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Mapping temporal constructs: Actions reveal that time is a place

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Many languages employ metaphors that associate temporal constructs with locations in space (e.g., back in the old days). However, whether such space–time mappings extend beyond the linguistic domain has received little empirical attention. Noting that motor action represents a pathway through which the integration of spatial and temporal information can be revealed, the current work examined the dynamics of hand movements during a time-classification task. Results revealed that when participants were instructed to process information pertaining to the past (or future), their movements were drawn towards the left (or right). This affirms that spatiotemporal processing is grounded in the sensory-motor systems that regulate human movement.

Keywords: Spatiotemporal mapping; Cognitive dynamics; Movement.

Think about time and it is difficult not to entertain simultaneous ideas about space. For example, people routinely report that the past lies behind them (e.g., back in the summer of ’69), the future ahead (e.g., looking forward to the weekend), and that life (i.e., the passage of time) is a journey from one place to the next (Boroditsky, 2000; Lakoff & Johnson, 1980, 1999). Such is the utility of the spatial coding of time that most languages employ metaphors that associate temporal constructs (e.g., past, present, future) with specific locations in space (see Alverson, 1994). Reflecting the mind’s tactic of grounding abstract conceptual knowledge in concrete sensory-motor experiences (Barsalou, 2008; Lakoff & Johnson, 1980, 1999), space–time mapping provides a framework in which temporal understanding can unfold.

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When mentally integrating time with space, people predominantly use the horizontal "back–front" axis both to map temporal constructs to spatial locations (i.e., past = back, future = forward) and to communicate the manner in which the passage of time is experienced (e.g., *ego-moving*-metaphors, *time-moving*-metaphors; see Boroditsky, 2000). According to Lakoff and Johnson (1980, 1999), knowledge of abstract domains—such as time—is tied directly to bodily experiences (i.e., image schemas) and universal sensory-motor processing operations (Barsalou, 2008; Boroditsky, 2000). Underpinning the experiential basis of space–time mapping are morphological constraints (e.g., eyes to the front of the head), which necessitate that image schemas are derived primarily from forward locomotion (Lakoff & Johnson, 1980). Reflecting the significance of this spatiotemporal relationship, recent research has demonstrated that the past–behind/future–ahead mapping of time is spontaneously employed when processing temporal constructs (e.g., Miles, Karpinska, Lumsden, & Macrae, 2010a; Miles, Nind, & Macrae, 2010b; Torralbo, Santiago, & Lupiáñez, 2006).

As it turns out, locating time along the antero-posterior (i.e., "back–front") axis is not the only spatiotemporal mapping available; anecdotal and empirical evidence suggests an additional mediolateral (i.e., "left–right") characterization of space–time. Outside the laboratory, time is commonly depicted as flowing from left to right (e.g., graphs, depictions of hominid evolution, cartoon strips), a space–time mapping that has also been reported in several studies, at least among Western participants. Tversky, Kugelmass, and Winter (1991), for example, demonstrated that when asked to associate events in time (e.g., breakfast, lunch, dinner) with locations in space, American children followed the early–left/late–right ordering of events, whereas Arab children displayed the opposite effect. Replicating and extending these findings, recent work has revealed a bias in the ease with which manual responses can be elicited by verbal stimuli that have temporal implications. Specifically, while past-related words are responded to most quickly with the left hand, future-related words yield a right-hand advantage—an effect that is reversed in Hebrew speakers (Ouellet, Santiago, Israeli, & Gabay, 2010b).

While it is evident that in cultures in which language is written from left to right the past and future are mapped onto corresponding spatial locations, a number of important theoretical questions remain. In particular, is space–time mapping an exclusively linguistic phenomenon? As Weger and Pratt (2008) put it: "Are the spatial connotations specific to how we communicate about time and thus confined to the linguistic domain, or are these spatial implications more general in nature, affecting performance in other (non-linguistic) tasks?" (p. 426). In one of the first attempts to elucidate this issue, Ouellet, Santiago, Funes and Lupiáñez (2010a) used a visual-cueing paradigm to establish whether words with temporal reference direct attention to specific locations in space. The results revealed that activation of past or future concepts both oriented attention and primed motor responses to left or right space, respectively. Thus, even in nonlinguistic task contexts, people continue to use space as a proxy for time.

Extending work of this kind, the current investigation explored space–time mapping in another nonlinguistic domain in which effects may be expected to emerge—movement dynamics. Aside from work exploring the gestural components of space–time mapping (e.g., McNeill, 2005), few laboratory studies have considered how temporal processing may be revealed in people's actions (but see Miles et al., 2010b). This is perhaps surprising given the contention that temporal processing is grounded in the sensory-motor systems that regulate human movement (i.e., temporal processing is embodied, see Barsalou, 2008). Characterized in this way, space–time mapping gives rise to quite specific predictions. Specifically, if: (a) time's arrow (i.e., past = left, future = right) is grounded in a perception–action system that integrates temporal with spatial information (Miles et al., 2010a; Miles et al., 2010b); and (b) embodied constructs can be revealed motorically (Barsalou, 2008), then one would expect that thoughts about the past or future may influence people's movements. In fact, Oliveri et al. (2009) draw a similar conclusion, suggesting that "motor action could represent the link between spatial and temporal dimensions" (Abstract, Conclusions section). To this end, we expect people's movements to be sensitive to the spatial location (i.e., left or right) into which temporal constructs (i.e., past or future) are mapped.

To explore this possibility, we examined the continuous dynamics of people's hand movements during a simple time-categorization task. This technique has been employed to explore a range of phenomena including decision making, language processing, semantic categorization, person construal, and stereotype activation (for overviews see Freeman & Ambady, 2010; Freeman, Ambady, Rule, & Johnson, 2008; Spivey & Dale, 2006; Spivey, Grosjean, & Knoblich, 2005). In brief, this approach requires participants to make a binary classification of target stimuli with a computer mouse (i.e., hand) movement. The trajectory of the movement reveals, in real time, the nature of the cognitive operations that underlie the decision process (Spivey & Dale, 2006). In particular, deviation towards the unselected response option is indicative of dynamic competition between the potential alternatives as the selection of the eventual response unfolds over time.

In the present study we utilized this technique for assessing cognitive dynamics by requiring participants to classify past and future times according to a spatial location (i.e., left or right). It was anticipated that movement trajectories would show greater curvature (i.e., greater attraction to the unselected alternative) when participants were asked to classify future time to the left and past time to the right than for the reverse mapping (i.e., past to the left, future to the right).

Method

Participants and design

Twenty right-handed undergraduates (aged 17–32 years, 15 females) took part in the research in exchange for course credit. All participants were fluent English speakers. The experiment had a single factor (trial type: compatible vs. incompatible) within-participants design and was reviewed and approved by the School of Psychology, University of Aberdeen ethics committee.

Materials and procedure

All testing sessions took place between 12:00 p.m. and 1:00 p.m. in order that past and future were always represented by times prior and subsequent to this period. Two quasi-random lists of times (e.g., 8:54 a.m.) were constructed with the restrictions that for each list only two items were drawn from each one-hour interval between 1:00 a.m. and 11:00 p.m. (e.g., between 1:00 a.m. and 2:00 a.m.), and no items were drawn from the intervals between 12:00 p.m. and 1:00 p.m. or between 12:00 a.m. and 1:00 a.m. In total, each list comprised 44 items, 22 times occurring prior to 12:00 p.m. (i.e., "past" items) and 22 times occurring after 1:00 p.m. (i.e., "future" items). List and trial type (i.e., compatible or incompatible) orders were fully counterbalanced, and target times were presented in a unique random order for each participant.

Participants arrived at the laboratory individually and were told that the study concerned how people process temporal information. It was explained that a time would appear on the screen, which they were to categorize as "past" or "future" within the context of the current day. Participants were instructed to indicate their response as quickly and accurately as possible by clicking, with a mouse, on an appropriate label on the screen. Immediately prior to the start of the procedure the experimenter informed the participant of the current time.

The experiment was conducted using the MouseTracker software package (Freeman & Ambady, 2010) and was run on a standard desktop PC with a 19″ LCD monitor (1,280 × 1,024 pixels). At the beginning of each trial, the label "START" appeared at the bottom-centre of the screen, with the labels "PAST" and "FUTURE" in the top left and right corners. For the compatible trials, "PAST" appeared on the left side of the screen and "FUTURE" on the right, while this was reversed for the incompatible trials. To initiate each trial participants clicked on the "START" label causing the target time (e.g., 1:30 p.m.) to appear and the cursor to be relocated to a fixed starting position in the centre of the label. Participants then used the mouse to move the cursor to the appropriate response (i.e., past or future) and clicked on it to indicate their answer. The cursor remained visible for the duration of each trial. Initially participants performed a short practice block of 4 trials followed by the two test blocks of 44 trials each.

Data collection and preparation

The MouseTracker software package (Freeman & Ambady, 2010) was used to record and process the trajectories of the mouse movements made by participants. The streaming x and y coordinates of the mouse cursor were recorded (sample rate $\approx$ 70 Hz) for each trial. To accommodate intertrial variation in movement time, raw trajectories were time-normalized by linearly interpolating each trial to 101 samples (i.e., time steps). Finally, trials on which participants clicked on the target located on the left side of the screen were rightward remapped (i.e., inverted along the x axis) to permit averaging across trials.

Results

Initially, any trials on which participants made errors (2.2%) or for which the response time exceeded 3,500 ms (0.6%) were excluded from the data.[1] The trajectory of each of the remaining trials was then individually examined for aberrant movements (e.g., multiple gross changes of direction or looping; see Freeman et al., 2008), resulting in a further 1.2% of trials being excluded. Average movement trajectories were then calculated separately for compatible and incompatible trials (see Figure 1).

Two measures of spatial attraction (i.e., the degree of curvature towards the "unselected" response option) commonly used in research of this type (e.g., Freeman et al., 2008; Spivey & Dale, 2006) were computed on a trial-by-trial basis by comparing observed to ideal (i.e., a straight line between the starting point and the target) response trajectories (see Freeman & Ambady, 2010).

Maximum deviation (MD) was calculated as the largest perpendicular deviation from the idealized straight-line trajectory and was compared using a 2 (trial type: compatible vs. incompatible) × 2 (time: past vs. future) repeated measures analysis of variance (ANOVA). This revealed a main effect of trial type, $F(1, 19) = 5.90$, $p < .05$, $\eta_p^2 = .24$ (see Figure 1, upper inset) indicating a greater average MD on incompatible ($M = 0.38$) than on compatible trials ($M = 0.33$). There was no significant effect of time or any interaction between trial type and time.[2]

Area under the curve (AUC) was calculated as the geometric area between the observed and ideal response trajectories and was compared using a 2 (trial type: compatible vs. incompatible) × 2 (time: past vs. future) repeated measures ANOVA. As above, a main effect of trial type was revealed, $F(1, 19) = 8.28$, $p < .05$, $\eta_p^2 = .30$ (see Figure 1, lower inset), indicating a larger average AUC on incompatible ($M = 0.55$) than on compatible trials ($M = 0.42$). Again, there were no other significant effects (see Footnote 2).

Discussion

When asked to classify times representing the past or future according to a spatial location, participants revealed a bias toward locating the past to their left and the future to their right compared to the reverse mapping. Specifically, the trajectory

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[1] Errors (compatible: $M = 0.4$, $SD = 0.8$; incompatible: $M = 0.6$, $SD = 1.1$), movement initiation times (compatible: $M =$ 275 ms, $SD = 106$ ms; incompatible: $M = 286$ ms, $SD = 111$ ms), and response times (compatible: $M = 1{,}236$ ms, $SD =$ 352 ms; incompatible: $M = 1{,}279$ ms, $SD = 376$ ms) were compared using separate 2 (trial type: compatible vs. incompatible) × 2 (time: past vs. future) repeated measures analyses of variance (ANOVAs). No effects were revealed.

[2] Additional analyses were conducted to examine the influence of the temporal distance from present of the target time (binned into hours) for both the MD and the AUC measures. There was no effect of temporal distance from present, nor any interaction with trial type (i.e., compatible vs. incompatible); hence these analyses are not discussed further.

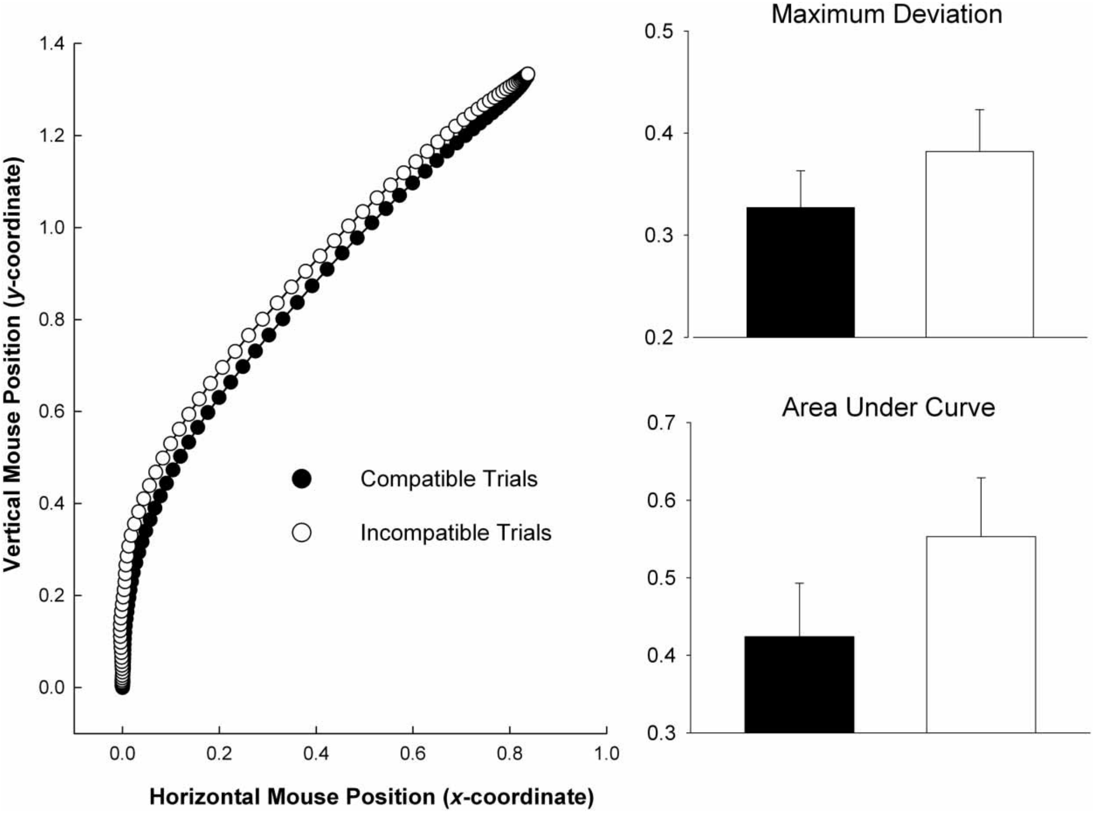

Figure 1. *Mean mouse trajectories (rightward remapped) as a function of trial type (compatible vs. incompatible). Insets show the main effect of trial type on measures of spatial attraction (upper inset = maximum deviation; lower inset = area under curve). Error bars represent 1* SEM.

of hand (i.e., mouse) movements showed a greater degree of curvature towards the unselected (i.e., erroneous) response option when the task context dictated that the future be located to the left and the past to the right. In this way, spatial locations were seen to act as *attractors* for temporal constructs such that when participants were instructed to process information pertaining to the past (or future), their movements were literally drawn towards the left (or right). This result is consistent with research demonstrating spatial mappings of time along the mediolateral axis (e.g., Ouellet et al., 2010b; Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo et al., 2006; Tversky et al., 1991) and extends this work into the domain of movement dynamics. In so doing, the present research reveals that the real-time cognitive operations that support the processing of temporal information can indeed be revealed in patterns of action (Miles et al., 2010b).

Importantly, the design of the present study allows more general explanations pertaining to the spatial representation of other cognitive phenomena to be ruled out. For instance, the spatial−numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993) indicates that when processing numerical information, responding to smaller numbers is faster when made to left side of space, while larger numbers are judged more rapidly when responses are made to the right side of space. Although numbers (i.e., times) were employed in the current study to represent the past and future, SNARC-like effects cannot account for the findings as the magnitude of the numerals themselves was equivalent across the past and future conditions. Moreover, we found no evidence that the temporal magnitude (i.e., amount of time from present) of targets influenced participants' spatial classifications of the past and future (but see Arzy, Adi-Japha, & Blanke, 2009).[3] In this way, we can be confident that the current effects reflect cognitive operations specific to the spatial mapping of time, rather than more general representations of magnitude.

At a theoretical level, the present results draw attention to the utility of assessing movement dynamics in order to expose otherwise hidden cognitive operations (Spivey & Dale, 2006). Complementing more traditional approaches that infer patterns of thought from, for example, linguistic structure or processing efficiency, accessing cognitive activity via movement offers the advantage of online access to the phenomena of interest (Freeman & Ambady, 2010). Thus, instead of relying solely on the outcomes of cognitive operations (e.g., verbal responses, reaction times) to index information processing, examining actions as they unfold in time provides a means to reveal mental events as continuous streams of activity. Indeed, the evidence we present here for the spatial mapping of time was shown by examining participants' movements during the decision-making process—end-point measures (i.e., reaction time, accuracy) did not reveal these effects. In this respect, we suspect that the nature of movement (i.e., occurring in space) provides a direct and temporally relevant means to expose the spatial characteristics of mental events. Such correspondence suggests that movement may serve as an ideal vehicle for examining the spatial component of mental activity (Oliveri et al., 2009).

The current results also have implications for theories of embodied cognition (see Barsalou, 2008; Lakoff & Johnson, 1980, 1999). Beyond demonstrating that the processing of temporal information entails a motoric component (Miles et al., 2010b), here we show that the people's actions can echo specific regularities of their world (e.g., depictions of time "flowing" from left to right). In this way, the processing of intangible concepts (i.e., past, future) are manifest as tangible bodily actions (i.e., movement through space), reflecting not only the mind's tactic of grounding abstract information in more concrete perceptual representations (Barsalou, 2008), but also the embodiment of metaphorical notions of time within the spatial domain (Lakoff & Johnston, 1980, 1999). Interestingly, compared to anteroposterior space−time mappings (i.e., past = back, future = forward), which are argued to be grounded in human morphology (Lakoff & Johnson, 1980, 1999), locating time along the mediolateral axis appears to have sociocultural origins. Although no spoken languages employ metaphors that describe time in this way (Santiago et al., 2007), other conventions (e.g., reading/writing direction) are reported to play a prominent role in determining whether time is seen to flow from left to right or right to left (Santiago et al., 2007; Torralbo et al., 2006; Tversky et al., 1991). In this way, both biological (e.g., morphology) and cultural (e.g., learned associations) factors can potentially shape how the mind embodies abstract representations of temporal information.

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[3] Of course, it is possible that participants may have focused on the a.m./p.m. suffix used to designate past and future when making their judgements, which would not have produced a magnitude effect.

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