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Constructing mental time without visual experience

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Across many cultures, people create spatial representations of time. The direction of mental timelines often follows the direction of writing in a person's language. A new study demonstrates that blind participants (who read with their hands) also show mental timelines that follow reading direction.

How do we think about abstract ideas like time or number, things that we cannot see or touch? Across many cultures and contexts, people create spatial representations of both time and number. We use spatial language (e.g., the past is 'behind' us), create spatial artifacts like graphs, timelines, and calendars, and automatically construct mental timelines and numberlines when reasoning [1,2].

How do our mental timelines and numberlines develop? The way people spatialize time and number can differ dramatically across cultures, suggesting that cultural experience shapes our representations of these domains. For example, the direction of writing in a language is one predictor of how people mentally organize time. Those who read and write from left to right construct timelines that go from left to right [2]. The reverse is true for those who read and write from right to left [1]. Numberlines also sometimes follow writing direction. [2]

Some theorists suggest that representations of space, time, and number originate from the same fundamental representation [3]. However, a recent paper by Bottini *et al.* [2] demonstrates that mental timelines and mental numberlines likely result from different sources.

Why do people who read from left to right have left-to-right timelines? Is visual experience with text necessary, or might manual experience reading Braille produce the same representation? Further, is the timeline anchored on the body itself or on the space outside the body?

Bottini *et al.* tested sighted and blind Italian participants on a task designed to measure their mental timelines. Italian is written from left to right, both in visual and Braille forms. Participants heard words like 'earlier', 'yesterday', or 'next'. They had to indicate as quickly as possible whether each word referred to the past or the future. They pressed a key on one side of the keyboard for 'past' and the other side for 'future'. For some trials, the 'past' key was to the left of the 'future' key (consistent with a left-to-right timeline), and for other trials the keys were reversed.

Both sighted and blind participants showed left-to-right timelines, responding more quickly when the 'past' key was on the left than when it was on the right. Even without visual experience, blind participants had the same mental timeline as sighted participants.

Each participant also completed the experiment with their hands crossed. If a person's left-to-right mental timeline is anchored on their body, instead of the space in front of them, then they should be faster to make 'past' judgments with their left hand and 'future' judgments with their right, even when their hands are crossed. If the mental timeline is instead anchored in the space in front of the body, then participants should always be faster to make 'past' judgments on the left side of the space in front of them, regardless of the hand being used.

Prior work has shown that while sighted participants have a numberline anchored in the space outside their bodies, blind participants' mental numberlines appear hand-dependent [4]. Are blind participants' mental timelines likewise body-based?

This is where Bottini *et al.*'s timeline data diverged from the work on numberlines. Whether their hands were crossed or uncrossed, both sighted and blind participants were faster when the 'past' key was to the left of the 'future' key. Italian blind participants' left-to-right mental timelines were anchored in external space, as were the sighted participants'. These results suggest that reading-induced mental timelines may be invariant to whether one reads using eyes or hands. The fact that blind participants use different spatial frames for representing time and number suggests that these representations are rooted in different kinds of experience.

The idea that mental timelines and mental numberlines may arise differently is supported by extensive work on how people represent time. In addition to writing direction, representations of time also depend on the spatial metaphors that are common in the languages a person speaks, their degree of proficiency or experience with those languages, and the metaphors that are being used in the moment [1]. For example, unlike English, the Aymara language talks about the past as in front and the future as behind, and this pattern is also evident in Aymara speakers' spontaneous gestures when talking about the past and future [5]. Mandarin speakers, who use both horizontal and vertical time metaphors, show both horizontal and vertical timelines, but they are more likely to construct a vertical timeline if they are completing a task in Mandarin (than in English), are more proficient in Mandarin, or are using Mandarin vertical metaphors in the moment [6].

Importantly, although the left-to-right timeline is prominent in English speakers' minds, other timelines peacefully coexist and are brought to mind in appropriate contexts. Different kinds of temporal relationships may be represented on different axes. For American English

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Box 1. Representing time in absolute space

Although left/right, front/back, and up/down axes are commonly used to organize time, other spatial frames of reference are also used. For example, the Kuuk Thaayorre – an Australian Aboriginal group – use absolute spatial coordinates to organize time from East to West [1]. That is, when laying out a temporal sequence while facing south, participants created left-to-right timelines; when facing north, right-to-left timelines; when facing east, timelines that came toward the body. Other landscape-based schemes have also been observed, for example, with time flowing uphill in Tzeltal, [9] or in a bent line downhill and across the valley for the Yupno [10].

speakers, thinking about the order of events with respect to each other (sequencing) evokes both front–back (sagittal) and left–right (lateral) timelines, while thinking about the time of events relative to now (deictic time) only evokes a left-to-right timeline [7]. Beyond body-relative coordinate frames like left-to-right or front-to-back, some groups represent time in landscape-based space, for example, from East to West (Box 1).

Time is not a unitary entity. In addition to deictic and sequential time, we also represent duration and rhythm. Humans make timing decisions on the order of milliseconds when planning motor movements, but can also entertain relationships that span geological time, and different neural substrates are critical for making decisions about time on such different scales [8].

Around the world people construct different timelines using different axes, going in different directions, based in different spatial frames of reference, and originating from different elements of physical, cultural, and linguistic experience. Further, different timelines coexist within individual minds, and people dynamically create different representations for different tasks. Our representations of abstract domains like time are not fully articulated, logically cohesive knowledge structures, but rather a bricolage of many different (sometimes conflicting) structures that are brought to mind for different purposes. The findings of Bottini *et al.* help shed light on some of the elements of experience through which mental timelines arise.

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