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Neural correlates of event clusters in past and future thoughts: How the brain integrates specific episodes with autobiographical knowledge

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ABSTRACT

When remembering the past or envisioning the future, events often come to mind in organized sequences or stories rather than in isolation from one another. The aim of the present fMRI study was to investigate the neural correlates of such event clusters. Participants were asked to consider pairs of specific past or future events: in one condition, the two events were part of the same event cluster (i.e., they were thematically and/or causally related to each other), whereas in another condition the two events only shared a surface feature (i.e., their location); a third condition was also included, in which the two events were unrelated to each other. The results showed that the processing of past and future events that were part of a same cluster was associated with higher activation in the medial prefrontal cortex (PFC), rostrolateral PFC, and left lateral temporal and parietal regions, compared to the two other conditions. Furthermore, functional connectivity analyses revealed an increased coupling between these cortical regions. These findings suggest that largely similar processes are involved in organizing events in clusters for the past and the future. The medial and rostrolateral PFC might play a pivotal role in mediating the integration of specific events with conceptual autobiographical knowledge 'stored' in more posterior regions. Through this integrative process, this set of brain regions might contribute to the attribution of an overarching meaning to representations of specific past and future events, by contextualizing them with respect to personal goals and general knowledge about one's life story.

Introduction

The capacity to envision events that could happen in the future has attracted a growing interest in the past few years, probably due to the increasing recognition of its importance in the regulation of human behavior (Schacter et al., 2012; Seligman et al., 2013; Suddendorf and Corballis, 2007; Szpunar, 2010). Findings from cognitive, neuropsychological, and neuroimaging research have accumulated rapidly, such that we now have a reasonably clear understanding of the cognitive and neural processes that support the mental representation of individual future events (Schacter et al., 2012; D'Argembeau, 2012; Mullaly and Maguire, 2014). Recent research suggests, however, that future-oriented thinking involves more than imagining isolated events and often consists in considering a set of related events (D'Argembeau and Demblon, 2012; Demblon and D'Argembeau, 2014, in press). The processes involved in linking and organizing imagined events in coherent themes and sequences are not fully understood, and our aim here is to explore the neural bases of knowledge structures that contribute to these event clusters.

Neuroimaging studies have revealed that the recall of past events and the imagination of future events involve a common set of frontal, temporal, and parietal regions (for a recent meta-analysis, see Benoit and Schacter, 2015). Within this core network, regions such as the medial temporal lobe and retrosplenial cortex are thought to support the construction of specific event representations based on episodic details (Schacter and Addis, 2007; Hassabis and Maguire, 2007), whereas other regions (such as the lateral temporal cortex) may store semantic knowledge that provides a coherent scaffolding for constructing such representations (Irish et al., 2012; Irish and Piguet, 2013; Duval et al., 2012). In addition to these brain regions involved in the representation of individual events, other regions within the core network might support the processing of higher-order autobiographical knowledge, which provides a framework for linking imagined events and organizing them in personal themes and stories.

Conway (Conway and Pleydell-Pearce, 2000; Conway, 2005; Conway et al., 2004) has proposed that autobiographical memory is organized in a hierarchy in which specific event representations are part of "general event" representations, which bind a set of specific events on the basis of their thematic similarity and causal relations (see also Barsalou, 1988; Thomsen, 2015). Research has shown that this kind of general autobiographical knowledge is frequently accessed both when recalling specific past events (Haque and Conway, 2001) and when

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imagining specific future events (D'Argembeau and Mathy, 2011). Furthermore, there is evidence that general autobiographical knowledge contributes to organize specific memories and future thoughts in coherent themes and causal sequences, referred to as *event clusters* (Brown and Schopflocher, 1998; Burt et al., 2003; D'Argembeau and Demblon, 2012; Demblon and D'Argembeau, 2014, in press).

The present research aims to investigate the neural basis of such higher-order autobiographical knowledge that contributes to organize specific events in thematic clusters. Previous neuroimaging studies have shown that the representation of general personal information and events involves medial and lateral prefrontal, lateral temporal, posterior cingulate, and inferior parietal cortices (Addis et al., 2004a; Holland et al., 2011; for a meta-analysis, see Martinelli et al., 2013). However, the brain regions that contribute to the organizational function of general autobiographical knowledge (i.e., to link a set of specific events together) have not been investigated. Furthermore, these previous studies focused only on the retrieval of past events, and thus it remains unknown whether the activation of higher-order autobiographical knowledge is supported by the same brain regions during remembering and future thinking.

To investigate these questions, we devised a new task that required participants to simultaneously consider two specific past or future events, and we manipulated the involvement of higher-order autobiographical knowledge by varying the types of relational dimensions linking these two events. Specifically, in one condition the two events were thematically and/or causally related to each other (i.e., they were part of the same event cluster), whereas in another condition the two events shared a surface feature (i.e., their location); a third condition was also included, in which the two events were unrelated to each other. For each pair of events, the participants' task was to determine what relational dimension (if any) links the two events together (i.e., thematic, location, or no relation).

We hypothesized that processing events that are part of the same cluster (compared to events that share a surface feature or that are unrelated to each other) would activate higher-order autobiographical knowledge and recruit brain areas involved in integrating events with such knowledge. A prominent candidate region for this process is the medial prefrontal cortex (mPFC), a region that is activated when processing general autobiographical knowledge (such as general representations of personal information and goals; for recent meta-analyses, see Martinelli et al., 2013; Stawarczyk and D'Argembeau, 2015) and might support the integration of specific experiences with such conceptual knowledge (Brod et al., 2013; Kroes and Fernandez, 2012; Preston and Eichenbaum, 2013; van Kesteren et al., 2012). In addition to the mPFC, rostrolateral regions of the PFC that have been shown to support relational integration and causal reasoning (Barbey and Patterson, 2011; Christoff et al., 2001; Wendelken et al., 2011) could also participate in the processing of event clusters. Finally, given that event clusters rely on higher-order (i.e., more abstract) autobiographical knowledge, we predicted that areas in the temporal and inferior parietal lobes that support semantic processing (Binder and Desai, 2011; Binder et al., 2009; Jefferies, 2013) would also be recruited to a greater extent when participants consider events that are part of the same cluster.

In summary, we expected that, relative to the control tasks (i.e., considering events that share a surface feature or that are unrelated to each other), thinking about past and future events that are part of the same cluster would activate higher-order autobiographical information that provides personal meaning beyond the meaning conveyed by each event taken in isolation, and we predicted that this process would recruit the mPFC, rostrolateral PFC, and lateral temporal and parietal cortices.

Material and methods

Participants

Twenty-eight healthy young adults with no history of neurological or psychiatric disorders took part in the study. Data from five participants were excluded because they did not follow instructions correctly (four participants) or because of poor performance (leaving an insufficient number of correct trials for the analyses; one participant); thus, the analyses were conducted on data from the remaining twenty-three participants (11 females). All of them were native French speakers and ranged in age from 19 to 27 years ($M = 22.5$ years, $SD = 2.4$ years). All participants provided a written informed consent to take part in the study, which was approved by the Ethics Committee of the Medical School of the University of Liège.

Tasks and procedure

Pre-scan session

The day before the scan session, participants took part in a pre-scan interview, the purpose of which was to collect the descriptions of autobiographical past and future specific events which were then used as stimuli during the fMRI session. Participants first received a definition of the notion of 'general event' (i.e., an event extended in time which includes more specific events that are organized in sequences, are causally related to each other, and/or involve the same theme or goal)[1] and some examples of general events were provided (e.g., a vacation in Egypt; the last exam period; moving in a new apartment; learning to drive). Based on this definition, participants were asked to report five general events that might likely happen to them in the next year. For each general event, participants were then asked to imagine three specific events that might likely happen in the context of this general event but would not occur in the same location (i.e., in the same room or area). A definition of specific event (i.e., a particular event occurring in a specific place at a specific time, and lasting a few minutes or hours) and some examples (e.g., passing my driving license test; packing my suitcase to go in Egypt) were provided. The experimenter wrote a short description of each general and specific event that was produced.

Participants were also asked to report five particular locations (i.e., a particular room or area) where they would likely be in the next year. Then, for each location, they imagined three specific events that might occur in this place but that are not part of the same general event (i.e. events that have no relation with each other except that they occur in the same location). Once again, the experimenter wrote a description of each location and specific event that was produced.

The three specific future events that were part of a same general event were used by the experimenter to form three event pairs (i.e. formed by events 1 and 2; events 2 and 3; events 1 and 3), leading to the formation of fifteen pairs of events (3 pairs for each of the five general events reported) that are part of a same event cluster but that occur in different locations. Similarly, the specific future events occurring in the same location were used to form three event pairs, leading to the formation of fifteen pairs of events that occur in the same location but that are not part of a same event cluster. Finally, participants were asked to use the descriptions of the same specific events to assemble fifteen pairs of unrelated events (events that are not part of a same event cluster and do not happen in the same location).

Participants then reproduced exactly the same task with past instead of future events. Thus, they had to recall five general (extended) events that occurred in the past year, five familiar locations where they were regularly in the past year, and three specific memories for each general event and each location. This resulted in the constitution of fifteen pairs of past events that were part of a same event cluster but did not happen in the same location, fifteen pairs of past events that happened in the

[1] In the present study, the term 'general event' as used during the pre-scan and scanning sessions referred to events extended in time (or short 'autobiographical periods'; Thomsen, 2015), and not to repeated events (for further discussion of the various types of general events, see e.g. Conway and Pleydell-Pearce, 2000). Indeed, our aim was to collect specific events that are not only part of higher-order clusters, but also that are clearly distinct from each other, which would be difficult to produce on the basis of repeated events.