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The long and the short of it: On the nature and origin of functional overlap between representations of space and time

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ABSTRACT

When we describe time, we often use the language of space (*The movie was long*; *The deadline is approaching*). Experiments 1–3 asked whether—as patterns in language suggest—a structural similarity between representations of spatial length and temporal duration is easier to access than one between length and other dimensions of experience, such as loudness. Adult participants were shown pairings of lines of different length with tones of different duration (Experiment 1) or tones of different loudness (Experiment 2). The length of the lines and duration or loudness of the tones was either positively or negatively correlated. Participants were better able to bind particular lengths and durations when they were positively correlated than when they were not, a pattern not observed for pairings of lengths and tone amplitudes, even after controlling for the presence of visual cues to duration in Experiment 1 (Experiment 3). This suggests that representations of length and duration may functionally overlap to a greater extent than representations of length and loudness. Experiments 4 and 5 asked whether experience with and mastery of words like *long* and *short*—which can flexibly refer to both space and time—itself creates this privileged relationship. Nine-month-old infants, like adults, were better able to bind representations of particular lengths and durations when these were positively correlated (Experiment 4), and failed to show this pattern for pairings of lengths and tone amplitudes (Experiment 5). We conclude that the functional overlap between representations of length and duration does not result from a metaphoric construction processes mediated by learning to flexibly use words such as *long* and *short*. We suggest instead that it may reflect an evolutionary recycling of spatial representations for more general purposes.

1. Introduction

Central to human sophistication is the ability to engage in abstract thought—thought about things that we cannot directly perceive with our senses. Consider the ability to reason about time. The experience of time is fundamental—as Robert Ornstein (1969) has remarked, "…time is one of the continuing, compelling, and universal experiences of our lives, one of the primary threads which combine in the weave of our experience." Yet there is no bodily organ specialized for temporal representation, nor any physical process in the world that gives rise to its experience. A challenge for cognitive science is to characterize the representations that underlie our experience of time and account for how they arise over evolution and ontogenesis.

The study of the nature and origin of abstract concepts has often taken representations in the domain of time—considered by many to be an example of an abstract domain *par excellence*—as a test case (e.g., Boroditsky, 2000, 2001; Casasanto, 2008; Casasanto & Boroditsky, 2008; Gentner, Imai, & Boroditsky, 2002; McGlone & Harding, 1998). Some clues to the representation of time come from language. Linguists have noted that when we talk about temporal experience (and our experiences in other abstract

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domains), we co-opt the language of space, describing time as something we can actually see (Clark, 1973; Gruber, 1965; Jackendoff, 1983; Lakoff & Johnson, 1980; Langacker, 1987; Talmy, 1988). For example, in English, we speak of a '*long* meeting', the '*approaching* deadline', and the 'future that *lies ahead*' (see Table 1). The use of spatial language to describe time is also robust across languages (Alverson, 1994; Sweetser, 1991; Traugott, 1978).

These uses of language motivate a provocative proposal: we may use spatial language to describe time because we have adapted our cognitive faculties of spatial reasoning (for which we have richer perceptual experience) to the task of temporal reasoning, resulting in structural similarities and functional overlap among representations in the two domains (Casasanto, 2008; Casasanto & Boroditsky, 2008; Jackendoff, 1983; Lakoff & Johnson, 1980; Murphy, 1996; Pinker, 1997, 2007). Of course, it would be hasty to draw sweeping conclusions about how we think from the presence of metaphorical language (cf. Murphy, 1996; Pinker, 1997). In order to gain new meanings, words were initially extended creatively (e.g., from using *long* to refer to not only space, but also to time). But over time, the initial motivation for these extensions could have faded, and could no longer be transparent to speakers today. This would suggest that, in these cases, metaphorical language is just an etymological relic (see Keysar, Shen, Glucksberg, & Horton, 2000; but see also Thibodeau & Durgin, 2008).

But while metaphorical language need not reveal relationships among concepts, a compelling body of evidence suggests that spatial and temporal representations *are* intimately related in the mind (Boroditsky, 2000, 2001; Casasanto, 2008; Casasanto & Boroditsky, 2008; Gentner et al., 2002; McGlone & Harding, 1998; Xuan, Zhang, He, & Chen, 2007). A first contribution of the present experiments is to add another phenomenon in support of this position, which demonstrates that magnitude representations of space and time more spontaneously engage with and align with one another than do other structurally similar representations. We suggest that spatial and temporal representations functionally overlap to a large extent, perhaps due to a shared neural substrate. A second contribution of these experiments is to elucidate the role of ontogenetic and evolutionary processes in establishing this functional overlap. On the one hand, it is possible that spatial representations have been recycled, over evolutionary time (see Gould & Vrba, 1982), for the purpose of representing time, resulting in an innate, generalized representation for both space and time. Alternatively, functionally overlapping representations of space and time could result from a metaphorical construction process over development that is motivated by learning to use spatial words such as *long* and *short* to metaphorically describe temporal experience (see Boroditsky, 2000). We test whether this type of linguistic experience is necessary for the creation of functional overlap among spatial and temporal representations and provide evidence that it is not.

Table 1
Parallels between spatial and temporal language (from Jackendoff, 1983).

Spatial reference	Temporal reference
At the corner	At 6:00 P.M.
From Denver to Indianapolis	From Tuesday to Thursday
The bus is fast approaching	Christmas is fast approaching
The train crept by	Tuesday crept by
The border lies ahead of us	Our future lies ahead of us
In Cincinatti	In 1976

In the present studies, we focus on one aspect of the representation of time: namely, the representation of temporal duration, as invoked in phrases such as "a long tone" or "this tone is longer than that one." The structurally similar representations of space we consider are representations of spatial length, as invoked in phrases such as "a long line" or "this line is longer than that one."

1.1. Structural similarity

Two representational systems are *structurally similar* if they can be relationally aligned as follows: symbols (a, b, c, ...) and relations (P, Q, ...) in one system are mapped to symbols (a', b', c', ...) and relations (P', Q', ...) in the other such that if a given relation holds among symbols in the first system, a mapped relation among mapped symbols holds in the second, *structurally similar* system. This is a fairly weak sense of structural similarity and it describes many systems of representation. Under this definition, for example, dimensions in which symbols are serially ordered (e.g., numbers, days of the week, and letters of the alphabet) are structurally similar and can be aligned by virtue of that relation (e.g., 1 = Monday, 2 = Tuesday, 3 = Wednesday, etc.). However, structurally similar representations can have even richer relational mappings. Consider the case of analog magnitude representations, which include representations of numerosity as well as other continuous quantities and intensities such as area, spatial length, duration, brightness, temperature, and loudness (Brannon, Suanda, & Libertus, 2007; Feigenson, 2007; Meck & Church, 1983). The structural similarity among these dimensions goes beyond the fact that each is characterized by a serial order. First, each has an analog format—each dimension of experience is represented by a physical magnitude that is proportional to the quantity it depicts. Second, in virtue of their analog formats, these representations are inherently noisy, such that representations of increasing values are increasingly more variable. This ensures that comparison of different values along a particular dimension is subject to Weber's law, where discriminability is a function of the ratio of two values, rather than their absolute difference. Third, locating individual values along each of these continua depends upon a contextually defined standard, as evidenced by the semantic congruity effect (Banks, Clark, & Lucy, 1975; Holyoak & Walker, 1976; Petrusic, 1992).

Analog magnitude representations meet the basic conditions of structural similarity: a pair of dimensions can be relationally aligned such that the ratio between a pair of values on a first dimension is the same as that between a pair of mapped values on a second dimension (e.g., 1 = a line one inch long, 2 = a line two inches long, etc.). Classic work in psychophysics on cross-modal matching demonstrates that people can access this structural similarity when they are instructed to do so (Stevens, 1975; Stevens