Moving Through Time

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Take yourself back to your first proper teenage kiss — pounding heart, sweaty palms and all. Now transport yourself to a future vacation, somewhere on a tropical island with a warm breeze and a cool drink. Chances are that imagining such past and future scenarios is a relatively simple task. Indeed, the apparent ease and flexibility with which we can shift our mind away from the here-and-now showcases the uniquely human capacity for mental time travel (MTT). By reflecting on the past and anticipating the future, we can shape our behavior in order to satisfy both the challenges of daily life and our longer-term goals and ambitions. To date, however, empirical research exploring MTT has primarily been focused on elucidating the neuro-anatomical correlates and conditions that lead to impairments to this social-cognitive ability. Little work has addressed questions regarding the core psychological characteristics of MTT — that is, *how* exactly is the mind transported through time?

In this chapter, we will present recent evidence from our laboratory that demonstrates consistent links between mentally moving through time and physically moving through space. Drawing from the existing literature on embodied cognition, we argue that MTT is grounded in the spatial representation of temporal information (e.g., past = backward, future = forward). To this end, we consider the possibility that the perception-action systems that govern movement through space also provide a scaffold for the mind's journeys through time.

Mental Time Travel

An important facet of day-to-day conscious experience is the capacity to shift attention away from the details of the immediate environment and focus on temporally remote events. Whether day-dreaming about dinosaurs or planning what to wear to the office Christmas party, a good deal of one's mental life is spent entertaining thoughts about things that either have already, or are yet to occur. This faculty for past and future thinking, or as Suddendorf and Corballis (1997, 2007) have termed it, mental time travel (MTT), is believed to serve a pivotal function in human cognition. As well as providing a rich and stimulating inner life, MTT endows the individual with important social-cognitive abilities that enable them to modify their behaviour to fulfil the challenges of daily life (Schacter, Addis, & Buckner, 2007; Tulving, 2002a). For instance, when confronted with complex and challenging judgements (e.g., should I buy stocks or deposit my savings in the bank?), simulating future outcomes (i.e., prospection) on the basis on prior experience (i.e., retrospection) is a tactic which optimizes decision making and behavioural selection (Boyer, 2008; Gilbert, & Wilson, 2007; 2009). In this way, the ability to mentally revisit the past and anticipate the future can be seen to provide a unique opportunity to learn from previous experiences in order to guide subsequent behavior (Kahneman, & Miller, 1986). In fact, it has been suggested that the capacity for MTT is a core component of effective psychological functioning (e.g., Gilbert & Wilson, 2007; Schacter, Addis & Buckner, 2007; Suddendorf & Corballis, 2007; Szpunar, 2010). This claim is perhaps best illustrated by considering the difficulties faced when MTT is impaired.

A Case Study

In a now seminal work in the field of memory research, Tulving (1985) presented the case of patient K.C. who, at the age of 30, suffered a traumatic brain injury as a result of a motorcycle accident. Although a good deal of K.C.'s cognitive faculty was left intact following the injury — for example, his general intelligence and language skills were preserved — he displayed an unusual pattern of memory loss. While he could recount knowledge of the world (e.g., semantic memories) and recite very recently encountered information (e.g., short-term memories), K.C. was unable to recall the details of his personal experiences. He knew, for instance, who the members of his family were but was unable to remember any specific event relating to them. When asked describe occurrences from his past, K.C. simply reported that his mind was blank. This led Tulving to suggest that K.C. displayed a total loss of episodic memory (i.e., memories of personally experienced events). Notably however, K.C. also reported the “same kind of blankness” (p. 4) when asked to contemplate personally relevant future events, such as what he might do the next day. Put simply, K.C. had lost the ability to travel mentally through time. In the same way he was unable to revisit past experiences, he was also unable to prospectively look into the future, leaving his mind perpetually stranded in the here-and-now.

Past and Future Thinking

The case of K.C. has had a notable impact with respect to theories of human cognition (Rosenbaum et al., 2005). Of particular relevance to the present chapter, the apparent symmetry between the impairment to the retrospective and prospective aspects of K.C.’s memory has also been observed in other contexts. For instance, deficits in the ability to imagine past and future episodes have been linked not only to brain damage, but also to aging and mental illness. When asked to generate details of imagined events, older adults report fewer episodic but more semantic details than their younger counterparts (Addis, Wong, & Schacter, 2008). Importantly, this effect is equivalent for both past and future scenarios. Aging therefore appears to influence both retrospective and prospective thinking to a comparable degree (Spreng & Levine, 2006). In much the same way, relative to control participants, individuals with schizophrenia typically recall fewer episodes from the past and display consistent difficulties in generating specific future events (D’Argembeau, Raffard, & Van der Linden, 2008). Indeed, patient populations who characteristically experience poor episodic memory also tend to display a simultaneous inability to vividly imagine their future (Szpunar, 2010).

In fact, the link between past and future cognition is also evident in healthy individuals. Suddendorf (2010), for instance, demonstrated that 3-4 year old children who were able to accurately report what they had done yesterday were also more likely to be able to generate ideas about what they would do tomorrow. Similarly, Szpunar and McDermott (2007) reported that the vividness with which college students imagined future scenarios depended on the degree of perceptual detail that aspects of this imagery were represented in memory. Indeed, episodic future thinking characteristically features familiar contextual information; that is, information drawn from past experiences (Spreng & Levine, 2006). These findings point to a commonality between the cognitive mechanisms that support retrospective and prospective thinking. More specifically, the ability to think about future events appears to rely on the sampling of details about past experiences (i.e., the constructive episodic simulation hypothesis; Addis, Wong & Schacter 2008; Buckner & Carroll, 2006; Szpunar, 2010). Mental time travel, therefore, can be conceptualized as the flexible reconstruction of the content of episodic memory.

Neural Correlates of MTT

Alongside the cognitive and behavioral work that has demonstrated consistencies between past and future thinking, there has been a surge of interest in identifying the neural correlates of MTT. Primarily via functional magnetic resonance imaging (fMRI) techniques, a core network of brain regions has been identified that is used not just for remembering the past, but is also active when creating mental simulations of future events. For instance, in a study representative of the area, Szpunar, Watson, and McDermott (2007) scanned the brains of participants while they silently imagined past and future events (e.g., birthdays). Irrespective of the temporal location of the imagery, a very similar set of same brain regions were engaged. Specifically, in a recent review Buckner and Carroll (2007) reported that, whilst thinking about hypothetical situations concerning either the past or the future regions of the medial prefrontal cortex, posteromedial parietal cortex, and the medial temporal lobes are consistently engaged. These authors argued that this core network, previously established as basis for memory retrieval, also contributes the contents used to simulate a future scenarios. In this way, retrospection and prospection are seen to rely on largely overlapping neural structures (Szpunar et al., 2007; Schacter, Addis, & Buckner, 2007; Bar, 2009; Buckner, & Carroll, 2007).

In summary, the striking similarities between past and future thinking, with respect to both the overlapping neural structures and the consistent relationship between the characteristics of retrospection and prospection provide solid grounds to suggest that recollection guides simulation during instances of MTT. What remains unclear however, is quite how episodic thoughts are linked to moments in subjective time. That is, how does the mind distinguish between the past and the future?

Thinking About Time

A challenging issue for cognitive science concerns the manner in which the mind apprehends abstract concepts, in particular time (Barsalou, 2008; Lakoff & Johnson, 1980, 1999). Although we can never experience time via our sensory systems — time cannot be directly seen, touched or heard — we nevertheless successfully navigate through time-dependent worlds. We meet deadlines, remember birthdays, and never mistake the past for the future. But how is this so? How can we so effortlessly comprehend abstract information that has no direct referent in the world? One suggestion is that in order to understand the abstract components of the environment, our mind translates such concepts into more concrete domains (e.g., Lakoff, & Johnson, 1980; 1999). Boroditsky and Ramscar (2002), for example, argue that abstract knowledge is represented in terms of information that can be directly experienced. In this sense, abstract notions of time are often characterized in terms of the more concrete domain of space. In much the same way as we tend to map numbers to space (i.e., mental number lines, Dehaene, Izard, Spelke, & Pica, 2008), time is frequently imbued with spatial properties (Casasanto, & Boroditsky, 2008). For instance, cultural conventions dictate that time flows in a particular direction (e.g., graphs, cartoon strips), people situate life events along an imaginary time-line (Arzy, Adi-Japha, & Blanke, 2009), and patterns of language tend to prescribe temporal concepts to spatial locations (e.g., past = backwards, future = forwards; Boroditsky 2000). As such, it is argued that we are able to understand time through knowledge and experiences within the more concrete domain of space (Boroditsky, & Ramscar, 2002; Casasanto, & Boroditsky, 2008; Ramscar, Matlock, & Boroditsky, 2009). The frequent use of metaphoric language that associate space and time reflects this relationship.

Space-Time Metaphors

Everyday language typically features an abundance of conceptual metaphors that describe temporal constructs in spatial terms (Boroditsky, 2000). In English, for example, people routinely report that the past is 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 (e.g., a long vacation, a short concert; Alverson, 1994). Moreover, the passage of time is often also given spatial qualities such that people are thought of as moving through time (i.e., ego-moving metaphor) or, conversely, that time flows past the individual (i.e., time-moving metaphor). In fact, the metaphorical link between time and space is even reflected in non-verbal behavior whereby gestures that accompany temporal language are systematically aligned with spatial properties (e.g., direction, distance; Nunez & Sweetser, 2006). Of particular interest to the current work, the relationships between space and time that feature in metaphoric language also influence the how temporal information is processed.

Space-Time Cognition

The metaphorical relationship between space and time is reflected in the way time is cognitively represented (Tolman, 1948). 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. Casasanto and Boroditsky (2008) reported that judgements of temporal duration were dependent upon spatial information. Importantly, this work employed a non-linguistic task suggesting that metaphorical space-time relationship observed in language also exists in the more basic representations of distance and duration.

When mentally integrating time with space, people commonly locate temporal constructs along a horizontal plane (i.e., front-back, left-right). In fact, a growing body of research demonstrates that just such mappings of time (e.g., past = behind, future = in front) are spontaneously employed when processing temporal information. Torralbo, Santiago, and Lupiáñez (2006) presented participants with a silhouette of a human head displayed in profile (i.e., looking either rightward or leftward) and a speech bubble containing a time-relevant word (e.g., yesterday). The location of the speech bubble was either congruent (e.g., yesterday was located behind the silhouette) or incongruent (e.g., yesterday in front of the silhouette) to the meaning of the word. Participants were asked to make a vocal judgment about whether the 'person' (i.e., silhouette) was thinking about the past or the future. The results indicated that responses were facilitated when the word location was congruent with the past-behind/future-ahead mapping.

As it turns out, locating time along the anteroposterior (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. For example, Tversky, Kugelmass, and Winter (1991) asked English speaking American children and Arabic speaking Israeli children to associate events in time (e.g., breakfast, lunch, dinner) with locations in space. They found that all the children spontaneously mapped time to space in a systematic manner. Consistent with the direction of written language, the English-speaking children followed the early-left/late-right ordering of events, whereas the Arabic-speaking children displayed the opposite effect. Ouellet, Santiago, Israeli, and Gabay (2010b) replicated and extended these findings, revealing 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). While the precise pattern of space-time mappings appears to vary according to sociocultural conventions (Boroditsky, Fuhrman, & McCormick, 2011), it nevertheless appears to be a universal tactic.

Movement and MTT

In both everyday language and in non-linguistic task contexts, people use space as a proxy for time. Evidence for space-time mapping in other domains however has received little empirical attention. To this end, we have initiated a programme of research that is aimed at evaluating how temporal thinking might be grounded in the perception-action systems that regulate human movement. Contemporary theories of embodied cognition posit a coupling between higher-order cognitive processes and lower level bodily actions (Barsalou, 2008). Characterizing the process of mental time travel in this way yields some interesting behavioural predictions. Specifically, if: (a) the metaphorical arrow of time is grounded in a perception-action system which integrates temporal with spatial information; and (b) embodied constructs can be revealed motorically (Barsalou, 2008), then one would expect that thoughts about the past or future (e.g., episodes of MTT) may influence people's movements. Put simply, travelling mentally through time may initiate associated bodily movements through space.

In fact, Oliveri et al. (2009) draw a similar conclusion, suggesting that, "motor action could represent the link between spatial and temporal dimensions" (p. 1). Thus, people's movements should be sensitive to the spatial location (i.e., left or right) into which temporal constructs (i.e. past or future) are mapped. Moreover, 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 association suggests that movement may serve as an ideal vehicle for examining the spatial component of mental activity (Oliveri et al., 2009). Noting the gap in this area of research, we conducted a series of experiments which investigated the possibility that movement represents a pathway through which the integration of spatial and temporal information can be revealed. Guided by the viewpoint that higher cognitive activity can have a sensory-motor grounding, here we report three studies that explore the relationship between mentally moving through time and physically moving through space.

Mouse-Tracking

To explore the possibility that actions provide insight into the cognitive processes that support the comprehension of time, we initially examined the continuous dynamics of people's hand movements during a simple time-categorization task. In brief, this approach draws from a dynamical approach to cognition whereby cognitive activity is seen not as a series of discrete logical operations, but rather a self-organized, continuously emerging pattern of neural activity (Spivey & Dale, 2006). One important implication of this approach is the claim that people's movements are coupled, in real-time, with their mental operations. Therefore, an understanding of the dynamics of their movements will also provide insight into their cognition. Research adopting this approach typically requires participants to make classifications of target stimuli by enacting movements (e.g., computer mouse movement, eye 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 an unselected response option is indicative of dynamic competition between the potential alternatives as the selection of the eventual response unfolds over time.

We utilized this technique for assessing cognitive dynamics by requiring participants to classify past and future times (within the context of the current day) according to a spatial location (i.e., left or right). Specifically, we evaluated the extent to which people spontaneously associated the past with left and the future with right using the MouseTracker software package (Freeman & Ambady, 2010). 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. On compatible trials, "PAST" appeared on the left side of the screen and "FUTURE" on the right, while this was reversed for the incompatible trials. Upon clicking the "START" label the target time appeared on screen, which the participants were required to classify. 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).

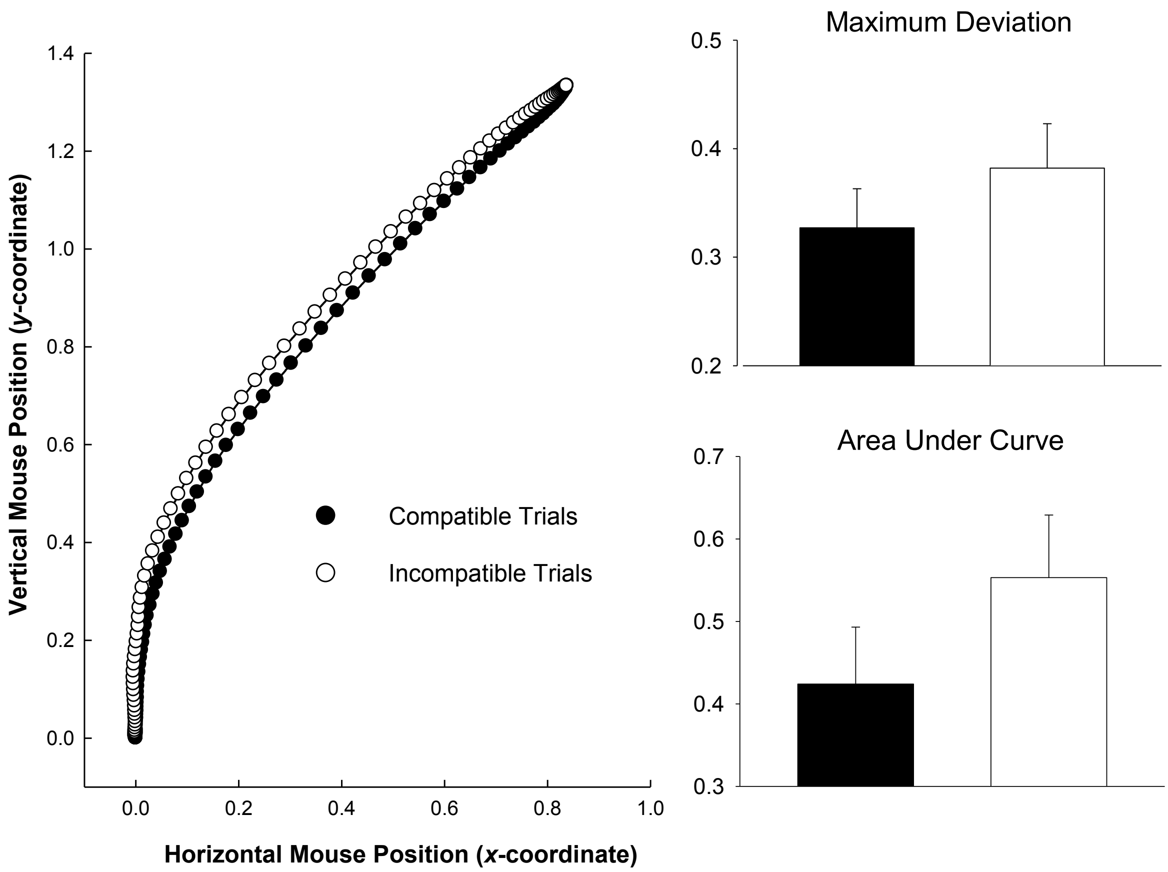

Figure 1. Mean mouse trajectories (right-ward remapped) as a function of trial type (compatible vs. incompatible). Insets show the main effect of trial type on measures of spatial attraction. The upper inset displays Maximum Deviation (the largest perpendicular deviation from the idealized straight-line trajectory) and the lower inset displays Area Under Curve (the geometric area between the observed and ideal response trajectories). Error bars represent 1 SEM.

Indeed, the results revealed a bias toward locating the past to the left and the future to the right compared to the reverse mapping (see Figure 1). Specifically, the trajectory 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 location was seen to act as an *attractor* 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, this research reveals that the real-time cognitive operations that support the processing of temporal information can indeed be revealed in patterns of action.

Swaying in Time

On the basis that people's movements are able to reveal the way they think about time, our second study examined how temporal information is processed when one revisits the past or anticipates the future. If MTT entails a coupling of thought and action, episodes of retrospection and prospection may be accompanied by backward and forward motion, respectively. To explore this possibility, we measured spontaneous fluctuations in the magnitude and direction of postural sway whilst individuals engaged in MTT over a 15 second period. Specifically, participants were instructed to stand comfortably on a designated spot and to follow specific imagery instructions: either (a) to recall what their everyday life circumstances had been like 4 years previously and to envisage the events of a typical day or (b) to imagine what their everyday life circumstances might be like 4 years in the future and to envisage the events of a typical day at that time. Participants were asked to wear a blindfold in an effort to encourage more vivid imagery and increase the magnitude and variability of postural sway (Riley, Balasubramaniam, Mitra, & Turvey, 1998). Postural sway was measured using a magnetic motion tracking system, with a sensor attached at the knee. The results indicated that participants who engaged in retrospective thought moved backward but those who thought about the future moved forward (see Figure 2).

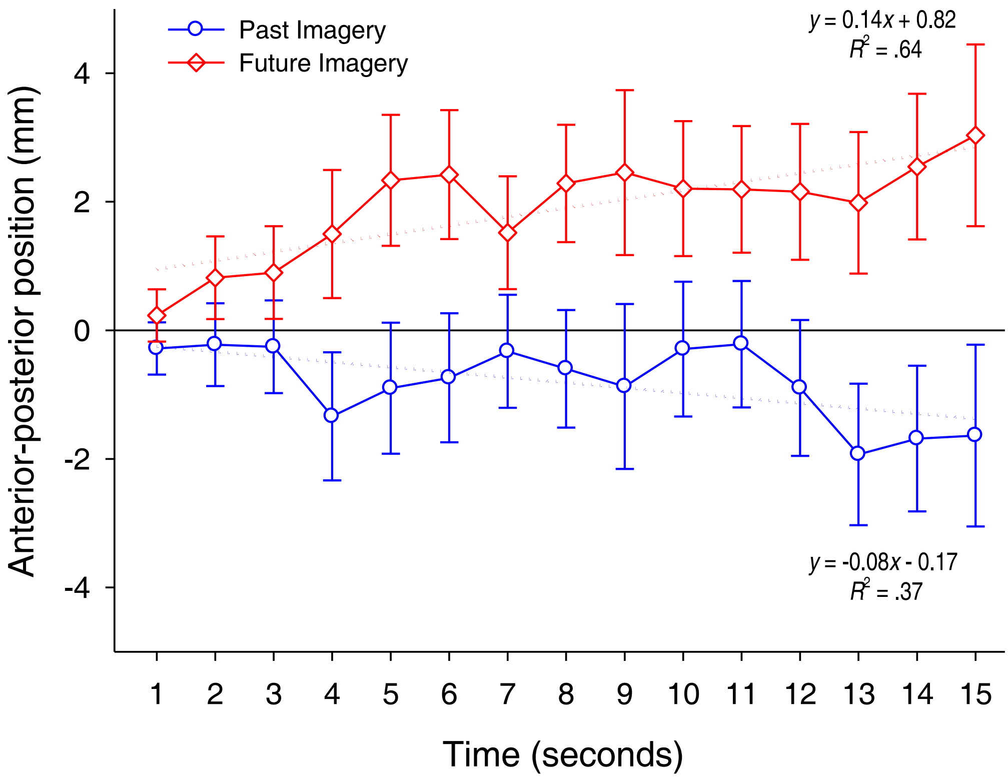

Figure 2. Mean change in participant anterioposterior position over time as a function of condition (i.e., past vs. future thought). Error bars represent ±1 SEM.

Thus, these results demonstrate that mental time travel has an observable behavioural correlate; the direction of people's movements through space. As with the MouseTracker study, the embodiment of time and space yielded an overt behavioural marker of an otherwise invisible mental operation. What is more, this behavior (i.e., postural sway) was entirely consistent with the patterns of space-time mappings that feature in metaphoric language (i.e., past = backward, future = forward).

Space Travel and Time Travel

On the basis that travelling mentally through time entailed associated movements in space consistent with the direction of time travel, we conducted a third study designed to evaluate the converse relationship. That is, does moving through space influence the temporal locus of mental activity? Extant accounts of embodiment point to a bi-directional relationship between, for instance, thoughts and actions (Barsalou, 2008; Maass, 2009; Mussweiller, 2006). Therefore, if thinking about the future produces forward movement, does forward movement also produce future-oriented thoughts?

In this study, participants were informed that they would be required to monitor a moving display for designated targets and to click a mouse button when they detected a target (O) but to withhold clicking when a distracter (X) appeared. However, the targets were rare over the course of the 6 minute task, only 6 were presented, thereby creating a somewhat dull context in which daydreaming was expected to occur (Mason, Norton, Van Horn, Wegner, Grafton, & Macrae, 2007). Importantly, the target were embedded in a dynamic visual display that conveyed *vection*, the illusion of self motion (Dichgans & Brandt, 1978; Owen, 1990). Vection is a common experience in daily life. Consider, for example, sitting on a stationary train and observing a carriage on an adjacent track begin to move. This situation can trigger a compelling impression that it is oneself, rather than the nearby train that is moving. Of relevance to the current inquiry, comparable sensations of self-motion can be elicited by visual displays depicting simple patterns of optical flow (Gibson, 1979; Trutoiu, Mohler, Schulte-Pelkum, & Bülthoff, 2009). To this end, we employed a basic star-field animation, common to many computer screensavers, in which the stars appeared to move either towards (i.e., centripetal inflow) or away from (i.e., centrifugal outflow) the center of the display (see Figure 3). This manipulation has the effect of inducing backward or forward linear vection, respectively (Trutoiu et al., 2009).

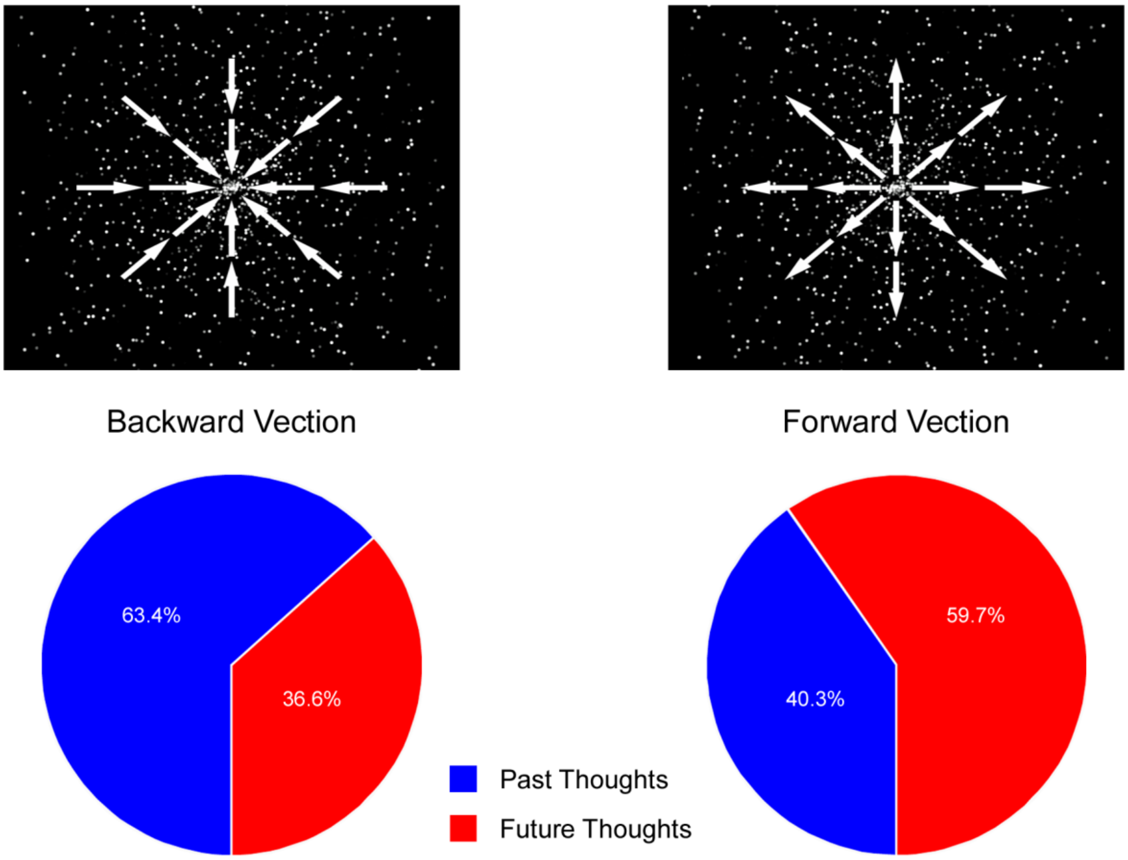

Figure 3. Illustrations of the direction of optical flow (i.e., centripetal vs. centrifugal) specified by the star-field displays (top panels) and the proportion of past- compared to future-oriented task-unrelated thoughts reported by participants (bottom panels) as a function of vection condition (i.e., backward vs. forward).

Following the vigilance task, the contents of the participants' mind wandering experiences were probed. After screening out one individual who reported no off-task thinking, the remaining participants were asked to estimate what proportion of their daydreams were related to past compared to future events. The results revealed that the direction of apparent motion influenced the temporal focus of mental time travel (see Figure 3). When viewing the backward vection display, participants reported a greater preponderance of thoughts about the past, while those who saw the forward vection reported more thoughts about the future. In other words, the direction of apparent motion modulated the temporal locus of MTT.

Conclusions

In this chapter, we have highlighted research and ideas from two distinct domains of enquiry concerning MTT. First, neuroscience research has revealed that past and future episodic thinking relies on common neural substrates and cognitive mechanisms (e.g., Gilbert & Wilson, 2007; Schacter, Addis & Buckner, 2007; Suddendorf & Corballis, 2007; Szpunar, 2010). Second, work on abstract thinking suggests that in order to comprehend notions of time people routinely map temporal constructs to the spatial domain (e.g., Boroditsky, 2000; Casasanto, & Boroditsky, 2008; Lakoff, & Johnson, 1980, 1999). Moreover, we have drawn together these ideas and, in the context of a dynamic, embodied approach to cognition, sought to understand if spatiotemporal mapping provides a framework by which the mind navigates through time. To this end, we have used movement dynamics as a window to the cognitive activity that supports MTT. Across three studies, we have demonstrated that when thinking about temporal constructs, people's actions are consistent with the spatial properties ascribed to time. Specifically, when thinking about past and future times of the day participants' arm movements were attracted to the left and right side of space respectively; when thinking about past or future episodes participants tended to move backwards or forwards respectively; and when exposed to apparent backward or forward motion participants tended to think of the past or future, respectively. Collectively, these studies suggest that the core cognitive capacity of mental time travel may be grounded in the embodiment of spatiotemporal information.

References:

Addis, D. R., Wong, A. T., & Schacter, D. L. (2007). Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsycholoia, 45*, 1363-1377.

Addis, D. R., Wong, A. T., & Schacter, D. L. (2008). Age-related changes in the episodic simulation of future events. *Psychological Science, 19*, 33-41.

Alverson, H. (1994). *Semantics and experience: Universal metaphors of time in English, Mandarin, Hindi, and Sesotho*. Baltimore: John Hopkins University Press.

Barr, M. (2009). The proactive brain: memory for predictions. *Philosophical Transactions of the Royal Society of Biological Sciences, 364*, 1235-1243.

Barsalou, L. W. (2008). Grounded-cognition. *Annual Review of Psychology, 59*, 617-645.

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition, 75*, 1-28.

Boroditsky, L., & Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychological Science, 13*, 185-189.

Boyer, P. (2008). Evolutionary economics of mental time travel? *Trends in Cognitive Science, 12*, 219-224.

Buckner, R. L., & Carroll, D. C. (2007). Self-projection and the brain. *Trends in Cognitive Sciences, 11*, 49-57.

Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition, 106*, 579-593.

D'Argembeau, A., Raffard, S., & Van der Linden, M. (2008). Remembering the past and imaging the future in schizophrenia. *Journal of Abnormal Psychology, 117*, 247-251.

Dehaene, S., Izard, V., Spelke, E., & Pica, P. (2008). Log or linear? Distinct intuitions of the number scale in Western and Amazonian indigene cultures. *Science, 320*, 1217-1220.

Dichgans, J., & Brandt, T. (1978). Visual-vestibular interaction: Effects on self-motion perception and postural control. In R. Held, H. W. Leibowitz, & H. Tueber (Eds.), *Handbook of sensory physiology* (Vol. 8). Berlin: Springer-Verlag.

Freeman, J. B., & Ambady, N. (2010). MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior Research Methods, 42*, 226–241.

Gardiner, J. M. (1988). Functional aspects of recollective experience. *Memory and Cognition, 16*, 309-313.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Gilbert, D. T., & Wilson, T. D. (2007). Prospection: Experiencing the future. *Science, 317,* 1351-1354.

Gilbert, D. T., & Wilson, T. D. (2009). Why the brain talks to itself: Sources of error in emotional prediction. *Philosophical Transactions of the Royal Society of Biological Sciences, 364*, 1335-1341.

Hassabis, D., Kumaran, D., Vann, D. S., & Maguire, E. A. (2007). Patients with hippocampal amnesia cannot imagine new experiences. *Proceedings of the National Academy of Sciences, USA, 104*, 1726-1731

Kahneman, D., & Miller, D. T. (1986). Norm Theory: Comparing reality to its alternatives. *Psychological Review, 93*, 136-153

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought*. Chicago: University of Chicago Press.

Maass, A. (2009). Culture's two routes to embodiment. *European Journal of Social Psychology, 39*, 1290-1293.

Mason, M.F., Norton, M.I., Van Horn, J.D., Wegner, D.M., Grafton, S.T., & Macrae, C.N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science, 315*, 393-395.

Mussweiler, T. (2006). Doing is for thinking. *Psychological Science, 17*, 17-21.

Oliveri, M., Bonni, S., Turriziani, P., Koch, G., Lo Gerfo, E., Torriero, S., et al. (2009). Motor and linguistic linking of space and time in the cerebellum. *PLos ONE, 4*, e7933. doi:10.1371/journal.pone.0007933.

Ouellet, M., Santiago, J., Funes, M. J., & Lupiáñez, J. (2010a). Thinking about the future moves attention to the right. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 17-24.

Ouellet, M., Santiago, J., Israeli, Z., & Gabay, S. (2010b). Is the future the right time? Experimental Psychology, 57, 308-314.

Owen, D. H. (1990). Lexicon of terms for the perception and control of self-motion and orientation. In R. Warren & A. H. Wertheim (Eds.), *Perception and the control of self-motion* (pp. 33-50). Hillsdale, NJ: Lawrence Erlbaum.

Rajaram, S. (1993). Remembering and knowing: Two means of access to the personal past. *Memory and Cognition, 21*, 89-102.

Ramscar, M., Matlock, T., & Boroditsky, L. (2009). Time, motion, and meaning: The experiential basis of abstract thought. *The Spatial Foundations of Language and Cognition, 17,* 66-82.

Rosenbaum, R. S., Köhler, S., Schacter, D. L., Moscovitch, M., Westmacott, R., Black, S. E. et al. (2005). The case of K.C.: contributions of a memory-impaired person to memory theory. *Neuropsychologia, 43*, 989-1021.

Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: The prospective brain. *Nature Reviews Neuroscience, 8*, 657-667

Schacter, D. L., Addis, D. R., & Buckner, R. L. (2008). Episodic simulation of future events: Concepts, data, and applications. *Annuals of the New York Academy of Sciences, 1124*, 39-60.

Spreng, R. N., & Levine, B. (2006). The temporal distribution of past and future autobiographical events across the lifespan. *Memory and Cognition, 34*, 1644-1651.

Suddendorf, T. (2010). Linking yesterday and tomorrow: Preschoolers ability to report temporally displaced events. *British Journal of Developmental Psychology, 28*, 491-498.

Suddendorf, T., Addis, D. R., & Corballis, M. C. (2009). Mental time travel and the shaping of the human mind. *Philosophical Transactions of the Royal Society of Biological Sciences, 364*, 1317-1324.

Suddendorf, T., & Corballis, M. C. (2007). The evolution of foresight: What is mental time travel, and is it unique to humans? *Behavioural and Brain Sciences, 30*, 299-351.

Szpunar, K. K. (2010). Episodic Future Thought: An Emerging Concept. *Perspectives on Psychological Science, 5*, 142-162.

Szpunar, K. K., & McDermott, K. B. (2008). Episodic future thought and its relationship to remembering: Evidence from rating of subjective experience. *Consciousness and Cognition, 17*, 330-334.

Szpunar, K. K., Watson, J. M., & McDermott, K. B. (2007). Neural substrates of envisioning the future. *Proceedings of the National Academy of Sciences, USA, 104*, 642-647.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*, 189-208.

Torralbo, A., Santiago, J., & Lupiáñez, J. (2006). Flexible conceptual projection of time onto spatial frames of reference. *Cognitive Science, 30*, 745-757.

Trutoiu, L. C., Mohler, B. J., Schulte-Pelkum, J., & Bülthoff, H. H. (2009). Circular, linear, and curvilinear vection in a large-screen virtual environment with floor projection. *Computers and Graphics, 33*, 47-58.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology, 26*, 1-12.

Tulving, E. (2002a). Chronesthesia: Conscious awareness of subjective time. In D. T. Stuss & R. C. Knight (Eds.), *Principles of frontal lobe function* (pp. 311-325). New York: Oxford University Press.

Tulving, E. (2002b). Episodic memory: From mind to brain. *Annual Review of Psychology, 53*, 1-25.