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Short Communication

The mental time line: An analogue of the mental number line in the mapping of life events

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ABSTRACT

A crucial aspect of the human mind is the ability to project the self along the time line to past and future. It has been argued that such self-projection is essential to re-experience past experiences and predict future events. In-depth analysis of a novel paradigm investigating mental time shows that the speed of this "self-projection" in time depends logarithmically on the temporal-distance between an imagined "location" on the time line that participants were asked to imagine and the location of another imagined event from the time line. This logarithmic pattern suggests that events in human cognition are spatially mapped along an imagery mental time line. We argue that the present time-line data are comparable to the spatial mapping of numbers along the mental number line and that such spatial maps are a fundamental basis for cognition.

1. Introduction

Where were you on your last birthday? What where you doing while hearing about September 11? What did you eat last night for dinner? Your life is the events you experience (deVries & Watt, 1996; Schroots & Assink, 2005; Schroots, van Dijkum, & Assink, 2004). The conscious re-experience of yourself at these specific moments, so-called "episodic" memory, is believed to be a neurocognitive system, distinct from other memory systems, that enables human beings to remember past events (Tulving, 1984, 2002). It was argued that episodic thinking is crucial not only for the ability to "project" one's self mentally in time in order to re-experience the past, but also to pre-experience the future (Atance & O'Neill, 2001; Schacter & Addis, 2007; Schacter, Addis, & Buckner, 2007; Suddendorf & Corballis, 2007; Szpunar, Watson, & McDermott, 2007; Tulving, 2002). In addition, recent studies showed that the temporal-distance (TD) between one's self-location in time to an event ("how long ago" an event occurred; TD-effect) is also associated with the ability to "project" oneself mentally to a moment in past or future, rather than the mere storage of that actual event as in episodic memory ("when and what") (Rubin & Schulkind, 1997; Spreng & Levine, 2006). However, it is not known what role such TD effects play in the cognitive processing of the mental time. Here, we analyzed TD effects during the re-experiencing and pre-experiencing of own life events.

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2. Methods and results

In order to investigate the potential role of TD effects in the mental time, we performed an in-depth analysis of a recent data set on self-projection in mental time (Arzy, Molnar-Szakacs, & Blanke, 2008) obtained in Lausanne, Switzerland in summer 2007. In different conditions, 14 healthy university graduates participants (seven males, aged 29–38 years; mean ± SD,

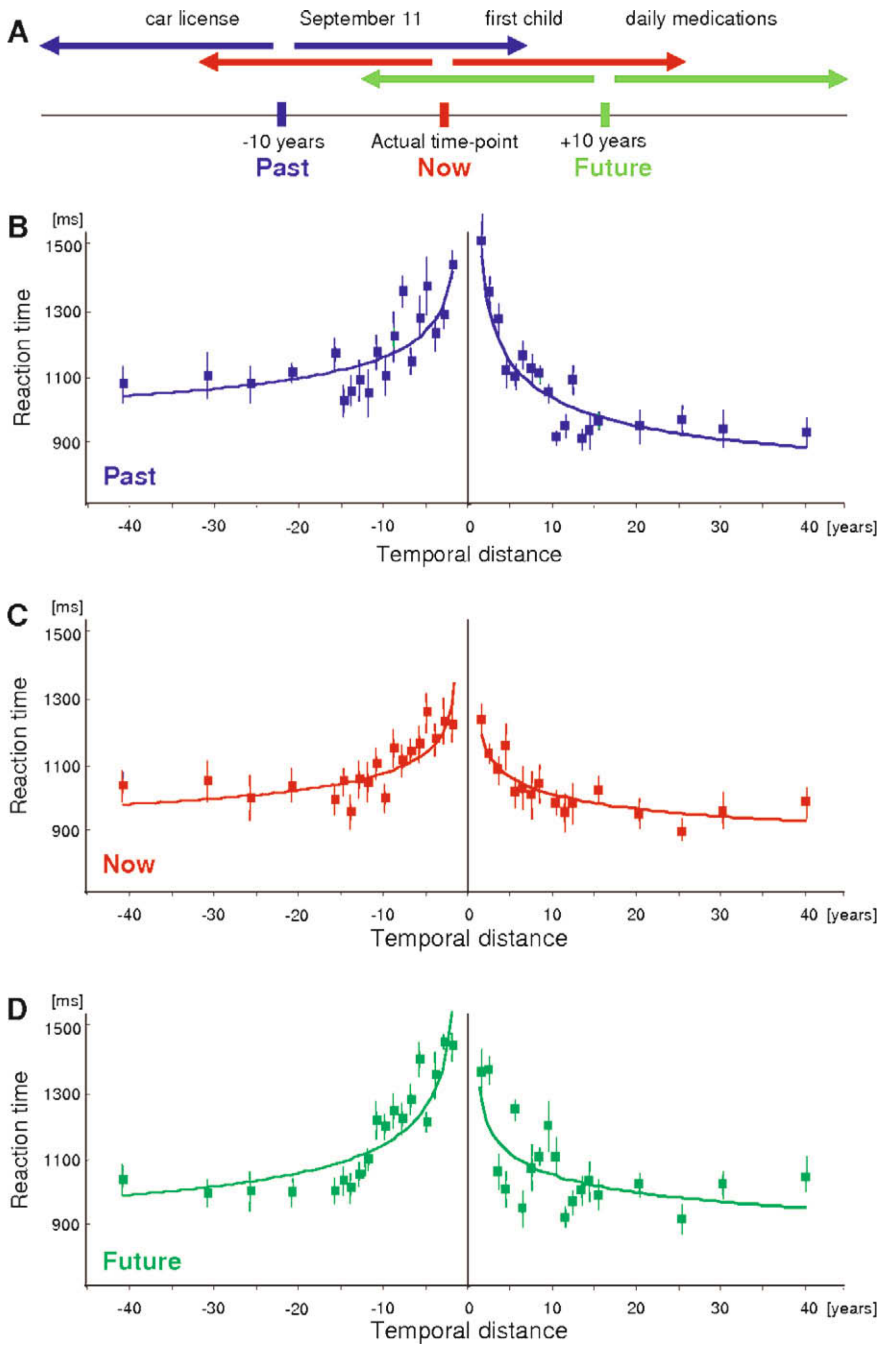

Fig. 1. (A) Participants were presented with different events that could either happen in the past (obtaining car license, September 11) or are previewed to happen in the future (probable use of daily medications, birth of first child). From the present time (red) as well as from past (blue) and future (green) self-location in time they had to judge if these events already happened or not. (B–D) Reaction times are plotted here as function of the temporal-distance between the presented event and the imagined self-location in time (error-bars show the standard error of the mean). This analysis shows a logarithmic decreasing dependence of reaction times on temporal-distance. This pattern was independent of the imagined time-point showing similar patterns for past and future events. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
R^2 and β_{log} weights for the logarithmic regressor in a multiple regression analysis in each condition. Both reaction times (RTs) vs. log-transformed temporal-distance (TD) and log-transformed RTs vs. log-transformed TD are given. Significance (p) values are given as well as standard error (SE) of the mean.

	Relative past		Relative future	
	R^2	β (SE)	R^2	β (SE)
RT vs. Log |TD|				
Past	.63	−99.86 (18.54)***	.84	−147.16 (17.45)***
Now	.58	−77.08 (15.90)***	.72	−68.82 (11.47)***
Future	.66	−136.68 (23.88)***	.47	−92.50 (26.17)**
Log RT vs. Log |TD|				
Past	.61	−.09 (.02)***	.83	−.14 (.02)***
Now	.47	−.09 (.02)***	.70	−.08 (.01)***
Future	.60	−.17 (.03)***	.42	−.08 (.03)**

** p<.01,
*** p<.001.

31.5 ± 2.9 years) were asked to "project" themselves to three different locations in time: present time (now), 10 years ago (past), or 10 years ahead (future). They were then presented with different life events (either personal life events or world history events (Rappaport, Enrich, & Wilson, 1985)) (Fig. 1A) appearing as two-words phrases on a computer screen (for detailed experimental procedure see (Arzy et al., 2008)). Participants were asked to indicate if these events took place before (relative-past) or after (relative-future) the imagined self-location in time (Fig. 1A). We reported previously that reaction times (RTs) and accuracy were similar in the past and future conditions (1135.6 ± 46.7 ms and 1137.6 ± 46.4 ms, respectively) but slower and less accurate than in the now condition (1073.6 ± 49.3 ms). Moreover, participants were always faster and more accurate for relative-future (1103.6 ± 45.1 ms) than for relative-past (1129.6 ± 49.9 ms). Here we investigate the relation between reaction times and TD in mental time.

In an in-depth analysis we investigated whether RTs varied as a function of the TD between imagined and experienced event. This was done for personal life events as well as world history events (Rappaport et al., 1985). For each condition (past, now and future), the presented events (120 events for each condition) were classified for each participant according to the TD (in years) between her imagined self-location in time and the time of the event. A linear regression model was not found to represent the participants' RTs. Rather, in all conditions, regardless of one's imagined self-location in time (past, now or future) a regression equation of the of the participants' RTs as a function of the log-transformed absolute value of TD showed a negative coefficient (Table 1; Fig. 1B–D), and RT distributions were positively skewed. Statistical pairwise comparison of RT distributions using the Kolmogorov–Smirnov test did not show any significant difference, suggesting similar distributions of the log-transformed RTs over conditions. Accordingly, for all conditions, Pearson product moment correlation analysis of the log-transformed TD revealed a significant negative correlation between participants' RTs and the TD of both personal and world events (after log-transforming of TD: all r's > .64, p's < .01; Log-transformed RTs and log-transformed TD: all r's > .63, p's < .01; Correlation of the non-transformed data did not reach significance: all r's > .43, p's < .1). We note that this was found for relative-past and relative-future events and thus independent of what time period our participants were asked to imagine as the experimental present time. These behavioral data show that – independently of the imagined self-location in time (past, present, or future) – RTs to life events logarithmically depend on the TD between the imagined self-location in time and the presented life event, demonstrating that TD may play a larger role in self-projection in mental time and episodic thinking (Rubin & Schulkind, 1997; Schroots & Assink, 2005; Schroots et al., 2004; Spreng & Levine, 2006) as previously thought (Addis, Wong, & Schacter, 2007; Arzy et al., 2008; Buckner & Carroll, 2007; Okuda et al., 2003; Schacter & Addis, 2007; Schacter et al., 2007; Szpunar et al., 2007).

3. Discussion

RTs were found to be longer for past and future self-locations in time than in the now self-location. Seminal work regarded mental time as "episodic thinking" – a combination of self-related episodic memory recall and episodic future imagination (Addis et al., 2007; Atance & O'Neill, 2001; Okuda et al., 2003; Schroots & Assink, 2005; Tulving, 1984, 2002), whereas more recent authors proposed that mental time can be seen as "self-projection" in time, similarly to "self-projection" in space, emphasizing the role of visuo-spatial perspective taking, spatial navigation, and mental imagery in mental time (Arzy et al., 2008; Buckner & Carroll, 2007; Hassabis, Kumaran, Vann, & Maguire, 2007). The current results support the latter proposal, as "self-projection" in time was found to be similar to past and future, and different from the now where judgements do not involve such "self-projection" in time.

Logarithmic curves were previously shown to fit the relation between TD and memory retention, as logarithmic curves characterize the distribution of the correct recall of events from different points in time (Rubin & Schulkind, 1997; Spreng & Levine, 2006). Our data extend these data by showing that cognitive performance (RT with respect to events) was decreasing logarithmically as TDs to the events increased. Moreover, both abovementioned studies investigated the TD effect for different events from the present time. This was different in the present study as we asked our participants to also imagine a time-point in the past and the future as an experimental present time. We found that the same logarithmic pattern is found when a human imagines himself to be located at another self-location in time, either in past or future. Thus, an event that occurred 12 years ago required a shorter RT when retained from the future or the now self-location in time (as its TD is 22 or 12 years from the experiencer imagined self-location in time). However, if retained from the past, the same event required a longer RT, as its TD from the imagined self-location in time is now only 2 years. Our results therefore suggest that similar mechanisms that relate events in different TDs to the present time are used to re-map these events with respect to the imagined self-location in time (Maylor, Chater, & Brown, 2001). This behavioural pattern also shows that participants did not use mental calculation strategy in order to solve the task as for given events simpler calculations (i.e. closer to one's self-location in time) require longer reaction time. Mental calculation should have led to the opposite effect. In addition, while asked to use a mental calculation strategy and not self-projection in time, none of the participants (in a small separate experiment in five subjects) was able to perform the task in the given interstimulus interval of 2000 ms. This shows that mental calculation cannot account for the behavioural results recorded in the mental-time task. We therefore propose that humans automatically represent different events as well as their own self-location in time on a "mental time line". On this mental time-line facility of access to these events is changing with the change of the subject's imagined self-location in time.

Our findings may also relate to logarithmic scaling observed when performing numerical calculations. Thus, experiments on mental number scaling in archaic cultures, children, and adults have revealed the mapping of numbers along a logarithmic scale (Banks & Hill, 1974; Dehaene & Cohen, 1995; Dehaene, Izard, Spelke, & Pica, 2008; Siegler & Booth, 2004). As this logarithmic scaling of numbers suggested that humans are mapping numbers onto space on a so-called "mental number line" (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999), the logarithmic scale found in our data on mental time might hint on similar mechanism of spatial mapping for the processing of mental time. Our data suggest that such a spatial mapping may also be present during processing of events in different TDs from one's actual or imagined self-location on such a time line. Hence, we propose the term "mental time line" to capture that humans spatially map events in real and imagined past and future on an imagined time line. Self-projection in time (Buckner & Carroll, 2007) might then be perceived as imagining oneself located in a specific point on such a mental time line. Finally, this similarity between mental time and mental number is also supported by neuroimaging studies, as both kinds of studies identify underlying brain mechanisms in inferior parietal cortex (Addis et al., 2007; Arzy et al., 2008; Buckner & Carroll, 2007; Dehaene & Cohen, 1995; Dehaene et al., 1999; Spreng, Mar, & Kim, 2009).

We conclude that when imagining time and their own and other life events, humans do not only retrieve or predict when events have occurred or will occur, but also automatically "project" themselves as well as different events on an imagined mental time line. Processing of these events depends logarithmically on the TD between these events and the actual or imagined self-location in time of the subject who is experiencing them. Shared logarithmic effects in mental time and mental number suggest similar, and potentially more elementary, spatial mechanisms to underlie both these cognitive faculties.

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