

**The ego-moving metaphor of time relies on visual experience:
no representation of time along the sagittal space in the blind**

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ABSTRACT

In many cultures, humans conceptualize the past as behind the body and the future as in front. Whether this spatial mapping of time depends on visual experience is still not known. Here, we addressed this issue by testing early blind participants in a space–time motor congruity task requiring them to classify a series of words as referring to the past or the future by moving their hand backward or forward. Sighted participants showed a preferential mapping between forward movements and future-words and backward movements and past-words. Critically, blind participants did not show any such preferential time-space mapping. Furthermore, in a questionnaire requiring to think about past and future events, blind participants did not appear to perceive the future as psychologically closer than the past, as it is the case of sighted individuals. These findings suggest that normal visual development is crucial for representing time along the sagittal space.

Keywords: time; space; blindness; spatial representation; temporal asymmetries; locomotion.

Introduction

In a broad range of cultures, humans tend to conceptualize time along the sagittal space (Bender & Beller, 2014; Clark, 1973). Indeed, many Western languages share a prototypical spatial metaphor mapping future events onto spatial locations in front of one's own body and past events onto locations behind it (Núñez & Cooperrider, 2013). This spatial mapping of time is revealed by various linguistic expressions, such as when encouraging someone to “*take a step back*” to reflect about a past event or to “*look forward*” to something happening in the future. According to the so-called *ego-moving metaphor of time* (Clark, 1973), time is therefore metaphorically conceived as a stationary sagittal line, with the speaker moving forward along it (Núñez & Sweetser, 2006). In line with this, motor responses to past- and future-related information are faster when the response direction is compatible with a sagittal mental time line (MTL) (Rinaldi, Locati, Parolin, Bernardi, & Girelli, 2016; Sell & Kaschak, 2011; Ulrich, Eikmeier, de la Vega, Fernández, Alex-Ruf, & Maienborn, 2012; Walker, Bergen, & Núñez, 2017; see also Torralbo, Santiago, & Lupiáñez, 2006). Further, English speakers tend to lean subtly forward when thinking about the future and backward when thinking about the past (Miles, Nind, & Macrae, 2010; but see Stins, Habets, Jongeling, & Cañal-Bruland, 2016). Yet, whether the sagittal MTL is automatically activated during the processing of past- and future-related information during task-irrelevant conditions is still a controversial issue (e.g., Ulrich et al., 2012; Sell & Kaschak, 2011).

Evolutionary perspectives have suggested that the MTL is strongly rooted in visual experience during locomotion and in the perception of moving objects along a path (Clark, 1973; Lakoff & Johnson, 1980). The human body is indeed clearly asymmetrical along the sagittal axis, as we are most sensitive to stimulation in front of the body and because we typically move in a forward direction. It is this preferential direction during locomotion that would lead us to accumulate a preponderance of perceptual experiences whereby past events are associated with

the space behind our body, and future events with the space in front of us (see Casasanto & Jasmin, 2012; Núñez, Motz, & Teuscher, 2006; Núñez & Sweetser, 2006). More specifically, the origins of the MTL have been traced back to visuo-locomotor coupling (Clark, 1973; Lakoff & Johnson, 1980), which occurs whenever we walk in a natural environment (Pelah, Barbur, Thurrell, & Hock, 2015). In fact, as an individual walks along a straight path, a sagittal pattern of optic flow is created on the retina, with a focus of expansion originating in the direction of locomotion (Gibson, 1950; Warren, Kay, Zosh, Duchon, & Sahuc, 2001). Interestingly, visual experience during locomotion would also be responsible for the systematic tendency to experience the future as psychologically closer than the past (Caruso, Van Boven, Chin, & Ward, 2013; Rinaldi, Locati, Parolin, & Girelli, 2017). Indeed, as future events are associated with diminishing distance during locomotion, they also appear psychologically closer than past events, which in turn are associated with increasing distance from the body (Caruso et al., 2013). Accordingly, exposing individuals to a backward optic flow reduces the reported temporal asymmetry (Caruso et al., 2013).

Critically, the view that spatial mapping of time may be rooted in low-level sensorimotor processes has been recently challenged by studies suggesting that the MTL may reflect a conceptual overlap between time and space (de la Fuente, Santiago, Román, Dumitrache, & Casasanto, 2014; Eikmeier, Schröter, Maienborn, Alex-Ruf, & Ulrich, 2013). Accordingly, space-time congruency effects emerge also when purely verbal (i.e., not motor) responses are required (Eikmeier, Hoppe, & Ulrich, 2015). Moreover, the sagittal direction of the MTL is not universal across cultures (Cooperrider & Núñez, 2009; de la Fuente et al., 2014; Núñez & Sweetser, 2006). For instance, in languages such as Aymara of the Andes region, the future is construed as behind the body and the past in the front; thus, opposite to the more widespread direction of the MTL (Núñez & Sweetser, 2006). As a tentative explanation of this reverse space-time mapping, it has been recently proposed that what is perceived as “in front” is likely to

depend on the cultural “temporal focus”, that is, whether the past or the future is given more importance (de la Fuente et al., 2014).

Whether the spatial mapping of time along a backward-to-forward sagittal space depends on visuo-locomotor coupling (e.g., Clark, 1973; Lakoff & Johnson, 1980), or rather reflects a conceptual (i.e. linguistically mediated) association is thus a matter of current debate. To shed light on this issue, we addressed for the first time the possible experiential origins of the MTL by testing individuals with early onset and profound blindness. In a first task, we required early blind and control sighted participants to classify a series of words as referring to the past or to the future by responding with a backward or forward hand movement respectively. A second task aimed at testing the presence of possible temporal asymmetries in the mental representation of past and future events (see Caruso et al., 2013; Rinaldi et al., 2017) by employing a questionnaire requiring participants to think about past or future events and report how “distant” they perceived them from the present. If the MTL mainly relies on a visuo-locomotor coupling, blind participants should not show a preferential mapping between forward movements and future-related words and backward movements and past-related words, as it is in turn the case of sighted individuals (e.g., Rinaldi et al., 2016; Sell & Kaschak, 2011; Ulrich et al., 2012). Similarly, if previous visual experience is indeed crucial, blind participants should not experience the future as psychologically closer than the past (Caruso et al., 2013; Rinaldi et al., 2017).

2. Method

2.1 Participants

Prior to the experiment, we conducted an a priori sample size calculation (GPower 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007). Assuming an $\alpha=.05$ and power=.8, the projected sample size needed to detect a medium effect size ($f=.25$) was determined to be 34 [ANOVA, Repeated measures, within-between interaction, 2 groups (blind, sighted) and 2 measurements (congruent, incongruent)]. Accordingly, we recruited 17 early blind participants (9 males; *mean*

age=41.6 ys, SD=11.7, range=20-65 ys; mean education=16.5 ys, SD=2.3) and 17 sighted control participants (9 males; *mean age=41.4 ys, SD=14.2, range=24-65 ys; mean education=15.8 ys, SD = 2.1*) for the purposes of this study. They were all right-handed, except for one sighted and one blind participant who were left-handed, and all had normal motor function. None of the participants had any prior history of neurological or psychiatric disorders. In blind participants, profound blindness (defined as visual function no greater than light perception) occurred prior to the age of 24 months and was due to ocular and/or pregeniculate pathology or damage. None of the blind participants had any recollection of visual memories, and they were all experienced Braille readers (see Supplemental Table 2 for further details). The study was approved by the local ethics committee and all participants offered written informed consent before starting the experiment.

2.2 Procedure

2.2.1 Temporal classification task

A schematic illustration of the task is shown in Figure 1. The task consisted of a temporal classification paradigm that has been used in a number of previous studies to investigate the spatial representation of time (e.g., Rinaldi et al., 2016; see also Bottini, Crepaldi, Casasanto, Crollen, & Collignon, 2015). Participants were seated comfortably at a table and were auditorily presented with a series of words (verbs and adverbs) using professional headphones. Participants were instructed to categorize the words as referring to the past or to the future by pressing a corresponding response key placed ahead or behind a starting point respectively. For this purpose, a standard computer keyboard was rotated 90 degrees, thus creating a sagittal response mapping space (see Figure 1). The keys not used for response were removed from the keyboard to facilitate finger movements. Each trial started with participants pressing a central key with the index finger of their dominant hand. When the word was presented, participants had to release their hand from the central key as fast as possible and move it backward or forward so as to press the corresponding response key. Response keys were equidistant from the

central key. After moving, participants had to return to the starting position and await for the next trial (time interval between trials: 2000 ms). The non-dominant hand was positioned next to the central key throughout the experiment. Each participant took part in two experimental blocks. In the first, the participant had to make a backward movement in response to past-related words, and a forward movement in response to future-related words (congruent condition). In the second, the response assignment was inverted (incongruent condition). The order of blocks was counterbalanced across participants. In each block, 46 auditory words were presented with half referring to past and the other half referring to future (see Supplemental Table 1; see for a similar method, Rinaldi et al., 2016; Torralbo et al., 2006). Words within each block were presented in random order except for the constraint that there were no more than three consecutive items referring to the same temporal direction (i.e., future or past). Each item lasted 800 ms, all items had equal auditory properties (44,100 Hz, 32 bits, stereo), and were played at a constant intensity level using E-prime2 (Psychology Software Tools, Pittsburgh, PA). Sighted participants were blindfolded throughout the entire experiment.

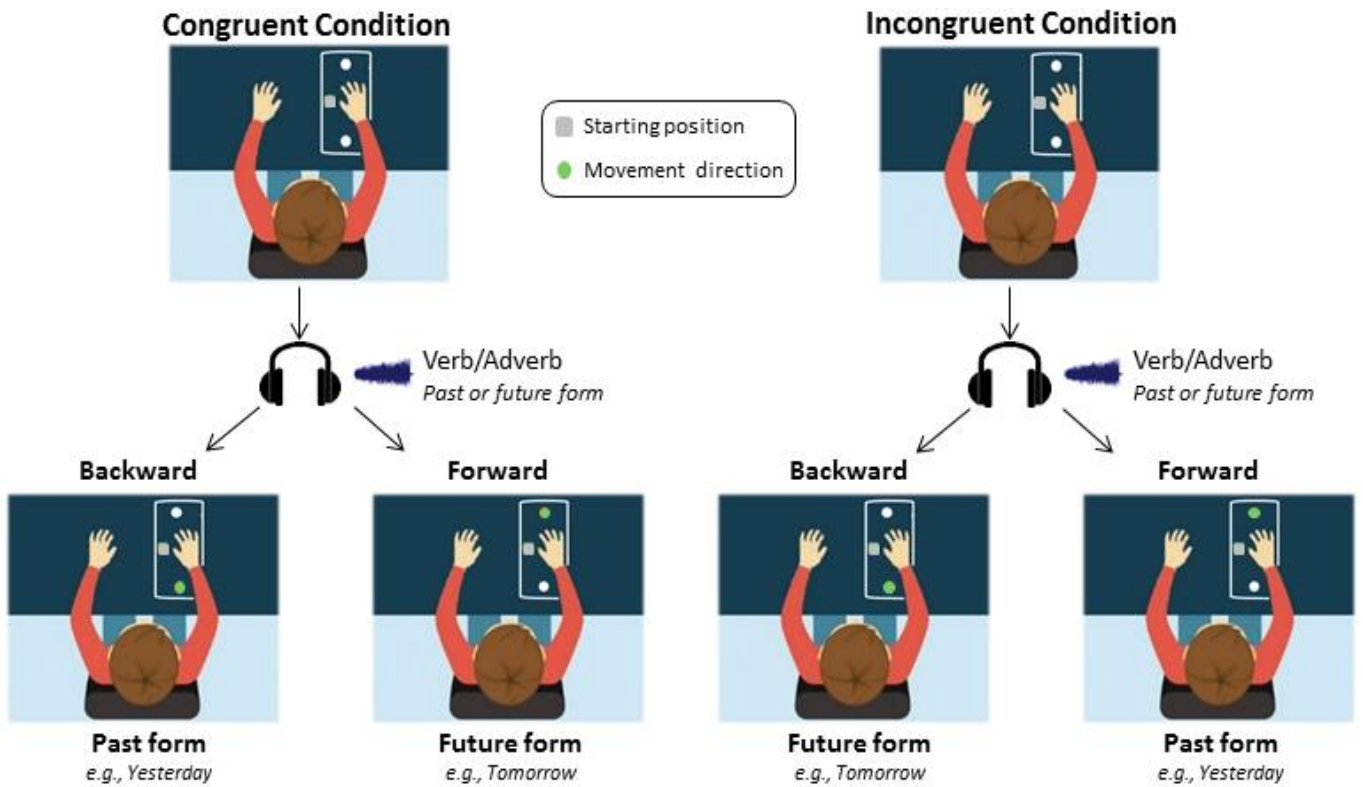


Fig. 1. Apparatus and procedure used for the temporal classification task. Participants were asked to categorize auditorily presented words (verbs and adverbs) as referring either to the past or future by pressing a corresponding response key with their dominant hand. In the congruent condition, participants had to make a backward movement from the starting position in response to past-related words, and a forward movement in response to future-related words (and *vice versa* for the incongruent condition).

2.2.2 Temporal asymmetries questionnaire

In the second task, participants were presented with a questionnaire consisting of 16 items (read aloud by the experimenter) and they were required to think carefully ahead to an event in their future (8 items) and to think carefully back to an event in their past (8 items) (for a similar procedure, see Caruso et al., 2013; Rinaldi et al., 2017). Specifically, the personal events were referred to as occurring at a distance (in the future or in the past, depending on the item) of 1 day, 3 days, 1 week, 3 weeks, 1 month, 3 months, 1 year, 3 years (see Supplemental Material for specific instructions). For each item, participants were asked to express how they considered the event they were thinking about as close to now or far from now (i.e., perceived psychological distance) using a 0 to 10 point Likert scale (ranging from 0=“really close to now” to 10=“really far from now”). Participants were instructed to provide a response within 10 seconds. Past and future

items were intermixed so that an item referring to future was always followed/preceded by an item referring to past, and randomized across participants. Sighted participants were blindfolded throughout the administration of the questionnaire.

2.3 Data analysis

In the temporal classification task, we computed reaction times (RTs) for correct responses and percentage of errors. RTs were computed as the time elapsed between the onset of the auditory word and the onset of the manual movement, that is, release from the central key (trials falling below 250 ms or above 2500 ms were excluded from the analyses; following this criterion, 3.16% of trials were excluded). RTs and error scores were entered into separated repeated measures ANOVAs with condition (congruent, incongruent) as the within-subjects factor and group (blind, sighted) as the between-subjects factor.

In the temporal asymmetries questionnaire, the temporal distance scores were computed by averaging the 8 estimates given to past events and the 8 estimates given to future events, respectively. The temporal distance scores were then entered into a repeated measures ANOVA with time (past, future) as the within-subjects factor and group (blind, sighted) as the between-subjects factor.

3. Results

3.1 Temporal classification task

The 2x2 ANOVA on mean correct RT revealed a significant main effect of condition, $F(1,32)=19.03$, $p<.001$, $\eta^2_p=.37$, no significant main effect of group, $F(1,32)=1.08$, $p>.250$, and a significant interaction group by condition, $F(1,32)=7.03$, $p=.012$, $\eta^2_p=.18$ ¹. Post-Hoc comparisons (Bonferroni correction applied) showed that faster responses were observed to temporal words in the congruent (*mean RT*=1095 ms, *SD*=176) compared to the incongruent condition in sighted

¹ When the block order (congruent first vs. incongruent first) was included in the analyses, no significant main effect or interaction with the other variables was found to be significant.

participants (*mean RT*=1220 ms, *SD*=238; $t(16)=6.05$, $p<.001$), but not in blind participants (*mean congruent RT*=1076 ms, *SD*=164; *mean incongruent RT*=1106 ms, *SD*=191; $t(16)=1.05$, $p>.250$) (see Figure 2; see also Supplemental Figure 1).

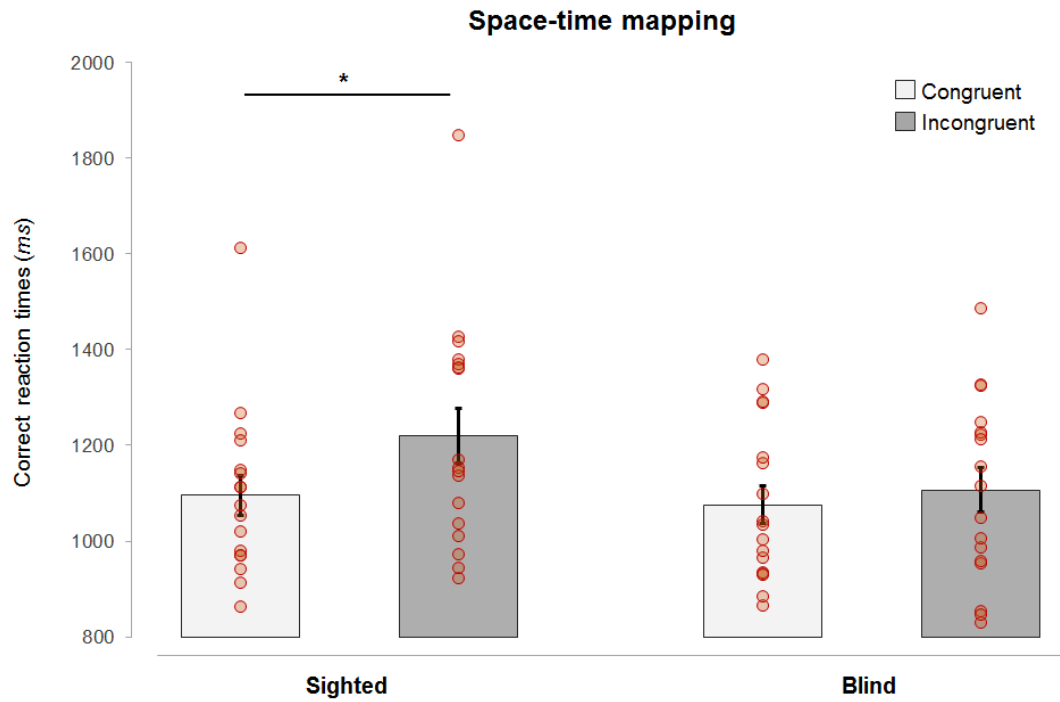


Fig. 2. Mean and individual correct reaction times in the temporal classification task. Responses were initiated faster in the congruent compared to the incongruent condition in sighted participants, who showed a space-time mapping consistent to the ego-moving metaphor of time (i.e., past behind and future in front). Response latencies of blind participants were similar in the two experimental conditions. Error bars show \pm SEM; asterisks indicate a significant difference between conditions ($p<.05$).

The ANOVA on mean percentage of errors did not show any significant effect of group, $F(1,32)=.18$, $p>.250$, $\eta^2_p=.14$, condition, $F(1,32)=3.12$, $p=.087$, and the interaction group by condition, $F(1,32)=.19$, $p>.250$ (see Supplemental Fig. 2).

3.2 Temporal asymmetries

The 2x2 ANOVA on mean temporal distance scores revealed no significant main effect of group, $F(1,32)=.16$, $p>.250$, no significant effect of time, $F(1,32)=1.62$, $p=.212$, $\eta^2_p=.05$, and a significant

interaction group by time condition, $F(1,32)=9.53$, $p=.004$, $\eta^2_p=.23$. Post-Hoc comparisons (Bonferroni correction applied) showed that the sighted individuals perceived the future (*mean distance*=3.19, *SD*=1.73) as psychologically closer than the past (*mean distance*=4.02, *SD*=2.04; $t(16)=3.2$, $p=.025$), whereas no difference in perceived distance for past and future events was observed in blind participants (*mean distance for future*=3.55, *SD*=1.59; *mean distance for past*=3.21, *SD*=1.64; $t(16)=1.24$, $p>.250$) (see Fig. 3; see also Supplemental Fig.3).

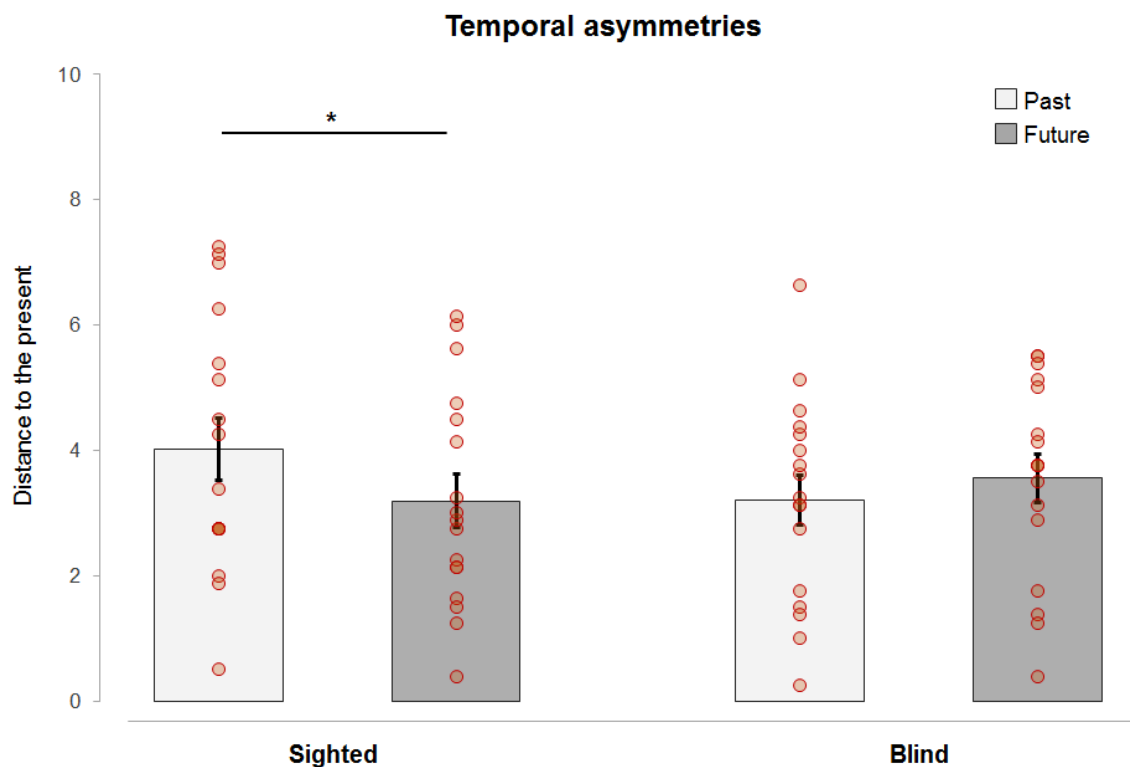


Fig. 3. Mean and individual perceived temporal distances from “present” (i.e., day of test) of imagined past and future events as measured by the temporal asymmetries questionnaire. Sighted participants perceived the future as psychologically closer than the past, whereas no difference in perceived temporal distance of past and future events was found in blind participants. Error bars show \pm SEM; asterisks indicate a significant difference between conditions ($p<.05$).

4. Discussion

When speaking about time, people often tend to borrow words and concepts from the domain of space (Boroditsky, 2000; Clark, 1973). Although the tight relationship between space and time has been found to go beyond the simple extension of word meaning (for a review see Bender & Beller, 2014; Núñez & Cooperrider, 2013), the impact of prior visual experience on the mental time line (MTL) has never been directly investigated before. In this study, we addressed this issue by comparing performance of early blind participants and a matched group of sighted controls on a space-time congruity task. Critically, blind participants did not show a response facilitation when processing temporal words in a direction compatible to the typical spatial mapping of time (i.e., past associated with the back space and future with the front space), while this pattern was observed in sighted participants (see Rinaldi et al., 2016; Sell & Kaschak, 2011; Ulrich et al., 2012). These findings suggest that despite being exposed in everyday life to similar language expressions, visual experience seems to be important for the development of the representation of time along the sagittal space.

When we walk, what we have already experienced tends to be visually located in the space behind us, and what has yet to come tends to be visually located in the space in front of us. This is consistent with the idea that optic flow patterns created on the retina and processed by the entire visual system during locomotion may contribute to the mapping of time along a backward-to-forward oriented sagittal space (Warren et al., 2001). Blind individuals share with sighted participants the experience of past events behind the body and future events in front of the body when walking forward. However, and critically, they do not experience optic flow during locomotion and thus a visual association between space (back and front) and time (past and future). Our findings therefore suggest that the sagittal MTL is likely rooted in a normal visual experience during walking, and specifically in the visuo-locomotor coupling.

The influence of visual experience on time representation is further corroborated by the results of the questionnaire. In this task, the perceived distance to imagined events increased proportionally as a function of the provided (objective) time reference (e.g., one month, three months, etc.) in both sighted and blind participants (see Supplemental Figure 3), ensuring that all participants were adhering to task requirements. Critically though, blind participants did not show the tendency to perceive future events as closer than past ones, as it is the case of sighted participants (Caruso et al., 2013; Rinaldi et al., 2017). Indeed, blind participants judged past and future events as equidistant from the present, supporting the view that asymmetries in temporal perception are grounded in the metaphorical mapping of spatial movement along the depth plane (Boroditsky & Ramscar, 2002; Caruso et al., 2013; Rinaldi et al., 2017). The basis for this association may be related to the fact that in typical forward locomotion, future events are visually associated with diminishing spatial distance, whereas past events are associated with increasing distance from the body (Caruso et al., 2013). Accordingly, the absence of any temporal asymmetry in psychological distance observed in our blind participants suggests that the optic flow visual processing during locomotion may be responsible for the reported temporal asymmetries in sighted individuals.

In considering the hypothesis that the mapping of time along the sagittal space critically depends on optic flow experience, it is important to clarify that traditional mobility aids (such as a white cane) allow a blind individual to experience kinaesthetic flow. However, a white cane can only detect a very limited portion of space (i.e., generally about 1 meter in front of the user). In comparison, when a sighted person walks forward, the eyes can rapidly detect objects both in close and far space, and the person can predict the temporal order in which they will pass them. Hence, vision allows for a more fine-grained relationship between time and sagittal space (Bruggeman, Zosh & Warren, 2007; Warren & Rushton, 2009) compared to other sensory information during locomotion. In this view, it is possible that new sensory substitution devices that provide blind users with longer range distance information (i.e., 5 meters, e.g., the EyeCane

Maidenbaum et al., 2014) compared to traditional aids, would also enhance time mapping into sagittal space in individuals lacking visual input.

Interestingly, previous studies have demonstrated that people develop spatial-numerical and spatial-temporal associations along the horizontal space in the absence of visual experience (Bottini et al., 2015; Cattaneo, Fantino, Silvanto, Tinti, & Vecchi, 2011; Crollen, Dormal, Seron, Lepore, & Collignon, 2013; Rinaldi, Vecchi, Fantino, Merabet, & Cattaneo, 2015). For instance, blind individuals show a typical SNARC (Spatial Numerical Association of Response Codes) effect (Dehaene, Bossini & Giraux, 1993), whereby responses to small numbers are faster in the left side of space, while responses to large numbers are faster in the right side of space (Castronovo & Seron, 2007; Crollen et al., 2013). Similarly, the MTL is oriented from left-to-right, with past events associated with the left side of space and future events with the right side, in both sighted and blind individuals (Bottini et al., 2015). This shared mapping of time along the horizontal dimension in sighted and blind individuals has been ascribed to the direction of reading experience (Casasanto & Bottini, 2014)². Indeed, Braille is read in a rightward direction as with the convention of Western alphabetic text. It is possible that this reading direction promotes the association between earlier/later times and left/right external spatial coordinates, respectively. In light of this, it is important to highlight that the absence of a sagittal MTL in the blind cannot be attributed to a lower predisposition in representing abstract information in a spatial format compared to sighted individuals. Furthermore, the absence of a space-time mapping in the blind is unlikely to depend on a lower task switching cost from the congruent to the incongruent condition compared to the sighted, since in prior studies (Bottini et al., 2015; Castronovo & Seron, 2007; Crollen et al., 2013) the blind participants were as sensitive as sighted participants to the incongruence manipulation. Rather, our findings strengthen the view that visual

² Based on existing evidence in the field of numerical cognition, we can speculate that sighted participants performing the task without the blindfold would show an increased congruency effect compared to when being blindfolded. Indeed, the spatial frame of reference onto which numbers are spatially mapped is more salient when it is visible (e.g., Crollen et al., 2013). Accordingly, the visual feedback of the moving hands during task performance may increase the mapping of temporal information along the sagittal space.

experience plays a crucial role in associating spatial locations to time events in the depth dimension.

Our findings should not be interpreted as suggesting that the sagittal MTL uniquely relies on visual experience. In fact, recent studies have indicated that space-time compatibility effects may emerge at higher cognitive levels (de la Fuente, 2014; Eikmeier et al., 2015). In line with this possibility, languages such as Aymara of the Andes use a sagittal gesture pattern whereby the future is construed as behind the body and the past as in front (Núñez & Sweetser, 2006). This opposite pattern has been explained by the temporal-focus hypothesis, which states that cultural attitudes and practices can shape habits of attending to past or future events and consequently also influencing the spatial representation of time (de la Fuente, 2014). In particular, people would place the time they focus on (i.e., either the future or the past) in front of them. The present findings, therefore, indicate that the way people spatialize time along the sagittal space depends not only on factors residing on higher levels of cognitive processing (i.e., temporal focus), but also on lower level mechanisms such as available perceptual experience.

Despite the fact that humans have a multitude of senses dedicated to perceiving the outside world, there is no sensory organ uniquely dedicated for the perception of time. Hence, humans compensate for the lack of a “time receptor” by sensing this abstract concept through more concrete dimensions that can be physically experienced such as space (e.g., Boroditsky, 2000). Thus, the way we experience space may in turn substantially affect the way we conceive time. Although blind individuals can generate accurate internal representations of the external space on the basis of auditory and haptic information (for reviews, see Cattaneo et al., 2008; Schinazi, Thrash & Chebat, 2016; see also Denis, 2017), their experience of space is qualitatively different from that of the sighted, being mainly anchored to sequential haptic exploration and through auditory input. Interestingly, the results of our questionnaire suggest that blind individuals may perceive time differently (and more specifically, closer) than sighted individuals. It may be that

the reduced spatial extent that can be explored via the tactile (and auditory) modality in the blind also results in a collapse of time. This represents a fascinating hypothesis that deserves further investigation.

In sum, this study provides the first empirical evidence that visual experience plays a key role in binding information about time and space along the sagittal plane. In particular, we provide direct support for the long-standing hypothesis that the ego-moving metaphor of time has a strong experiential basis (Clark, 1973). From an evolutionary standpoint, the fact that blind individuals do not show any space-time compatibility effect may indicate that the way we speak and talk about temporal concepts (such as the expression to *“look forward”*) has possibly evolved from our visual experience during locomotion in the depth space.

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