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# Space and Time are Mutually Contagious in Sound

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## Abstract

Time is talked about in terms of space more frequently than the opposite is true. Past experimental evidence suggests that this asymmetry runs deep, with results suggesting that temporal concepts and percepts find structure in spatial representations but not *vice versa*. However, these studies frequently involve verbal and/or visual stimuli. Because vision makes a privileged contribution to spatial processing it is unclear whether these results speak to a deep asymmetry between time and space, or a modality specific one. The present study was motivated by this ambiguity and a complementary correspondence between audition and temporal processing. In an auditory perceptual task, duration and spatial displacement judgments were shown to be mutually contagious. Irrelevant temporal information influenced spatial judgments and *vice versa* with a larger effect of time on space. The results suggest that the perceptual asymmetry between domains does not generalize across modalities and that time is not fundamentally more abstract than space.

**Keywords:** space and time; language and thought; metaphor; embodiment

## Introduction

*Time* is frequently talked about using the language of *space* (Clark, 1973; Hasplemath, 1997; Tenbrink, 2007). Events can be *long* or *short*, and can occupy a place that is either *behind* or *in front* of us *in time*. Space is used to talk about time not only frequently but also meaningfully. We talk about temporal extent or *duration* in terms of distance, and the *past* and *future* in egocentric locational terms. These ways of talking and thinking about space and time are thought to reflect something about how we experience these domains together. We may talk about duration in terms of *length* because it takes more time to visually scan or travel through more extended space, and the past as *behind*

because as we walk forward, objects we pass begin to occupy the unseen space behind our bodies becoming accessible only to memory as part of a temporal past. Experimental studies support the idea that the ways in which we experience space play a role in structuring the semantics of time (Boroditsky, 2000, 2001; Boroditsky & Ramscar, 2002; Casasanto & Boroditsky, 2008; Kranjec, Cardillo, Schmidt, & Chatterjee, 2010; Kranjec & McDonough, 2011; Matlock, Ramscar, & Boroditsky, 2005; Miles, Nind, & Macrae, 2010; Nunez, Motz, & Teuschner, 2006; Nunez & Sweetser, 2006; Torralbo, Santiago, & Lupianez, 2006).

In language, time–space relations are relatively asymmetrical. Not only is time talked about in spatial terms much more frequently than space is talked about in terms of time, but in many ways time *must* be talked about using the language of space, whereas the opposite is not true. These linguistic patterns have been interpreted to suggest a deeper conceptual organization. According to *conceptual metaphor theory* (Lakoff & Johnson, 1999) we think about relatively abstract *target* domains (like time) in terms of more concrete *source* domains (like space). This basic organizational principle is purported to serve the functional role of making more abstract concepts easier to talk *and think* about. It is argued that we depend on such a hierarchy because, for example, we can directly see and touch things “in space” in a way that we cannot “in time.” This suggests that thinking about time in terms of space runs cognitively deep, and reflects a mental organization more fundamental than that observed at the relatively superficial level of words.

In a widely cited paper, Casasanto and Boroditsky (2008) sought strong experimental evidence for this theoretical organizational principle. Specifically, they wanted to know if the asymmetry of space-time metaphors in language predicted a similar asymmetry in perception. They reasoned

that low-level perceptual biases demonstrating concordant asymmetry with patterns found in language would provide strong evidence that temporal representations are grounded on more concrete spatial representations.

In their study, participants viewed growing or static lines one at a time on a computer screen. Lines could be of nine durations crossed with nine displacement sizes to produce 81 unique stimuli. After the presentation of each line, participants were randomly prompted to either reproduce a line's spatial extent (by dragging a mouse) or a line's duration (by clicking a mouse). Each line was presented twice: once in each kind of reproduction trial (i.e., displacement or duration estimation).

They found that the remembered size of a line in space concordantly modulated recall for its duration, but not *vice versa*. That is, (spatially) longer lines were remembered as being presented for longer times, but lines of greater durations were not remembered as having greater spatial extent. The results were consistent with the idea that asymmetrical patterns of space-time mappings in language are preserved further down at the level of perception. They concluded, "these findings provide evidence that the metaphorical relationship between space and time observed in language also exists in our more basic representations of distance and duration" (p. 592).

That we use space to think about time is now widely acknowledged. The idea that time is fundamentally (i.e., ontologically) more abstract than space is regarded as a prerequisite for this relation. However, there are still reasons to question this general view. First, neural data supporting the idea that our temporal concepts are grounded in embodied spatial representations is scarce, partly because it is not entirely clear what an embodied spatial representation *is* in the first place (Kranjec & Chatterjee, 2010). Furthermore, recent fMRI evidence suggests that temporal and spatial concepts do not necessarily have privileged relations in the brain (Kranjec, Cardillo, Lehet, & Chatterjee, 2012). By focusing on space, embodied theories have neglected to investigate temporal conceptual grounding in neural systems that instantiate time perception in the body. Importantly, studies in this area of research tend to rely on visual tasks. This in particular makes it unclear whether observed behavioral asymmetries between time and space reflect (1) general ontological (or even metaphysical) relations dependent on each domain's relative level of "abstractness" or (2) a less general, modality-specific contribution of visual representations in humans.

To distinguish between these two alternatives, the present study directly probes time-space relations in the auditory domain. Audition was selected because there are intuitive reasons to think that those time-space asymmetries observed in vision might actually be reversed in sound. This is because time, more than space, seems to be an intimate

part of our auditory experience. [But see (Shamma, 2001) for a dissenting view.] For example, whereas spatial relations and visual objects tend to be persistent, sound, like time, is relatively transient (Galton, 2011). While the retina preserves analog spatial relations in early representations, the cochlea does not (Moore, 1977; Ratliff & Hartline, 1974). Sound localization is less precise than object localization in vision (Kubovy, 1988). And generally, temporal information is more critical and/or salient in common forms of experience grounded in sound perception (e.g., music and speech). In the context of music, "when" a sound occurs matters much more than "where" it does. In speech, the ability to perceive differences in voice onset time is critical for discriminating between phonological categories (Blumstein, Cooper, Zurif, & Caramazza, 1977). Thus, one might argue that in many critical contexts, relations between sound and time are relatively more concrete than relations between sound and space. The present research directly addresses these issues with a task closely following Casasanto and Boroditsky (2008) but using auditory instead of visual stimuli.

## Methods

Twenty members of the University of Pennsylvania community participated for payment. All participants were right-handed, native English speakers, and between 18-26 years of age. The participants were equipped with headphones and seated at a computer for a self-paced experiment. Participants initiated the beginning of each new trial and the start of each within-trial component. Each trial consisted of two sounds, a *target sound* followed by a *playback sound*. In the first part of each trial, the target sound was presented, and participants were instructed to attend to both spatial and temporal aspects of the stimulus. Target sounds consisted of bursts of white noise that changed in location relative to a participant's head position across time. White noise bursts were of nine durations (lasting between 1000 and 5000ms with 500ms increments) and 9 distances (moving between .5 and 4.5m in increments of .5m). All durations and distances were crossed to create 81 distinct target sounds. The initial location of the target sound was an average of 2.75m to the left or right of the listener with a jitter of between .1 and .5m. Starting locations on the right indicated leftward moving trials and starting locations on the left indicated rightward moving trials. Starting locations were randomly assigned to stimuli with an even number of right and leftward moving trials. The plane of movement was 1 meter in front of the listener. Stimuli were created using Matlab and played using the OpenAL library provided with Psychophysics Toolbox extensions (Brainard, 1997). The OpenAL library is designed to model sounds moving in virtual metric space.

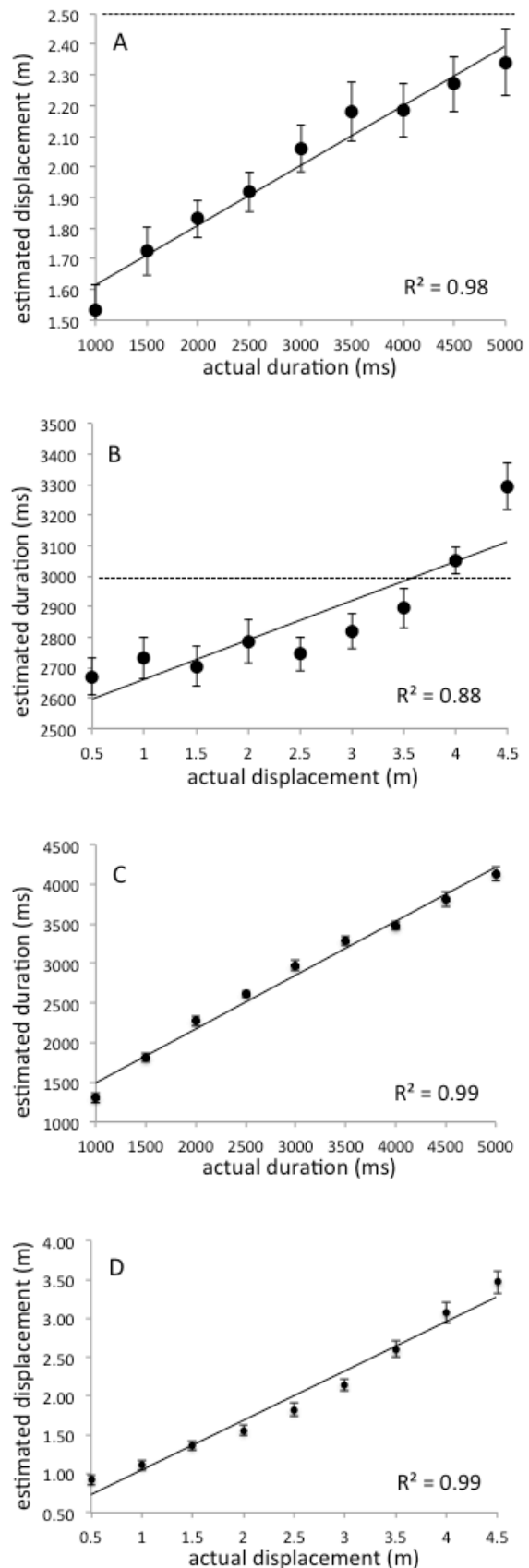
After attending to the target sound, participants were prompted to reproduce either the sound's duration or distance and then instructed to press the spacebar to begin

the playback sound. In this second part of each trial, the playback sound provided the medium for the participant's response. The playback sound began in the final location of the preceding target sound and moved in the reverse direction. So, if a target sound moved rightward, the playback sound moved leftward, and *vice versa*. On *distance* trials, participants were instructed to respond when the playback sound reached the start location of the target sound, thereby reproducing the distance from head to start point. In this manner, the participant's head provided a fixed reference point for judging distance. On *duration* trials, participants were instructed to respond when the playback sound duration was equal to the target sound duration. The playback sound lasted for a fixed 8500ms and moved 3.5m past the starting location of the target sound or until the participant responded. The playback sounds were designed in such a manner as to allow participants the possibility to both overshoot and undershoot their estimates. Participants heard each target sound in both duration and distance conditions for a total of 162 trials.

## Results

The results (Fig. 1) demonstrate that actual durations affected estimates of spatial displacement (Fig. 1A:  $y = 0.0002x + 1.4208$ ,  $r^2 = .98$ ,  $df = 7$ ,  $p < .01$ ) and that actual spatial displacement affected estimates of duration (Fig. 1B:  $y = 128.97x + 2532.8$ ,  $r^2 = .88$ ,  $df = 7$ ,  $p < .01$ ). On *distance* trials, for stimuli of the same average duration (3000ms), sounds shorter in length were judged to be of shorter duration, and sounds longer in length were judged to be of longer duration. On *duration* trials, for stimuli of the same average displacement (2.5m) sounds of shorter durations were judged to be shorter in length, and sounds of longer durations were judged to be longer in length. Time and space were mutually contagious in that irrelevant information in the task-irrelevant domain affected participants' estimates of both duration and spatial displacement. Compatible effects were found using multiple regression analyses. Duration was significantly correlated with distance judgments even when variance associated with each trial's actual distance was removed [ $\rho(r\delta I) = .81$ ;  $p < .01$ ]. Distance was significantly correlated with duration judgments when variance associated with actual duration was removed [ $\rho(r\delta I) = .64$ ;  $p < .01$ ]. There was no effect of direction (left-moving vs. right moving trials).

Figure 1A-D: (Opposite column) **Averaged duration and spatial displacement estimates.** The top scatterplots depict between domain effects. The dotted lines represent the line predicted by perfect performance. All space and time intervals were fully crossed. The average of all 9 displacement intervals is 2.5m at each duration (1A) and the average of the all duration intervals is 3000ms at each displacement length (1B). The bottom scatterplots (1C and 1D) depict within domain effects. Error bars refer to standard error of the mean.



Participants' overall estimates of duration and displacement were very accurate. The effects of actual duration on estimated duration (Fig. 1C:  $y = 0.6805x + 813.64$ ,  $r^2 = .99$ ,  $df = 7$ ,  $p < .001$ ) and actual displacement on estimated displacement (Fig. 1D:  $y = 0.6374x + 0.4115$ ,  $r^2 = .99$ ,  $df = 7$ ,  $p < .001$ ) were also very similar to each other and to analogous analyses of accuracy in Casasanto & Boroditsky (2008). This suggests that participants were approximately equal in accuracy when making duration and distance judgments within the present experiment and between comparable experiments using auditory and visual stimuli.

The effect of duration on displacement was significantly greater than the effect of displacement on duration (Fig. 2) (2A vs. 2B: difference of correlations = 0.10;  $z = 1.7$  one-tailed,  $p < .05$ ). However, some caution should be taken when interpreting this result. It is unclear to us whether differences in perceptual judgments between domains can be directly compared at such a fine grain when arbitrarily defined scales, intervals, and ranges (e.g., in seconds and meters) are used to define temporal and spatial aspects of the stimuli. This is a concern even though spatial and temporal judgments focused on identical stimuli. It is possible that other scaled relations could yield different patterns of results.

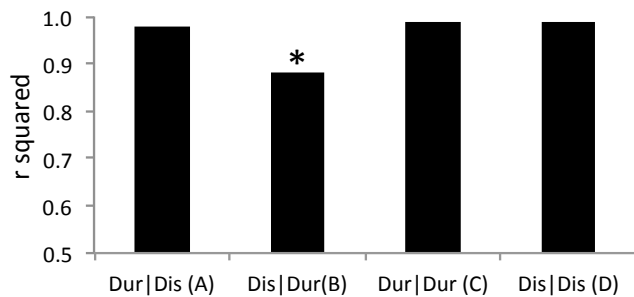


Figure 2: **Comparing differences between effects.** Effects of: Duration on Displacement (Dur|Dis); Displacement on Duration (Dis|Dur); Duration on Duration (Dur|Dur); Displacement on Displacement (Dis|Dis). A-D refer to corresponding scatterplots in Figure 1.

## Discussion

While strong claims about asymmetrical ontological relations between space and time in the auditory domain are premature, we can report a significant pattern of time-space asymmetry in the auditory domain. This asymmetry is predicted by the temporal nature of auditory processing and runs in the opposite direction of the asymmetry found in the visual domain as predicted by patterns of language use (Casasanto & Boroditsky, 2008) and the relatively spatial nature of vision.

A prior study using visual stimuli found strong evidence for an asymmetrical relationship between space and time, such

that the remembered size of a stimulus in space modulated recall for its duration, but not *vice versa* (Casasanto & Boroditsky, 2008). In contrast, the present study having an analogous design but using auditory stimuli found that space and time are mutually contagious. Furthermore, as predicted by the privileged relation between auditory and temporal processing, the perceived duration of a stimulus had a larger effect on perceived displacement than the reverse. While this is suggestive of a perceptual asymmetry running opposite to that observed in the visual domain, broader claims regarding a deep ontological asymmetry between time and space in the auditory domain are currently unwarranted. Although “in sound,” time appears to influence judgments of spatial displacement more than *vice versa*, these results may not generalize to other scales, intervals, and ranges of time-space relations. And importantly, the effect of spatial displacement on duration estimates was still strong in the auditory domain ( $r^2 = .88$ ). In Casasanto and Boroditsky’s 2008 study, actual duration had *no effect* on spatial displacement judgments.

These results demonstrate that time is not necessarily or fundamentally more abstract than space, and suggest that previously observed verbal and mental asymmetries of *representing time in terms of space* may at least be partially dependent on the human disposition to think visually. The general idea that visuospatial representations are central to how we think and reason in a more general sense about the world is well established (Johnson-Laird, 1986; Tversky, 2005) as is the more specific idea that spatial, visual, and verbal representations are deeply intertwined in giving rise to abstract semantics (Chatterjee, 2001, 2008; Jackendoff, 1996; Talmy, 2000). In the context of previous research demonstrating a strong asymmetry for time-space relations, the results of the present study suggest something very important about the nature of those “embodied spatial representations” that appear to structure patterns in language and thought. That is, such representations are likely visuospatial in nature.

It should be noted that the present results do not refute those reported in Casasanto and Boroditsky’s analogous (2008) study. Rather, our results suggest that the hypothesis that *time is more abstract than space* at the level of a deep ontology and/or basic cognitive architecture may need to be revised. This should not come as a total surprise because “space” is itself a very abstract concept and, like “time,” cannot be directly seen, touched, or heard. The present data suggest that what makes certain spatial or temporal *relations* more or less abstract is the sensory modality in which those relations are processed or experienced. As such, the present results support a refined but intuitive view of embodied cognition that takes into account contributions of a particular sensory modality in processing the abstract qualities of a stimulus. While space and time may be equally abstract, relations between objects immersed in either substrate (whether seen or heard) may be more or less

so depending on a range of species-specific and contextual variables.

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