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# Space–time interdependence: Evidence against asymmetric mapping between time and space

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ABSTRACT

Time and space are intimately related, but what is the real nature of this relationship? Is time mapped metaphorically onto space such that effects are always asymmetric (i.e., space affects time more than time affects space)? Or do the two domains share a common representational format and have the ability to influence each other in a flexible manner (i.e., time can sometimes affect space more than vice versa)? In three experiments, we examined whether spatial representations from haptic perception, a modality of relatively low spatial acuity, would lead the effect of time on space to be substantially stronger than the effect of space on time. Participants touched (but could not see) physical sticks while listening to an auditory note, and then reproduced either the length of the stick or the duration of the note. Judgements of length were affected by concurrent stimulus duration, but not vice versa. When participants were allowed to see as well as touch the sticks, however, the higher acuity of visuohaptic perception caused the effects to converge so length and duration influenced each other to a similar extent. These findings run counter to the spatial metaphor account of time, and rather support the spatial representation account in which time and space share a common representational format and the directionality of space–time interaction depends on the perceptual acuity of the modality used to perceive space.



## 1. Introduction

Though our immediate perception of the world is limited to our senses such as vision and hearing, we can build on these senses to develop other knowledge domains such as *space*. How we perceive and represent more abstract domains such as *time*, however, has been a perennial philosophical question. Many researchers have suggested that abstract domains are grounded to some extent in more familiar concrete domains that we develop through sensorimotor experience (e.g., Barsalou & Wiemer-Hastings, 2005; Clark, 1973; Gibbs, 1994; Lakoff & Johnson, 1980, 1999). Time, for example, can be understood through the domain of space, as reflected in our use of language. Speakers of English often talk about time in spatial terms (e.g., *a long/short time*) and sometimes space in temporal terms (e.g., *I am five minutes from the airport*). A range of studies have provided evidence that these linguistic expressions reflect a deeper conceptual bridge between time and space. For example, space affects the perception of temporal

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durations such that people experience longer subjective time when they imagine themselves inside a larger scale model of a room than inside a smaller one (DeLong, 1981), or when they see a larger square than a smaller one (Xuan, Zhang, He, & Chen, 2007), a longer sweeping gesture than a shorter one (Cai, Connell, & Holler, 2013), or a longer line than a shorter one (Casasanto & Boroditsky, 2008).

There are two alternative accounts of the relationship between time and space representations. According to the *spatial metaphor* account, people employ spatial metaphors in thinking or talking about time such that they use their concrete spatial experience to support their understanding of abstract time processing (Boroditsky, 2000; Clark, 1973; Gibbs, 2006; Lakoff & Johnson, 1980, 1999). The temporal relation of two events can be expressed metaphorically as a relation between two locations in space (e.g., tomorrow is ahead of yesterday). Similarly, a temporal duration can be metaphorically envisioned as the distance from a spatial location representing the onset of the duration and a spatial location representing the offset of the duration. Critically, the spatial metaphor account assumes that time and space remain two separate representational systems with an asymmetric mapping between them: concurrent spatial information should always affect its dependent domain of time to a greater extent than concurrent temporal information can affect space (Casasanto & Boroditsky, 2008; Casasanto, Fotakopoulou, & Boroditsky, 2010; Merritt, Casasanto, & Brannon, 2010). In other words, the asymmetry of space–time interaction manifests itself as one of the following two possibilities: either space unilaterally affects time; or space and time affect each other but the effect of space on time should be greater than that of time on space. The account rules out the possibility that time affects space but is not itself affected by space.

Alternatively, according to the *spatial representation* account of time–space relations, temporal and spatial information are processed in a common neural substrate and share representational and attentional resources. Such a position has received support from behavioural demonstrations of spatial interference on time perception (Frassinetti, Magnani, & Oliveri, 2009; Xuan et al., 2007), imaging findings of common neural substrates subserving space and time processing (Assmus, Marshall, Noth, Zilles, & Fink, 2005; Assmus et al., 2003; Oliveri, Koch, & Caltagirone, 2009; Parkinson, Liu, & Wheatley, 2014), and neuropsychological observations of distorted time perception in space-neglect patients (Basso, Nichelli, Frassinetti, & di Pellegrino, 1996; Danckert et al., 2007). According to the account, time is closely related to space in action and perception: space and time are often coordinated in action and correspond to each other in movement (e.g., things travel a certain distance in a certain time; Gallistel & Gelman, 2000; Srinivasan & Carey, 2010). Thus, temporal duration and spatial distance may share a representational format, such that two events are separated by a particular duration in the same way that two locations are separated by a particular distance. Some stronger versions of spatial representation theories have argued that time, space and number all share a common magnitude representation (Bueti & Walsh, 2009; Burr, Ross, Binda, & Morrone, 2010; Gallistel & Gelman, 2000; Lambrechts, Walsh, & van Wassenhove, 2013; Walsh, 2003), but a weaker version of the spatial representation account of time does not necessarily require the magnitude assumption, and hence can also accommodate the spatial representation of non-magnitude information such as acoustic pitch (Connell, Cai, & Holler, 2013). Critically, according to the spatial representation account, rather than comprising separate representational domains, time and space occupy an overlapping temporo-spatial representation that may be affected by concurrent temporal or spatial information. Since the same representation can subserve both temporal and spatial processing, the spatial representation account thus differs from the spatial metaphor account in allowing both directions of space–time interaction; importantly, in direct contrast with the spatial metaphor account, it allows time to unilaterally affect space in certain circumstances (as we describe below).

Empirical evidence has thus far favoured the spatial metaphor account, with the strongest evidence coming from studies showing apparently robust asymmetric effects of space on time in nonlinguistic paradigms. For example, Casasanto and Boroditsky (2008; see also Casasanto et al., 2010) showed participants a horizontal line onscreen, which varied in its length (200–800 pixels in steps of 75 pixels) and its presentation duration (1000–5000 ms in steps of 50 ms). After the disappearance of the line, participants were cued to reproduce either its length or duration. Length reproduction involved using the mouse to click first on an X symbol on the left of the screen, then moving the mouse rightwards and clicking again to demarcate a particular length. Duration reproduction involved clicking first on an hourglass symbol to start a particular duration and then clicking again to end it. They found that people's estimates of the line's duration increased as a function of its length, but that estimates of length remained unaffected by the duration of the line onscreen. Several variants of the task produced the same effects, regardless of whether duration was presented as an auditory tone as well as the visual line onscreen, or whether the line grew onscreen to its final length or remained fixed. A later study using a different paradigm, where participants categorised the length or duration of a line as long or short according to learned standards, did find an effect of time on space (Merritt et al., 2010; see also Srinivasan & Carey, 2010), but since this effect was smaller than that of space on time, the asymmetric hypothesis of the spatial metaphor account was supported.

The above studies all use the visual modality to present spatial information. However, spatial representations are not themselves visual, and rather are handled by a multimodal or supramodal system that draws perceptual input from visual, haptic, or auditory modalities (or even from linguistic descriptions) in order to create a common spatial representation (Bryant, 1992; Giudice, Betty, & Loomis, 2011; Lacey, Campbell, & Sathian, 2007; Renier et al., 2009; Struiksma, Noordzij, & Postma, 2009). In some cases, visual and haptic perceptions give rise to comparable representations. For example, people use the same mecha-