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Experiencing past and future personal events: Functional neuroimaging evidence on the neural bases of mental time travel

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Abstract

Functional MRI was used in healthy subjects to investigate the existence of common neural structures supporting re-experiencing the past and pre-experiencing the future. Past and future events evocation appears to involve highly similar patterns of brain activation including, in particular, the medial prefrontal cortex, posterior regions and the medial temporal lobes. This result seems to support the view of a common neurocognitive system, which would allow humans to mentally travel through time. Past events recollection was associated with greater amplitude of hippocampal and anterior medial prefrontal hemodynamic responses. This result is discussed in terms of the involvement of the self in the conscious experience of past and future events representations. More generally, our data provide new evidence in favour of the idea that re- and pre-experiencing past and future events may rely on similar cognitive capacities.

Keywords: Mental time travel; Autobiographical memory; Pre-experiencing; Event-related fMRI; HRF estimation analysis

1. Introduction

Tulving's theory of episodic memory postulates a neurocognitive system defined by both its content (personally experienced events spatially and temporally located) and the specific state of consciousness that accompanies retrieval (autonoetic consciousness; Tulving, 2001; Tulving, 2002). The equal inability of the patient KC to think about any part of his past or his future was observed 20 years ago by Tulving (1985); Tulving, Schacter, McLachlan, & Moscovitcch, 1988), who also suggested that the episodic memory system supports the ability to mentally travel through time (Tulving, 2001; Tulving, 2005; Wheeler, Stuss, & Tulving, 1997). The notion of mental time travel (MTT) has been extensively developed by Suddendorf and Corballis (1997), and refers to human beings' capacity to both *re-experience* episodes from one's personal past, and *pre-experience* possible events that may occur in the future (see also Atance & O'Neill, 2001; Suddendorf, 2006; Suddendorf & Busby, 2003; Tulving, 2001; Wheeler et al., 1997). Despite the distinct temporal orientation existing between these two MTT components, various lines of research suggest that they may rely on the same cognitive capacities. Firstly, developmental research has shown that the ability to recall personal events from the past and the ability to predict future events emerge in tandem, between age three to five (e.g. Busby & Suddendorf, 2005). Secondly, the factors influencing autobiographical recollection phenomenology, such as emotional valence, temporal distance, and visual imagery, seem to have similar effects on the phenomenology associated with projecting oneself into the future (D'Argembeau & Van Der Linden, 2004; D'Argembeau & Van Der Linden, 2006). A third line of evidence comes from brain-damaged patients who experience difficulties in both recalling experiences from their past, and imagining events that are likely to take place in their personal future (Klein, Loftus, & Kihlstrom, 2002; Tulving, 1985). Finally, some functional neuroimaging data reveal that past and future thinking share common cerebral bases (Okuda et al., 2003; see below).

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Functional neuroimaging studies of autobiographical memory often reveal a widespread left-predominant cerebral network showing, particularly, the involvement of the medial prefrontal cortex (PFC), the medial temporal lobes (MTL) and posterior regions (Addis, Moscovitch, Crawley, & McAndrews, 2004; Conway et al., 1999; Denkova, Botzung, Scheiber, & Manning, 2006a; Denkova, Botzung, Scheiber, & Manning, 2006b; Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004; Levine et al., 2004; Maguire & Frith, 2003a; Maguire & Mummery, 1999; Maguire, Mummery, & Büchel, 2000; Piefke, Weiss, Zilles, Markowitsch, & Fink, 2003; Piolino et al., 2004).

By contrast, little is known about the neural substrates sustaining future events and consequently about the existence of common neural structures underlying past events and future planning. The PFC has been hypothesized to be involved in planning future events (Fuster, 2001) and more generally in mental time travel (Levine, 2004; Wheeler et al., 1997). The clinical study by Fellows and Farah (2005) is more specific regarding the prefrontal area involved in future thinking. Based on a comparison between normal controls and dorso-lateral and ventromedial PFC brain-damaged patients, impairment in a generation task of future life events was exclusively shown in the last group of patients. This result pointed out the importance of the medial PFC in planning future events. Some clinical research also suggested MTL involvement in planning future events. Indeed, Tulving (1985) and Klein et al. (2002) reported patients who were unable to anticipate future events together with their inability to retrieve past events. In the case of Tulving's patient, MRI data showed a severe bilateral hippocampal and parahippocampal atrophy (Rosenbaum, McKinnon, Levine, & Moscovitch, 2004; Rosenbaum et al., 2000).

The neuroimaging study carried out by Okuda et al. (2003) appears to be the first that included tasks involving past and future components. The PET results indicated that past and future thinking share common cerebral bases that largely involve medial frontal and medial temporal lobe areas. Complementarily, modulation in these regions was also reported according to the temporal direction and/or temporal distance, which may result from the differences observed in the contents of the thoughts, since the subjects talked with no constraint about their past and future.

In the present study, we aim at characterizing the network of brain regions specifically and conjointly activated during *re-experiencing* past events and *pre-experiencing* future events. With this purpose, we matched past and future tasks as closely as possible in terms of feeling of experience, spatio-temporal specificity and time-periods: we used an event-related design that allowed us to consider only the "yes" responses in both directions and we conducted region of interest (ROI) study to refine our analyses of similarities and differences between past and future responses. Based on the sparse data from the literature (commented on above), our hypothesis is that the medial PFC and the medial temporal lobes will be activated during both re- and pre-experiencing past and future events.

2. Materials and methods

2.1. Participants

Ten right-handed volunteers (five females, mean age 34.5 years, *SD* 5.14, range 25–40) participated in the experiment. The education level was similar (mean 18.9 years of education, *SD* 2.08). They had been screened to exclude neurological or psychiatric conditions that might affect brain function. They all gave informed written consent prior to participation. The study was performed under a protocol approved by the Alsace (France) Ethics Committee for the Protection of People taking part in Biomedical Research.

2.2. Tasks and experimental design

Participants reported on past and future events the day before scanning. Data were collected individually; the participant was asked to freely recall and describe 20 events that occurred during the last week, and 20 projects that were planned for the week following the scanning experiment. Similarly to past events, the notion of a project was defined to the participants as being a potential future episode, that is, a detailed mental representation of an event, associated with a specific spatio-temporal context, with the difference being that they were planned or very likely to occur over the next week. This time-period was chosen on the basis of a preliminary behavioural study (30 subjects) indicating that the subjects provided a significantly greater number of past and future events for a period of one week, in comparison with periods of six months or one year. The participants were instructed to be precise regarding the spatial and temporal context and to give as many details as possible once the past event or future project was conjured up. Past events and future projects were directly controlled for spatial and temporal specificity and details during the pre-scanning interview by means of a one- to five-point scale initially used to score the modified Crovitz Test (Crovitz & Schiffman, 1974; Graham & Hodges, 1997; Hodges & Ward, 1989). Briefly, the scores were: 2, poorly detailed generic events; 3, richly detailed generic events; 4, poorly detailed specific event; 5, richly detailed specific event (scores 0 and 1 from the one- to five-point scale were not applicable to the present experiment). The interview ended once 20 past events and 20 future projects, all scored 5, had been obtained. Each of them was summarized by the subject using two cue-words, as a code for subsequent evocation (e.g. museum-exposition).

Each of the two experimental conditions ('past' and 'future') comprised four sequences of 7 stimuli, five pairs of cue-words plus two distracters. The latter corresponded to pairs of cue-words belonging to other subjects and were introduced to ensure that the subjects' attention was con-