individual participant data for Study 2.

Congruent Sagittal	Congruent Lateral	Singly Congruent Combined-axis	Doubly Congruent Combined-axis	Incongruent	TOTAL
8	7		1	4	20
2	15	1	1	5	24
1	2		1		4
2	9			4	15
	4			2	6
1	6		2	1	10
	1			1	2
1	28			1	31
	1				1
3	3		4	1	11
	6	1		1	8
	9		4	1	14
3					3
	26	2		3	31
	1				1
2	13		1	4	20
1	15		3	3	22
5	2		3	1	11
					233

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CHAPTER 7: Conclusion

Humans spatialize time in rich and nuanced manners when talking, gesturing, and thinking about time. The experiments presented in this dissertation highlight the variety of ways in which space and time are associated and provide support for the psychological reality of two key claims. First, space is a diverse domain, and the studies reported here reveal some of the ways that our spatial experience influences how we think about time. Second, just as space is a rich and complex domain, time is not homogeneous (Núñez & Cooperrider, 2013). We think about deictic and sequence time in different ways and this is reflected in the variety of ways space is used to structure these concepts.

Our experience with space is extremely multi-faceted: we place things in particular spatial locations, we move through space, we adopt different spatial perspectives, and the list goes on. For instance, take a closer look at two of the ways we can cut up the space around the body. The sagittal (front-back) axis that surrounds our bodies provides a particularly salient way of thinking about space relative to one's body. We tend to *move forward* through space to get from one point to another. This, in combination with the nature of our bodies, results in a variety of perceptual asymmetries (Clark, 1973): we see things that are in front of us, rather than behind us, we hear sounds coming from in front of us better than those coming from behind us, and we can move forward more easily than we can move backward or side to side. Furthermore, our body can easily serve as the center, or origin, of this axis**.** The lateral axis, on the other hand, has very different properties. In this case, the body does not need to serve as the origin, and it is spatially symmetrical (though it could easily be portrayed as asymmetrical as well, highlighting the flexibility of this axis). Furthermore, the entire lateral axis often lies in front of the observer, allowing him or her to see (or think about) the whole axis. As a result, the use of the lateral axis easily permits an *external perspective*, which is likely due to writing practices (e.g., Núñez & Cooperrider, 2013). On the other hand, the sagittal axis, which is yoked to the body, is inherently *internal* (Núñez & Cooperrider, 2013). Thus, the contrasting properties of these two axes, along with our experience using these two axes, may lead to important differences in the ways in which the two axes are likely to structure thoughts about time.

The particular ways we interact with the space around us tend to get picked up for use in abstract thinking, as can be seen in the case of time. But just as space is extremely multi-faceted, the concept of time is not homogeneous, and this has implications for the particular ways that space and time become associated. One consistent finding across the studies included here is that deictic and sequence time reflect different types of temporal relationships and are conceptualized (and spatialized) in different manners. This idea is not new. Indeed, it dates back to the philosopher McTaggart's (1908) distinction between A series and B series and has been discussed by many linguists since (e.g., Traugott, 1978; Moore, 2006; Tenbrink, 2011). However, the particular methods that are often employed in psychological research to investigate spatial construals of time tend to mask the differences between deictic and sequence time, which often leads psychologists to ignore this distinction. If researchers consistently only examine patterns of space-time associations along the lateral axis, they may come to the conclusion that "earlier" and "past" judgments are the same and "later" and "future" judgments are the same, as each of these pairs is aligned similarly along the lateral axis. For instance, Santiago et al. (2007), as well as Weger and Pratt (2008), had participants make judgments about a mix of deictic and sequence time words, making no distinction between the two categories (e.g., “past”, “future”, “before”, “after”, “subsequently”, “previously”, “earlier”, “later”, etc). In both cases, they find that left space and earlier/past events are associated, as are right space and later/future events. However, by directly comparing deictic and sequence judgments along the lateral and the sagittal axes, their differences become much more evident. In Chapters 2 and 3, we see that overall, sequence judgments are slower than deictic judgments and that deictic and sequence judgments are aligned differently along the sagittal axis than they are along the lateral axis. Furthermore, in Chapter 4, we observed that while the introduction of bodily motion through space affects how people make deictic judgments, it does not influence sequence judgments in the same way. Together, these findings demonstrate the psychological reality of the deictic/sequence time distinction.

What implications does this distinction have for how we reason about time? Deictic and sequence time capture different types of temporal relationships, one of which indexes events relative to a deictic center (the present moment), which is often yoked to the body, while the other indexes relationships relative to some other moment in time. As a result, these two types of time have different experiential bases, which in turn may affect how they get associated with space. For instance, due to the inclusion of a deictic center (the “now”) in deictic time, combined with patterns in language (and bodily experience), an internal perspective easily aligns with deictic time. Furthermore, due to the use of cultural artifacts such as horizontal timelines, we can easily project a deictic center onto the space in front of us, allowing an external perspective. However, in the case of sequence time, there is no deictic center. Thus, adopting an external perspective may be more useful, as it allows one to easily compare events to one another.

Across many studies in this dissertation, the lateral axis was found to be a particularly robust way of spatializing time in English speakers. Regardless of modality of stimulus presentation, response mode, framing of perspective, and interference, compatibility effects remained stable for both deictic and sequence judgments, with participants faster to make earlier and past judgments on the left than on the right and faster to make later and future judgments on the right than on the left. Such patterns were also observed using a completely different method, co-speech gesture, in Chapter 6. There, participants often made gestures to the left when referring to the past and made gestures to the right when talking about the future. This robustness is likely due to a lifetime of experience with particular cultural practices, including systematic patterns in reading and writing direction and other notational systems (e.g., Fuhrman & Boroditsky, 2010; Bergen & Lau, 2012; Núñez & Cooperrider, 2013). However, the consistency with which deictic and sequence judgments were associated with the lateral axis was not shared by the sagittal axis. Rather, compatibility effects along the sagittal axis were much more finicky and were affected by factors such as whether deictic or sequence judgments were being made, the perspective from which the events were described, and whether bodily motion through space was involved or not.

These findings are seemingly at odds with a series of studies conducted by Eikmeier and colleagues (Eikemeier et al., 2013; Eikmeier et al., 2015). They found stronger associations between space and time along the sagittal axis (Eikmeier et al. 2013) than along the lateral axis (Eikmeier et al., 2015). As a result, they claim 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 they simply may be capturing a different phenomenon. In both studies, participants vocally responded with “front” or “back” or “left” or “right” in response to past or future words written on a computer screen. As a result, the task examined whether temporal words prime spatial words, but not necessarily spatial location (or action in space). By using linguistic responses, the sagittal axis may be primed, as sagittal language is associated with the past/future, but lateral language is not. A similar pattern was seen in Chapter 6 (and in Casasanto and Jasmin, 2014) 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, 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 became the norm. Together, these results paint a bigger picture of the various ways that we think about space and how a variety of different spatial resources can be drawn upon when thinking about time.

These differences lead to a variety of questions about how using space in different ways may affect the conceptualization of deictic versus sequence time. For instance, under what circumstances do people opt to think about time laterally versus sagittally? Does the choice of axis have any implications for outcome of their reasoning? Does one really have to choose one axis over another (gesture studies suggest perhaps not)? Based on the work presented in this dissertation, along with what has been reported by others so far, a variety of predictions can be made based on what we know about the properties of these different axes. As discussed above, the lateral axis, which lies in front of the speaker, affords full access to the axis. As a result, one can easily place multiple points along the axis, making it particularly useful for making temporal comparisons. A sagittal axis that is centered around the body, however, does not permit such full access. Rather, it allows one to make broad distinctions using the space in front of and behind the body and thus may be more useful for binary categorizations. This idea has been proposed by Núñez and Cooperrider (2013), and suggests that the two axes afford different properties that may influence temporal reasoning in different ways. Thus, one would predict that in a task that places more demand on the sequential ordering of multiple events, the lateral axis may be more likely to be recruited than the sagittal axis, which may be more often used for simple binary categorization.

While the studies discussed above reveal a variety of novel observations regarding the association between space and time in the human mind, they have also led to a few important considerations and open questions for future research. First, the methods employed in a majority of this dissertation center around many variations on a theme: using stimulus-response compatibility studies to examine possible associations between space and time. Thus, it is worthwhile to consider what exactly the results of such experiments reveal about the nature of how we conceptualize time. Second, unlike the compatibility effect studies used in Chapters 1-5, where participants were forced to respond along one spatial axis or another, the gesture studies in Chapter 6 allowed participants to freely use the entire space around their bodies. What does examining co-speech gesture reveal that the stimulus-response compatibility studies used here could not? Third, while Chapter 5 started to dig into the question of the nature of the relationship between space and time, the results were inconclusive, leaving open the question of what role space plays in our conceptualization of time. Finally, these studies were all based on a very limited sample of the human population: a subset of undergraduate students at UCSD. What implications might this have for how the conclusions drawn in this dissertation can be generalized? Each of these questions and considerations will be addressed in turn below.

The stimulus-response compatibility method

Measuring compatibility effects between different stimuli and response conditions is a tried and true method that has been used in the domain of space and time for almost a decade (e.g., Torralbo et al., 2006; Weger & Pratt, 2008). This particular method is quite flexible and allows researchers to manipulate a variety of factors that may influence how individuals associate time and space, from the writing direction of a particular language (e.g., Ouellet et al. 2010; Fuhrman and Boroditsky 2010) to the modality of response and presentation (Walker et al, 2014), while keeping the general structure the same across experiments. The use of these controlled psychological experiments, informed by data from linguistics and gesture studies, can create a unique situation that allows experimenters to investigate what aspects of space participants are most likely to recruit during temporal reasoning. Indeed, it is often the case that when participants are presented with a novel spatial resource, space is not just used in a random manner. Rather, people appear to use whatever spatial resources are provided to them, and will use those resources in a way that is consistent with their experiences, whether those experiences are patterns of language use, patterns of interaction with cultural artifacts, or patterns of cultural practices more generally.

However, while such experiments provide insight into what aspects of space are the likely candidates for being recruited when reasoning about time, it is important to keep in mind that they don't necessarily reveal how space is *spontaneously* deployed beyond the experimental setting. A good example of this lies in the case of how people associated the sagittal axis with sequence judgments in Chapters 2 and 3. While participants tended to make earlier judgments more quickly when responding in front of their body than behind their body and to make later judgments more quickly when responding behind their body than in front of their body, this does not necessarily indicate that people spontaneously employ the sagittal axis when thinking about sequential relationships in time. Indeed, English speakers practically never *gesture* along the sagittal axis when talking about sequences of time (Casasanto and Jasmin, 2012). Rather, they almost exclusively gesture along the lateral axis. This suggests that reasoning about sequence time may be more strongly associated with the lateral axis, which is likely the result of associations with how cultural artifacts display events in time (e.g. calendars, graphs, timelines).

One possible reason that this axis is so often used in gesture is that the entire axis lies in front of the observer, allowing them to see (or think about) the whole axis. This makes comparisons between events (in terms of spatial distance) easier to visualize than along a sagittal axis, which can also introduce ambiguities if one uses the space solely in front of the speaker. Yet, it is clear that when provided with a sagittal axis, participants lay out earlier and later events along that axis in a manner consistent with how they talk about those events in English. Whether participants spontaneously make such associations in a situation beyond the experiment room, however, is less clear. Yet, the observation of such associations sheds light on the particular properties of space that people *could* put to work when reasoning about time and perhaps, with regular use, a previously novel use of space could lead individuals to begin to structure their thoughts about time in different but lasting ways.

Temporal gestures

While stimulus-response compatibility studies may be limited in terms of their ecological validity, studying the production of spontaneous co-speech gesture provides a unique perspective into how individuals associate space and time. Spontaneously-produced gestures are largely unconscious and can portray information that is not observed in speech alone (e.g. McNeill 1992). As a result, they are an ecologically valid method for capturing how people spontaneously construe time in terms of space and may reveal hidden conceptual structure that is not captured in linguistic patterns. Furthermore, by studying gesture, we allow the speakers to utilize the entire space around their bodies, not restricting them to a particular spatial axis, as is the case with the space-time compatibility studies described above. By removing this restriction, the results of Chapter 6 reveal that English speakers don't necessarily have to choose between sagittal or lateral representations of time. Rather, participants can *combine* the lateral and sagittal axes, producing backward-leftward gestures when talking about the past and forward-rightward gesture when talking about the future. While Chapter 6 discussed some possible hypotheses that could account for these findings, many open questions remain. Thus, future behavioral experiments may want to include a wider range of behavioral response options, not limiting participants to particular areas of space to respond in order to more thoroughly examine that nature of these “combined metaphors”.

The relationship between space and time

How exactly are space and time associated in the human mind? Chapter 5 explored the possibility that space may play a *functional* role in how we think about time. That is, is our ability to think about space necessary in order to think about time? Based on the results of that study alone, one may be tempted to conclude that such a strong dependency of time on space is not likely. However, that study focused on a very narrow definition of what “space” is, and as with the concept of time, *space* is not a single concept. Indeed, it is unlikely that using one particular spatial task (e.g., the Corsi Block Task) in a dual-task situation will interfere with every single cognitive process that involves some sort of spatial processing. As a result, one cannot draw strong conclusions about the relationships between space and time based on the limited evidence of space-time interference in Chapter 5. Thus, in order to determine whether the relationship between space and time is functional, epiphenomenal, or something entirely different, future work must examine a wider range of spatial tasks to examine what aspects of spatial cognition, if any, are more likely to interfere with temporal reasoning.

Rather than being a strictly functional relationship, it is also possible that how space is used to structure abstract concepts, such as time, changes over the course of an individual’s development. For instance, when an individual is first learning about time, space may play a more dominant role in structuring temporal reasoning. Then, after years of training and experience with associating time and space in particular ways, such associations become more entrenched in the individual's mind and may evolve into more complex representations (e.g., including the addition of verbal representations), making space less necessary. If this is the case, associations that are more well-learned through years of experience, for example, with artifactual notation and reading and writing practices, such as those between lateral space and the layout of temporal sequences, may no longer functionally rely on space. Space could still be a useful strategy to structure and organize thoughts about time, but it is no longer necessary. Under this account, individuals would be more sensitive to the relationship between space and time during the development of temporal concepts. As a result, one would predict that a novel association between space and time would be more affected by spatial interference than one that is more entrenched. However, future studies must investigate the nuances of the complex relationship between space and time and examine, for example, whether (and how) such representations change over the course of development.

Beyond the undergraduate population

All of the studies presented in this dissertation were completed at the University of California, San Diego (UCSD) with participants drawn from the SONA subject pool, which is almost exclusively made up of undergraduate students at UCSD that happen to be enrolled in a psychology, linguistics, or cognitive science course. As a result, the pattern of observations described in these studies may be limited in terms of generalizability. While many of the results reported in this dissertation conceptually replicate work completed by researchers in a variety of other Western European countries (e.g., Spain, Germany, Italy), many of those studies are also drawn from an undergraduate population. Thus, this phenomenon is not limited to the present set of studies, but is one that is faced by the Cognitive Science community at a larger scale. In order to better understand the relationship between space and time in the human mind, future studies should aim replicate these findings using tools such as Amazon's Mechanical Turk, which draws from a much larger and more diverse pool of participants than the typical undergraduate subject pool (Mason & Suri, 2012).

Other spatializations of time

Our spatial experience shapes and constrains the ways we think about time, and the particular ways we train ourselves to experience space seem to get scaled up to think about the abstract in a non-random manner. While the studies presented in this dissertation focused on how time is spatialized along the sagittal and lateral axes, these are far from the only ways that time is laid out in space. Indeed, as discussed in Núñez and Cooperrider (2013), cultural artifactual and notational practices for representing and reasoning about time can take many forms, from the left-right linear representation so often found in Western cultures, to cyclical and helic representations found in many other cultures around the world. While some of these representations may have long-standing roots in a particular culture, other communities may develop novel ways of representing time based on regular practices they engage in. For instance, archaeologists may develop vertical associations with time, where earlier events in time are located deeper into the ground while more recent events are closer to the Earth's surface due to digging practices (e.g., Goodwin, 1994). Similar vertical associations may develop in avid users of social media sites such as Facebook based on a completely different practice: interacting with

Facebook's "Timeline", where more recent events are posted at the top of the page and later events are further down the page. Whether such associations persist and extend beyond these particular contexts, however, is an open question. The particular mechanisms responsible for the creation of such associations, however, are still unknown. On a more practical level, understanding our spatial experience and biases can be a useful tool in realm of design (e.g., designers must consider which way the Facebook Timeline should flow in the first place).

Conclusion

Together, the psychological experiments and studies of co-speech gesture presented here reveal the flexibility, as well as the limits, of how we use space to structure our thoughts about time. Throughout these studies, we've seen that space and time are not associated in a monolithic manner. The particular biases we have for how we think about and cut up the space around us get consistently used to structure our thoughts about the abstract. Furthermore, the particular environments and contexts within which we use these different temporal concepts influences how they are associated with space. In sum, people have numerous spatial resources available to them, and the ways in which these resources are deployed when thinking about time happens in systematic ways that are consistent with each individual's linguistic, cultural, and contextual experiences.

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