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Brief article

Space and time in the sighted and blind

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ABSTRACT

Across many cultures people conceptualize time as extending along a horizontal Mental Time Line (MTL). This spatial mapping of time has been shown to depend on experience with written text, and may also depend on other graphic conventions such as graphs and calendars. All of this information is typically acquired visually, suggesting that visual experience may play an important role in the development of the MTL. Do blind people develop a MTL? If so, how does it compare with the MTL in sighted? In this study we tested early blind, late blind and sighted participants in a space–time congruity task. Participants had to classify temporal words by pressing a right and a left key, either with crossed or uncrossed hands. We found that the MTL develops in the absence of vision, and that it is based on the same external frame of reference in sighted and blind people. Reading braille may provide the same experiential link between space and time in the manual modality as reading printed text provides in the visual modality. These results showing a similar MTL in sighted and blind participants contrast with previous results showing that the Mental Number Line (MNL) depends on different spatial coordinates in the sighted and the blind, and suggest that spatial representations of time and number may have different experiential bases.

1. Introduction

Time and space are tightly intertwined in the human mind. For instance, temporal order is often represented in the mind by mean of a Mental Time Line (MTL) in which earlier and later events are mapped onto the left and right side of space, respectively. In Western cultures, people are faster to categorize earlier events by pressing a left key and later events pressing a right key compared to vice versa (Casasanto & Bottini, 2014; Fuhrman & Boroditsky, 2010; Santiago, Lupiãnez, Pérez, & Funes, 2007; Ulrich & Maienborn, 2010; Weger & Pratt, 2008). Accordingly, induced rightward or leftward biases of visual-spatial attention influence temporal judgments (Frassinetti, Magnani, & Oliveri, 2009; Vicario, Caltagirone, & Oliveri, 2007; Vicario, Pavone, Martino, & Fuggetta, 2011), patients with left spatial neglect also neglect the "left side" of time (Saj, Fuhrman, Vuilleumier, & Boroditsky, 2014), and people spontaneously gesture according to the MTL when talking about temporal relationships (Casasanto & Jasmin, 2012).

The experience of reading and writing seems to play a role in establishing the direction and orientation of the

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MTL (Casasanto & Bottini, 2014; Fuhrman & Boroditsky, 2010; Ouellet, Santiago, Israeli, & Gabay, 2010; Tversky, Kugelmass, & Winter, 1991). Events unfold rightward along the MTL in people who habitually read from left to right, and leftward in people who read from right to left (e.g. Israeli Hebrew-speakers; Fuhrman & Boroditsky, 2010; Ouellet et al., 2010). Beyond showing a correlation between reading direction and the MTL, a training experiment demonstrated a causal role for reading experience in determining which direction time flows in people's minds. Exposing people who usually read from left to right to mirror-reversed orthography reversed the direction of their MTLs (Casasanto & Bottini, 2014).

Why does reading experience influence the MTL? As people read, they move their eyes and attention 'through' both space and time. For each line of text in English, readers begin on the left of the page at an earlier time, and arrive on the right of the page at a later time. This experience is apparently sufficient to cause earlier time points to become implicitly associated with one side of space and later time points with the other (Casasanto & Bottini, 2014). Other cultural conventions that tend to covary with orthography may also contribute to this space–time association; these may include graphic representation of time in calendars and graphs, temporal sequences in comic strips, and spontaneous gestures toward the past or the future. Crucially, all of this information is acquired visually, suggesting that visual input plays an important role in shaping the MTL (Bonato, Zorzi, & Umiltà, 2012), at least in the people who have been tested to date. Yet, it is unclear whether visual experience *per se* is an "active ingredient" in the development of the MTL. Do people who have never experienced functional vision develop a MTL? If so, how does it compare with the MTL in sighted people?

One possibility is that the experience of moving systematically through both time and space in the act of reading is sufficient to determine the spatial characteristics of the MTL, regardless of the sensory modality in which reading occurs. Although blind people have limited access to some graphic representations of time, and cannot see co-speech gestures, many blind people have reading experience that is similar to visual reading in the aspects that are believed to be relevant for establishing a MTL. In reading braille text, which is conventionally written from left to right, the hand (or hands) moves rightward across the page following the direction of the orthography. Reading braille, therefore, may provide the same experiential link between space and time as reading printed text. If the development of the MTL depends on orthographic experience across modalities, then sighted and blind individuals should have similarly organized MTLs.

Alternatively, vision, or lack thereof, may determine the spatial characteristics of the MTL. Specifically, the way blind people experience spatial relationships sensorially may cause their temporal concepts to be constructed differently than their sighted counterparts', regardless of reading experience. Several experiments have shown that the mental organization of nonvisual spatial frames of reference (FoR) in early blind (who lost their sight before age ~3) is qualitatively different compared to sighted people (Crollen & Collignon, 2012). Studies of tactile stimulus localization (Röder, Rösler, & Spence, 2004) and multisensory control of action (Collignon, Charbonneau, Lassonde, & Lepore, 2009; Röder, Kusmierek, Spence, & Schicke, 2007) show that whereas sighted people tend to rely on an external spatial FoR (i.e., locations are represented within a framework external to the body), the early blind preferentially use an anatomical FoR (i.e., locations are represented with respect to the position of one's body and the position of one's limbs), to represent spatial relationships.

Does the difference between blind and sighted people's default FoR extend to the use of space for representing abstract concepts, in non-spatial domains? A study in the domain of numbers suggests that it does. Like temporal relationships, numerical relationships are also represented spatially by means of a horizontal Mental Number Line (MNL) where lower numbers are associated with the left side of space and higher numbers with the right side (Dehaene, Bossini, & Giraux, 1993). Although a space-number mapping can also be observed in the early blind (Castronovo & Seron, 2007), they use a different FoR to represent numbers compared to sighted or late blind (who lost their sight after age ~3; Crollen, Dormal, Seron, Lepore, & Collignon, 2013). In a space-number congruity task, participants pressed buttons on the left and right side of space to judge number magnitude. Results showed that for the sighted and late blind participants, lower numbers were implicitly associated with the left side of space and higher numbers with the right side. This was true no matter whether they pressed the buttons using a typical uncrossed hand posture (left hand on the left button and right hand on the right button) or with their hands crossed (left hand on the right button and right hand on the left button), indicating that they were mapping number onto an external FoR. By contrast, in early blind participants the space-number congruity effect reversed between the uncrossed and crossed-hands conditions. Lower numbers were implicitly associated with the left hand, and higher numbers with the right hand, indicating that they mapped number onto an anatomical, hand-based FoR. Do early blind also use a hand-based FoR to represent time?

Although numerous studies have documented the MTL in sighted people, to date no study has tested whether blind people also organize time according to an implicit MTL. Furthermore, no study has evaluated the spatial FoR used for temporal order, in any population.[1] In this experiment early blind, late blind and sighted individuals performed a temporal classification task by pressing two keys positioned on the left and the right side of space. In one condition their hands were uncrossed, and in the other condition they were crossed. We hypothesized that, since the direction of the MTL appears to be determined by reading experience in sighted participants, their MTL should be represented in external spatial coordinates: As people read Italian, they start on the left of each line of text and end

[1] One previous study showed that space–time congruity effects were unchanged in the uncrossed vs. crossed hands condition (Vallesi, Binns, & Shallice, 2008). However, this earlier study concerned a different aspect of time: duration (i.e. temporal magnitude), rather than temporal order.