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Mental time travel into the past and the future in healthy aged adults: An fMRI study

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ABSTRACT

Remembering the past and envisioning the future rely on episodic memory which enables mental time travel. Studies in young adults indicate that past and future thinking share common cognitive and neural underpinnings. No imaging data is yet available in healthy aged subjects. Using fMRI, we scanned older subjects while they remembered personal events (PP: last 12 months) or envisioned future plans (FP: next 12 months). Behaviorally, both time-periods were comparable in terms of visual search strategy, emotion, frequency of rehearsal and recency of the last evocation. However, PP were more episodic, engaged a higher state of autonoetic consciousness and mental visual images were clearer and more numerous than FP. Neuroimaging results revealed a common network of activation (posterior cingulate cortex, precuneus, prefrontal cortex, hippocampus) reflecting the use of similar cognitive processes. Furthermore, the episodic nature of PP depended on hippocampal and visuo-spatial activations (occipital and angular gyri), while, for FP, it depended on the inferior frontal and lateral temporal gyri, involved in semantic memory retrieval. The common neural network and behavior suggests that healthy aged subjects thought about their future prospects in the past. The contribution of retrospective thinking into the future that engages the same network as the one recruited when remembering the past is discussed. Within this network, differential recruitment of specific areas highlights the episodic distinction between past and future mental time travel.

1. Introduction

Episodic memory is the only memory system that allows individuals to mentally travel in subjective time, into either the past or the future (Tulving, 2002, 2005). This ability depends on autonoetic consciousness which mediates an individual's awareness of his or her existence and identity in subjective time. Converging lines of evidence from different fields of research indicate that remembering the past or envisioning the future share common cognitive and neural underpinnings. First, developmental studies suggest that the level of awareness for episodic remembering and the ability to identify with future interests develops around ages three to four (Atance & O'Neil, 2001; Levine, 2004; Wheeler, Stuss, & Tulving, 1997). Second, age-related changes seem to affect similarly the quality of past and future mental evocations, with older adults generating fewer details for past and future events compared to younger adults (Addis, Wong, & Schacter, 2008). Third, neuropsychological case studies have shown that patients with hippocampal lesions have difficulties in remembering their personal past, but also in foreseeing their personal future (patient KC, Tulving, 1985; patient DB, Hassabis, Kumaran, Vann, & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002), their productions lacking in episodic details compared to age-matched controls (Addis, Sacchetti, Ally, Budson, & Schacter, 2009; Gamboz et al., 2010). Fourth, certain phenomenological characteristics similarly affect past and future mental thinking, such as positive emotional valence and temporally close events which are associated with a stronger feeling of re-experiencing or pre-experiencing (Addis et al., 2008; D'Argembeau & Van der Linden, 2004; D'Argembeau & Van der Linden, 2006; Gamboz, Brandimonte, & De Vito, in press). Most recently, a growing number of neuroimaging studies detect a common neural network when thinking about the past or the future (Buckner & Carroll, 2007; Hassabis & Maguire, 2007, 2009; Schacter & Addis, 2007).

Main results from the neuroimaging literature indicate a striking overlap between past and future thinking, especially during the elaboration phase, attributable to common cognitive processes (Addis, Wong, & Schacter, 2007; Botzung, Denkova, & Manning,

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2008; D'Argembeau et al., 2008; Hassabis, Kumaran, & Maguire, 2007; Okuda et al., 2003; Spreng & Grady, 2010; Szpunar, Watson, & McDermott, 2007; Weiler, Suchan, & Daum, 2010). Indeed, past and future representations are intimately linked to the self, mediated, in particular, by the medial prefrontal cortex (Gusnard, Akbudak, Shulman, & Raichle, 2001; Kelley et al., 2002; Northoff & Bermpohl, 2004). Both past and future event constructions are strongly dependent on visual mental imagery, which increases the number of details retrieved and the subjective sense of remembering (Greenberg & Rubin, 2003), attributable to activity in the precuneus (Cavanna & Trimble, 2006; Fletcher et al., 1995). The ability to visualize complex spatial scenes is also necessary to mentally construct past or future events, reliant on activity in the posterior cingulate cortex (Hassabis, Kumaran, & Maguire, 2007; Szpunar, Chan, & McDermott, 2009; Szpunar et al., 2007). Past and future representations require the binding of details into a coherent event mediated by the medial temporal lobe, including the hippocampus (Eichenbaum, 2001). Its role in recombining details of past events during episodic autobiographical recollection has been shown previously (Viard et al., 2007, 2010) and extended to novel integration of details into coherent future events (Addis et al., 2007; Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Hassabis, Kumaran, & Maguire, 2007).

Different hypotheses have been proposed to account for this common core network. On one hand, Buckner and Carroll (2007) speculate that self-projection (i.e., the ability to mentally project oneself from the immediate present into a simulation of another time, place or perspective) may underlie the common brain network shared by past and future thinking, and other cognitive domains (theory of mind and navigation). A complementary idea, the "constructive episodic simulation hypothesis" formulated by Schacter and Addis (2007), posits that past and future events build on similar information stored in episodic memory and rely on similar cognitive processes (i.e., self-referential processing, imagery and flexible recombination of stored details). Novel events could, hence, be generated by reassembling and flexibly recombining stored event details. On the other hand, Hassabis and Maguire (2007) show that imagination, which may not depend on self-related nor on time-related processes, relies on the same brain regions. They propose that scene construction (i.e., the process of mentally generating and maintaining a complex and coherent scene or event) may better explain the commonalities in the brain areas engaged.

Although sharing remarkable similarities, both at the cognitive and neural level, past and future events obviously differ in that past events represent real experiences, while future events are based on predictions and estimations, reflected by differences at the phenomenological level. Past events contain more visual and other sensory details than future events (Addis et al., 2008; Anderson & Dewhurst, 2009; D'Argembeau & Van der Linden, 2004, 2006), in line with the "reality monitoring framework" which posits that memories of real events include more sensory and contextual details than memories for imagined events (Conway, Pleydell-Pearce, Whitecross, & Sharpe, 2002; Johnson, 1991; Johnson & Raye, 1981). Moreover, participants experience past events with a clearer representation of contextual (spatial and temporal) information, with a more coherent story, and perceive the event more from a field perspective compared to future events (D'Argembeau & Van der Linden, 2006). Conversely, future simulations are rated as being more positive and personally significant compared to past events, indicating the existence of an optimistic bias towards the future (Addis et al., 2008; D'Argembeau and Van der Linden, 2006; Sharot, Riccardi, Raio, & Phelps, 2007). Past and future evocations also change as people get older and, although all age groups produce intentions, those of older people take place closer to the present, become less frequent as time from present increases (Spreng & Levine, 2006) and tend to contain less episodic details than younger adults (Addis et al., 2008). Up to now, no study has yet compared brain activation during past and future thinking in older people.

In this study, we used functional imaging to examine brain activations while projecting into the past or the future, in an older population. In the scanner, upon presentation of a cue-phrase prompting a specific past or future event (obtained by questioning a close family member), participants were asked to mentally recall specific events from the past 12 months and specific plans they intended to pursue in the next 12 months. Our first aim was to assess whether past and future thinking shared common neural bases in healthy aged people. Our second aim was to determine, if a neural overlap was observed, how it could be explained by the phenomenological quality of the events produced. Debriefing was particularly thorough as past and future mental evocations were rated on a five-point episodic scale, as well as on the mental strategy used, the quality and number of mental images retrieved, perspective taken, emotional intensity and valence. To test the idea of mental time travel in subjective time and examine the influence of retrospective thinking, additional scales not previously used in neuroimaging studies examining the future evaluated the state of consciousness, frequency of rehearsal and recency of last evocation.

2. Materials and methods

2.1. Participants

Twelve right-handed (as measured by the Edinburgh handedness inventory) healthy females (mean age ± SD = 67.2 ± 5.2 years; ranging from 60 to 75 years old) with no history of psychiatric or neurological disorder were recruited through a university, a retirement association or a newspaper advertisement. To obtain a homogeneous group, we recruited only females. Indeed, gender-related differences have been shown to affect both the behavioral (Goddard, Pring, & Felmingham, 2005) and neural levels (Piefke & Fink, 2005) of autobiographical recollection. The study was approved by the Regional Ethics Committee and written informed consent was obtained from all subjects prior to their participation in the study. Participants had no abnormality on their T1-weighted high-resolution magnetic resonance imaging (MRI). They underwent a battery of neuropsychological tests to assess their cognitive abilities and all performed in the normal range (see Viard et al., 2007, for a full description). Each participant resided at home and all were active in cultural pursuits, continuing education or with responsibilities in diverse associations. The present data were obtained as part of a broader experiment exploring five past periods previously published (Viard et al., 2007, 2010). Here, we present new results concerning the future period (next 12 months) and compare them to the mirroring past period (i.e., past 12 months).

2.2. Task and experimental design

A few weeks before the scanning session, a close family member was interviewed on the participant's specific life events and future plans. On the day of the scanning session, a training period preceded the functional scan which was followed by a debriefing. Personal sentence-cues were elaborated from the family member's prior interview and cues were visually presented in white on a black background, using Superlab software (3.0 version, Cedrus). Upon presentation of the visual cue, participants were instructed to recall or envision a specific detailed event, unique in time and space, that had either occurred in the past 12 months (past period, PP) or was scheduled in the next 12 months (future period, FP). For