TECHNICAL REPORT

Investigating Spatial Axis Recruitment in Temporal Reckoning Through Acoustic Stimuli and Non-Spatial Responses

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Abstract
We talk about time using spatial terms ("ahead", "behind") and spatial gestures (front-back, left-right). Experimental investigation of such space-to-time mappings has focused primarily on the space in front of the participant, likely driven by the convenience of screen presentation and button responses. This has had two consequences: the disregard of the space behind the participant (exploited in language and gesture) and the creation of potential task demands produced by the spatialized manual button-presses. We present a new paradigm that addresses these issues. Participants, responding vocally, made temporal judgments about deictic (past, future) or sequential (earlier, later) relationships presented auditorily along a full front-back or left-right axis. Results involving the left-right axis replicated previous work. Participants mapped past and earlier judgments onto the left and future and later judgments to the right. Surprisingly, deictic judgments did not use the front-back axis but sequential judgments did, in a novel way. Participants mapped earlier judgments onto the space in front of them and later judgments onto the space behind them, which, to our knowledge has never been demonstrated. These findings suggest that different time concepts recruit space differently, mediated by meaning, stimulus modality and response mode.

Keywords: semantics, conceptual organization, temporal lobe, neuroimaging, aphasia, anomia

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 gesture, as when one points in front of the body when talking about the upcoming weekend (Núñez & Sweetser, 2006). But what is the psychological reality of these spatial construals of time?

Researchers have conducted a variety of psychological experiments that have looked for space-time compatibility effects along two axes: left-right (transversal) and front-back (sagittal). The transversal axis is systematically associated with time in a manner consistent with cultural technologies such as writing direction (Ouellet, Santiago, Israeli, & Gabay, 2010). For example, English speakers are faster to respond to past events on their left and future events on their right, but this pattern is reversed for Hebrew speakers, who read and write from right to left (Fuhrman & Boroditsky, 2010). While the sagittal axis is used in language and gesture, experimental results along this axis do not simply mirror patterns in language whereby speakers systematically talk about the future as located in the space in front of their bodies (e.g., The future ahead looks bright) and about the past as located behind their bodies (e.g., When I look back on my past...). Rather, some studies detect compatibility effects, with participants responding faster to the future in front and past behind, (e.g., Experiment 1: Sell & Kashak, 2010) while others do not (Experiment 2: Sell & Kashak, 2010; Fuhrman et al., 2011).

But there are limitations to previous studies. First, many of them, likely driven by the convenience of screen presentation and button responses, require participants to respond only using the part of the sagittal axis in front of them, which does not reflect the full extent of the front-back axis as manifested in language and gesture. Moreover, the use of button presses imposes the use of space onto participants’ responses, which may introduce task demands. Second, many studies have blurred the distinction between deictic and sequential time, making the results difficult to interpret. While deictic time reflects past/future relationships with respect to the present moment, as in The week ahead looks promising, sequence time captures “earlier” or “later” relationships in time, as in Spring follows winter. This distinction, as old as it is (McTaggart, 1908), has been largely overlooked in the psychological literature, leaving open the question of whether these two types of time concept are spatially construed in systematically different manners. To address these concerns, we propose a novel paradigm to investigate, via compatibility effects, the link between space and time along the full extent of both axes. We
use auditory stimuli and vocal responses, which allow for non-spatial responses and presentation of stimuli that surround the participant, and investigate compatibility effects with respect to the type of temporal concept involved—deictic or sequential (Evans, 2003; Núñez & Sweetser, 2006).

Different approaches regarding the use of spatial metaphors for time lead to contrasting predictions about the role space plays in structuring our thinking about time. For instance, the ‘Career of Metaphor Hypothesis’ (Bowlde & Gentner, 2005) and the ‘Structural Similarity Hypothesis’ (Murphy, 1996, 1997) propose that the use of spatial terms to talk about time becomes highly conventionalized over a lifetime of exposure such that speakers do not actively think about space when talking about time in conventional ways. Consistent with these proposals, reckoning about future and past events (deictic time), for which there are abundant front-back conventional metaphorical expressions (e.g., Back in my childhood), might not trigger associations with sagittal space. By contrast, ‘Conceptual Metaphor Theory’ (Lakoff & Johnson, 1980) views spatio-temporal mappings as occurring at the level of thought, manifesting themselves in language and gesture. According to this view, reckoning about deictic events should exhibit space-time compatibility effects along the sagittal axis, concordant with metaphorical language and gesture (future-front; past-behind). Sequential predictions for these theories are unclear, as sagittal language is not used to describe sequential time as systematically as for deictic time.

Predictions regarding the transversal axis pertain more to task or writing conventions (Bergen & Lau, 2012) than metaphor theory. Many studies have found right-future and left-past congruency effects, and yet English contains no metaphorical expressions that describe time in transversal terms (e.g., the week to the right looks promising does not mean “next week”). But all three metaphor approaches under consideration can accommodate such effects. Conceptual Metaphor Theory would predict that despite an absence of metaphorical language about the future on the right or left, gesture patterns index a cognitive mapping between time and the transversal axis that will lead to past/left and future/right compatibility effects. Both the Career of Metaphor Hypothesis and the Structural Similarity Hypothesis could interpret previously observed space-time compatibility effects along the transversal axis as resulting from forced spatialization of responses (e.g., left and right response keys), which compels 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 therefore it remains an open question whether, for the transversal axis, the previously documented compatibility effects are still observed when responses are not overtly spatial. The present study investigates these questions.

**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 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 (e.g., “past”). The stimuli were presented from one of four speakers—in front of, behind, to the left, and to the right of the participant (see Figure 1).

**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 a post-experiment questionnaire, thirteen subjects reported not being able to hear sound from at least one of the four speakers and were thus excluded from analysis. 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 forty 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. The sequential stimuli were composed of forty pairs of the life events used for the deictic judgments. Events in the sequential task were preceded with “her” rather than “your” (e.g., “her high school graduation”, “her college graduation”). Examples of deictic and sequential stimuli are listed in Table 1.

**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
Table 1. *Stimuli*

Deictic stimuli belonging to the categories “past” or “future”.

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

Examples of pairings of events for sequential stimuli.

<table>
<thead>
<tr>
<th>“Later” judgments</th>
<th>Reference Event</th>
<th>Test Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Her high school graduation</td>
<td>Her college graduation</td>
</tr>
<tr>
<td></td>
<td>Starting her first career</td>
<td>Her retirement</td>
</tr>
<tr>
<td>“Earlier” judgments</td>
<td>Having grandchildren</td>
<td>Having a child</td>
</tr>
<tr>
<td></td>
<td>Taking her SATs</td>
<td>Starting kindergarten</td>
</tr>
</tbody>
</table>
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. Participants then heard the critical stimulus from a single speaker along that axis and made the corresponding judgment.

### Analyses

Vocal response times were fitted with a series of linear mixed-effect models with subjects and items as crossed random effects using the *lme4* library (Bates, Maechler, & Bolker, 2011) in R (R Development Core Team, 2005). P-values were obtained using the *pvals.fnc* function in the *languageR* package (Baayen, 2011). Trials that were not picked up by the microphone, that were spoiled (e.g., coughing), were incorrect, 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, a linear mixed-effects model with type of judgment (deictic or sequential), axis (sagittal or transversal), and congruency (congruent: future or later responses in front or to the right; past or earlier responses in back or to the left) as fixed effects was fitted to the response times. Furthermore, to examine how each temporal concept was

<table>
<thead>
<tr>
<th>Table 2. ANOVA analyses.</th>
<th>By subject ANOVA results. By items results in parentheses.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deictic Sagittal</strong></td>
<td></td>
</tr>
<tr>
<td>Temporal Reference</td>
<td>$F$ (by-items) 64.47 (4.25) $MSE$ (by-items) 5526 (33333) $p$ (by-items) &lt;.001 (.045)</td>
</tr>
<tr>
<td>Location</td>
<td>.44 (1.05) 3623.3 (23120) .51 (.31)</td>
</tr>
<tr>
<td>Temporal Reference x Location</td>
<td>.57 (.28) 2117.5 (33333) .46 (.60)</td>
</tr>
<tr>
<td><strong>Deictic Transversal</strong></td>
<td></td>
</tr>
<tr>
<td>Temporal Reference</td>
<td>$F$ (by-items) 41.28 (15.99) $MSE$ (by-items) 6478 (64397) $p$ (by-items) &lt;.001 (&lt;.001)</td>
</tr>
<tr>
<td>Location</td>
<td>.001 (.25) 1140.8 (37878) .97 (.25)</td>
</tr>
<tr>
<td>Temporal Reference x Location</td>
<td>4.28 (.28) 2581.7 (64397) .047 (.012)</td>
</tr>
<tr>
<td><strong>Sequential Sagittal</strong></td>
<td></td>
</tr>
<tr>
<td>Temporal Reference</td>
<td>$F$ (by-items) 6.34 (.0028) $MSE$ (by-items) 4800.6 (1927.2) $p$ (by-items) .017 (.96)</td>
</tr>
<tr>
<td>Location</td>
<td>.0059 (1.58) 4539.8 (14197) .94 (.217)</td>
</tr>
<tr>
<td>Temporal Reference x Location</td>
<td>5.42 (5.32) 2701 (1927.2) .027 (.027)</td>
</tr>
<tr>
<td><strong>Sequential Transversal</strong></td>
<td></td>
</tr>
<tr>
<td>Temporal Reference</td>
<td>$F$ (by-items) 2.69 (.724) $MSE$ (by-items) 6120.3 (16046) $p$ (by-items) .11 (.40)</td>
</tr>
<tr>
<td>Location</td>
<td>1.16 (1.01) 3064.2 (2141.3) .29 (.036)</td>
</tr>
<tr>
<td>Temporal Reference x Location</td>
<td>3.51 (4.72) 3206.9 (2141.3) .071 (.036)</td>
</tr>
</tbody>
</table>
associated with each spatial axis, the deictic and sequential results, as well as results from each axis, were analyzed separately 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 fixed effects. Models were all significantly different from their respective null models. Corresponding ANOVA analyses are reported in Table 2.

Results

Results are summarized in Figure 2. Overall, participants were much faster to make deictic judgments than sequential judgments, β=109.33, SE = 51.45, p=.009. Furthermore, there was a marginal interaction between type of temporal concept and axis, β=8.66, SE = 13.90, p=.076. For deictic judgments, participants were just as fast to respond along the transversal as along the sagittal axis, p=.38. For sequential judgments, however, participants were faster to respond along the transversal than the sagittal axis, β=32.34, SE=10.27, p=.0016.

Contrary to predictions from language and gesture that there are systematic future-in-front and past-behind construals, our paradigm did not find evidence of deictic judgments eliciting an interaction between temporal reference and speaker location along the sagittal axis, p=.46. Results, however, revealed an unexpected interaction along this axis between temporal reference and spatial location for sequential judgments, β=-40.33, SE = 20.96, p=.054. Participants were faster to make later than earlier judgments presented behind them, β=-51.47, SE=28.64, p=.072.

Results along the transversal axis replicated previous work. An interaction between temporal reference and spatial location was observed for deictic judgments, β=-35.25, SE = 16.49, p=.033 and for sequential judgments, β=-37.51, SE = 18.92, p=.048. Participants were faster to make “later” judgments to stimuli presented to their right than to their left, β=-26.3, SE=13.74, p=.055. Participants were also faster to respond to past events than to future events during deictic judgments along both axes (sagittal: β=58.77, SE = 20.66, p=.005, transversal: β=119.39, SE = 19.54, p<.001).

Figure 1. Experimental set-up to investigate deictic and sequential judgments along the sagittal (front-back) and transversal (left-right) axes.
DISCUSSION

We introduced a novel paradigm that uses auditory stimuli and vocal responses to investigate the psychological reality of spatial construals of time. We replicated previous work involving the transversal axis for both deictic and sequential judgments—people were faster to make judgments about past and earlier events presented on their left and future and later events presented to their right. Along the sagittal axis, however, results were surprising. Compatibility effects were not observed for deictic judgments, but were observed for sequential judgments. Participants mapped earlier events to the space in front of them and later events to the space behind them during sequential judgments, a mapping that, to our knowledge, has not been previously reported in the experimental literature. Globally, our results are consistent with the idea that people exhibit a diversity of space-time associations, as compatibility effects were observed along both axes.

The absence of an effect for sagittal deictic judgments appears consistent with approaches like the Career of Metaphor Hypothesis and Structural Similarity Hypothesis. But it is also in principle compatible with a Conceptual Metaphor Theory account if the present paradigm failed to capture the right properties of space. Indeed, only studies involving imagined or actual motion in space appear to find compatibility effects for deictic time along the sagittal axis (Sell & Kashak, 2011; Ulrich et al., 2012). Perhaps motion—and not just location—is key to the representation of past/future relationships along the sagittal axis (Boroditsky & Ramscar, 2002; Sell & Kashak, 2011). Our results are consistent with this idea, as we found that non-spatialized responses failed to elicit a clear sagittal deictic mapping. Future work must carefully investigate to what extent and in what ways the motor system may be involved when using a sagittal axis centered around the participant.

While no deictic sagittal effect emerged, participants did recruit the sagittal axis when making sequential judgments—mapping earlier events in front of them and later events behind them. This surprising aspect of our results finds some affinity with a Conceptual Metaphor Theory account. The front-earlier mapping is 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 election. 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). Along the transversal axis, we found robust mappings of both deictic and sequential time, which squares with previous work. 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.

![Figure 2. Reaction times to deictic and sequential judgments (columns) along the sagittal and transversal axes (rows). Error bars indicate standard error.](image-url)
Overall, deictic and sequential time appear to be two different types of temporal concept (Núñez & Sweetser, 2006). In our work, this difference was reflected in two distinct ways. First, participants were much faster to make deictic judgments than sequential judgments. This difference likely reflects the relative difficulty of 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. Second, deictic and sequential time 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. Furthermore, while there was no difference in the timing of responses for deictic judgments between the two axes, participants were faster to make sequential judgments along the transversal than the sagittal axis. This suggests that though deictic judgments can easily be made along either axis, the transversal axis may be the default way of thinking about temporal sequences, consistent with how sequences are often presented in the culturally constructed world around us.

In sum, there are different types of temporal concept that recruit different spatial axes in manners that are not always consistent with patterns in language and are affected by stimulus modality and response mode. These findings 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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