Consciousness and Cognition 30 (2014) 201–209

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Eye movements during mental time travel follow a diagonal line

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ARTICLE INFO

Article history:
Received 12 June 2014

Keywords:
Mental time travel
Eye movements
Mental time line
Spatial–temporal association
Future
Past
Embodied cognition
Metaphors
Mental number line

ABSTRACT

Recent research showed that past events are associated with the back and left side, whereas future events are associated with the front and right side of space. These spatial–temporal associations have an impact on our sensorimotor system: thinking about one's past and future leads to subtle body sways in the sagittal dimension of space (Miles, Nind, & Macrae, 2010). In this study we investigated whether mental time travel leads to sensorimotor correlates in the horizontal dimension of space. Participants were asked to mentally displace themselves into the past or future while measuring their spontaneous eye movements on a blank screen. Eye gaze was directed more rightward and upward when thinking about the future than when thinking about the past. Our results provide further insight into the spatial nature of temporal thoughts, and show that not only body, but also eye movements follow a (diagonal) "time line" during mental time travel.

1. Introduction

The passing of time is not directly graspable by the human senses. The metaphorical mapping view assumes that abstract concepts are expressed in entities of concrete domains (e.g., Barsalou, 2008; Boroditsky, 2000; Gallese & Lakoff, 2005; Lakoff & Johnson, 1980). In line with this view, humans often use the domain of space, which is thought to be concrete, in order to understand and structure the more abstract concept of time (Boroditsky, 2000; Casasanto & Boroditsky, 2008). Especially, future and past events are often described by means of spatially distinct locations. For example, events in the past lie *behind* us, whereas we are looking *forward* to events in the future. In Western cultures, two spatial–temporal associations have been identified: past-back and future-front association (Casasanto & Jasmin, 2012; Hartmann & Mast, 2012; Miles, Karpinska, Lumsden, & Macrae, 2010; Miles, Nind, & Macrae, 2010; Ulrich et al., 2012; Walker, Bergen, & Núñez, 2013), as well as a past-left and future-right association (Casasanto & Jasmin, 2012; Ouellet, Santiago, Funes, & Lupianez, 2010; Saj, Fuhrman, Vuilleumier, & Boroditsky, 2014; Santiago, Lupianez, Perez, & Funes, 2007; Torralbo, Santiago, & Lupianez, 2006; Ulrich & Maienborn, 2010; Weger & Pratt, 2008). While the past-back and future-front association is in line with the metaphorical language use, there are no equivalent expressions in language associating past with the left and future with the right side of space (Casasanto & Jasmin, 2012; Cienki, 1998; Radden, 2004). It has been argued that temporal associations with the horizontal space can be explained by reading and writing direction from left-to-right in Western cultures (e.g.,

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http://dx.doi.org/10.1016/j.concog.2014.09.007
1053-8100/

Casasanto & Bottini, 2014; Fuhrman & Boroditsky, 2007; Santiago et al., 2007; Torralbo et al., 2006). The "mental time line" has been established as an analogous concept to the "mental number line": Not only numbers are represented in an ascending order from left to right (e.g., Dehaene, Bossini, & Giraux, 1993; Fischer, Castel, Dodd, & Pratt, 2003; Hartmann, Grabherr, & Mast, 2012; Hubbard, Piazza, Pinel, & Dehaene, 2005; Lourenco & Longo, 2010; Wood, Willmes, Nuerk, & Fischer, 2008), but also time flies from left to right (e.g., Santiago et al., 2007).

Most empirical evidence for the past-left and future-right association comes from temporal categorization tasks where future and past-related stimuli need to be categorized as future or past in two-alternative forced-choice reaction time tasks. Results show that left-sided responses are faster for past than for future-related stimuli, whereas the opposite is true for right-sided responses (e.g., Santiago et al., 2007; Torralbo et al., 2006; Ulrich & Maienborn, 2010). Because these tasks require participants to categorize stimuli to the past or future, the concepts of past and future as well as the response options left and right are explicitly part of the task representation. As a consequence, these results do not provide direct evidence that past events are inherently represented in the left, and future events in the right side of space. Rather, these congruence effects can also be explained by stimulus–response compatibility such as the polarity correspondence account (Proctor & Cho, 2006). This account would suggest that past and left are coded with a negative, and future and right with a positive polarity, thus leading to faster responses when theses polarities are congruent. Therefore, shorter response times in the congruent conditions can be explained without making the assumption of a direct link between the two concepts (past-left, future-right). In fact, when the same stimuli needed to be categorized as word or non-word (also with a left and right key), the past-left and future-right advantage disappeared (Flumini & Santiago, 2013; see also Ulrich & Maienborn, 2010). The nature of the past-left and future-right association and the conditions under which it occurs remain unclear. It is an open question whether the mental time line is automatically activated during temporal processing (Flumini & Santiago, 2013), and the polarity correspondence account points to the possibility that the horizontal mental time line is merely an epiphenomenon of temporal categorization tasks.

Mental time travel is an alternative paradigm that allows investigating spatial–temporal associations by avoiding stimulus–response compatibility effects. In episodic mental time travel, participants are asked to mentally displace themselves into their subjective past or future (i.e., remembering vs. autobiographical temporal imagining; see Stocker, 2012; Tulving, 2002). Mental time travel has been used to study the past-back and future-front association. For example, Miles, Nind, et al. (2010) found that participants leaned slightly forward when they imagined how their life circumstances would look like in the future, and their body swayed slightly backward when thinking about their life circumstances in the past. Miles, Karpinska, et al. (2010) also analyzed the future and past-related contents of spontaneous mind-wandering during a vigilance task. More future-related thoughts came to participants' minds when the task included visually induced forward motion (vection), whereas backward motion induced more past-related thoughts. Thus, thinking about the past and future seems to be intertwined with backward and forward motion, following the metaphorical language use (see also Hartmann & Mast, 2012).

In this study, we investigated the horizontal mental time line by asking participants to mentally displace themselves into the past and future (i.e., episodic mental time travel). If mental time travel has a behavioral correlate in the horizontal dimension of space, this would strengthen the evidence that the horizontal mental time line is more than an epiphenomenon of temporal categorization tasks. We used eye movements as an indicator of the location of spatial attention (e.g., Corbetta et al., 1998; Sheliga, Riggio, & Rizzolatti, 1994). Participants were asked to mentally displace themselves into their subjective past and future while spontaneous eye movements on a blank screen were measured (see Loetscher, Bockisch, Nicholls, & Brugger, 2010 for a similar approach in the domain of numerical cognition). If past-related events were inherently associated with the left, and future-related events with the right side of space, we would expect more rightward directed eye gaze behavior when participants think about the future than when they think about the past. This paradigm also allows for assessing whether there is a vertical component in the spatial–temporal association. The mental number line not only runs from left to right but also from bottom to top (Grade, Lefèvre, & Pesenti, 2012; Hartmann, Gashaj, Stahnke, & Mast, 2014; Hartmann et al., 2012; Ito & Hatta, 2004; Loetscher et al., 2010; Schwarz & Keus, 2004; Winter & Matlock, 2013). Given the analogy between the mental number line and the mental time line (Arzy, Adi-Japha, & Blanke, 2009; Bonato, Zorzi, & Umilta, 2012), it is conceivable that past is associated with the lower, and future with the upper space, which could also influence eye gaze behavior during mental time travel.

In addition to the implicit measurement of spatial–temporal associations by means of eye movements, we also asked participants to indicate their explicit associations between future and past and the horizontal and vertical space. We were interested to see whether there is a general agreement about explicit temporal associations with the horizontal and vertical space and whether there is a match between the explicit and implicit measurements.

2. Method

2.1. Participants

Nineteen right-handed undergraduate students from the University of Bern participated in this study for course credit (13 women, mean age: 21.9, range: 19–28 years). Participants gave written informed consent prior to the study, and the study was approved by the local Ethics Committee. All participants had normal or corrected-to-normal visual acuity.