The Temporal Unfolding of Event Construction while Thinking Aloud: Role of Ventromedial Prefrontal Cortex

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Abstract

■ Mental time travel (MTT), the ability to mentally project backward and forward in time, relies on navigating a hierarchical organization of mental representations, ranging from higher-level (semantic) to lower-level (episodic) knowledge structures. Ventromedial prefrontal cortex (vMPFC) is thought to initiate the activation of personal semantic information during MTT, but its precise role in the temporal dynamics of MTT remains unclear. In the present study, patients with focal vMPFC lesions, brain-damaged controls, and healthy participants completed a personal semantic interview followed by an MTT task in which they were instructed to remember past events and imagine future events while "thinking aloud," namely, uttering every information that came to their mind while constructing events. vMPFC patients showed degraded personal semantic information in the personal semantic interview compared with the control groups. In the MTT task, they generated more repeated events and fewer specific events than the control groups. Moreover, they exhibited atypical, "backward" transitions from lower-level (e.g., extended and repeated events) to higher-level (e.g., personal semantics) knowledge structures, indicative of an alteration of retrieval dynamics following vMPFC damage. These findings confirm that vMPFC damage impairs personal semantic memory and alters the retrieval dynamics of event construction, hindering access to specific events. ■

INTRODUCTION

A core feature of human cognition lies in the intrinsic tendency to decouple from stimuli in the external environment and engage in "mental time travel" (MTT; Suddendorf & Corballis, 2007; Tulving, 2005). MTT is a remarkable cognitive ability, allowing to project oneself backward in time to recall past events, and forward to envision future events. MTT serves as a fundamental driver for decision-making processes (Baumeister, Vohs, & Oettingen, 2016) and fosters the awareness of who we are (Prebble, Addis, & Tippett, 2013), with impact on personal well-being (Quoidbach, Berry, Hansenne, & Mikolajczak, 2010).

MTT has been studied extensively in cognitive neuroscience (e.g., D'Argembeau, 2016; Schacter, 2012; Szpunar, 2010; Suddendorf & Corballis, 1997). A prominent theoretical framework argues that MTT depends on the ability to navigate flexibly through a set of hierarchically structured knowledge structures (D'Argembeau, 2020; D'Argembeau & Mathy, 2011; Conway & Pleydell-Pearce, 2000). The apex of this hierarchy involves general and personal semantics, people and places, and one's preferences and goals (e.g., "I have had a happy childhood"). Moving down the hierarchy, general events encompass summary mental representations of repeated events (e.g., "my summer holidays in Viareggio in my childhood"), of single events spanning an extended time period (e.g., "the trip to Geneva last weekend"), and of sequences of events that follow a typical order (e.g., "the steps to complete a university degree," Barsalou, 1988; Brown & Schopflocher, 1998). At the lowest, most concrete level of the hierarchy, specific events contain episodic memories for unique past experiences, serving as detailed records of sensory, perceptual, and emotional content (e.g., "that family gathering, with the smell of a favorite dish and the sound of laughter"; Conway, 2009). Activating a specific event can occur both directly (bottom–up), through the immediate interaction between a retrieval cue and a memory trace, or indirectly (top–down), through a generative, iterative process, that requires the preliminary activation of abstract knowledge structures (personal semantics, general events) that are then used as cues to frame the search for specific events. D'Argembeau and Mathy (2011) showed that the same hierarchical structures are activated while constructing past as well as future events, even though direct access to specific events is less frequent for future compared with past events, and that future imagining relies more often on the indirect pathway, with the activation of semantic knowledge structures (mainly about personal goals) driving event construction.

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Neuroimaging evidence has shed light on the neural bases of MTT, defining a common core network of brain regions—also taking part in the default mode network (Raichle et al., 2001)—associated with episodic remembering and future thinking. This network includes the medial temporal lobes, ventromedial prefrontal cortex (vMPFC), retrosplenial cortex, posterior cingulate, and lateral parietal areas (e.g., Benoit & Schacter, 2015; Botzung, Denkova, & Manning, 2008; Addis, Wong, & Schacter, 2007; Szpunar, Watson, & McDermott, 2007; Okuda et al., 2003), and it exhibits significant activation during rest periods, wherein individuals typically focus their attention inward, on mental contents such as memories, desires, and plans (Ciaramelli & Treves, 2019; Schacter et al., 2012; Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010).

Several neuropsychological studies have highlighted the crucial role of vMPFC and hippocampus in MTT. Early lesion studies showed that patients with frontal lesions, including vMPFC, retrieved fewer autobiographical memories than healthy controls (HC), and this deficit was closely linked to their impairments in executive function (Kopelman, Stanhope, & Kingsley, 1999; Sala, Laiacona, Spinnler, & Trivelli, 1993). This led to hypothesize that vMPFC damage disrupts retrieval strategies (Moscovitch & Melo, 1997; Moscovitch, 1995). Bertossi, Tesini, and colleagues (2016) observed that vMPFC patients exhibited a marked impairment in recalling autobiographical memories and in constructing plausible future events (see also Stendardi, Biscotto, Bertossi, & Ciaramelli, 2021; Bertossi, Candela, De Luca, & Ciaramelli, 2017). The same deficit in episodic remembering and future thinking is also present in patients with hippocampal damage (Race, Keane, & Verfaellie, 2011; Hassabis, Kumaran, Vann, & Maguire, 2007). Crucially, whereas hippocampal patients mainly fail in providing the spatial details of constructed experience, vMPFC patients show a more basic deficit in providing multiple types of details, including event, sensory, and emotion details (De Luca et al., 2018). On the basis of this evidence, McCormick, Ciaramelli, De Luca, and Maguire (2018; see also Ciaramelli, De Luca, Monk, McCormick, & Maguire, 2019; Moscovitch, Cabeza, Winocur, & Nadel, 2016) proposed that vMPFC might play a superordinate role in MTT, activating semantic (schematic) knowledge to drive the collection of relevant details that the hippocampus would then help bind into spatially coherent events. Research on schematic knowledge (Ghosh, Moscovitch, Colella, & Gilboa, 2014; Burgess & Shallice, 1996) supports the view that vMPFC guides event construction by activating and maintaining stable schematic representations of relevant events (e.g., "a typical day out for a picnic"), acting as a scaffold for the recollection and imagination of episodic details (Ryom et al., 2024; Preston & Eichenbaum, 2013). Indeed, damage to vMPFC has been associated with impairments in classifying the belongingness of a series of words (e.g., "bride") to their corresponding event schema (e.g., "attending a wedding"; Ghosh et al., 2014). On this view, a failure in activating superordinate, schema-related knowledge may explain why vMPFC patients generate events lacking in episodic content (Bertossi, Tesini, et al., 2016).

An important research question, then, is to determine the exact role of vMPFC in activating and maintaining superordinate knowledge structures supporting MTT. Examining external details at the Autobiographical Interview (AI; e.g., Verfaellie, Wank, Reid, Race, & Keane, 2019; Bertossi, Aleo, Braghittoni, & Ciaramelli, 2016; Bertossi, Tesini, Cappelli, & Ciaramelli, 2016; Levine, 2004) is not suited to this aim, because individuals generally provide very few external details in the AI, as the task requires explicitly to recall specific events and not general (semantic) information. Moreover, only a subset of external details in the AI are semantic details (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). For this reason, in the present study, we adopted two different approaches to investigate the role of vMPFC in activating high-level memory structures and using them to drive MTT. We recruited patients with focal damage to vMPFC, and healthy and brain-damaged control individuals and had them complete a "personal semantic interview" concerning personal semantic information from their past and future. Then, participants underwent an event construction task, in which they were asked to construct past or future events using a lifetime period as the cue (remote past, recent past, and future). Crucially, in so doing, we used the "think aloud" method (see also Wank, Andrews-Hanna, & Grilli, 2021; D'Argembeau & Mathy, 2011; Haque & Conway, 2001; Burgess & Shallice, 1996; Barsalou, 1988; Reiser, Black, & Kalamarides, 1986), in which participants are instructed to report everything that comes to their mind while constructing an event, allowing us to examine the activation of all types of memory structures involved in MTT—from superordinate semantic structures to unique episodes—along with the order in which these structures get activated. Using the think-aloud method, D'Argembeau and Mathy (2011) have shown that, in healthy adults, personal semantic knowledge is typically activated before accessing specific events while both remembering the past and imagining the future (e.g., Haque & Conway, 2001). If vMPFC effectively enables the activation of semantic structures that then guides access to specific events, then we would expect vMPFC patients to exhibit (1) an impairment in producing personal semantic memories at the personal semantic interview, and (2) a deficit in activating high-level (semantic) knowledge structures during MTT compared with the control groups, with a consequent deficit in generating specific events.

METHODS

Participants

Thirty-six participants were included in the study: 15 patients with brain damage and 21 HC. Patients were recruited at the Centre for Studies and Research in Cognitive Neuroscience (Cesena, Italy), based on their lesion site, as documented by MRI or CT scans. Nine patients

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had lesions involving vMPFC (six male participants; mean age = 59.8 years; range = 50–73 years; mean education = 10.2 years, range: 5–13 years). vMPFC patients' lesions resulted, in all cases, from the rupture of an aneurysm of the anterior communicating artery. They were bilateral in six cases, left lateralized in two cases and right lateralized in one case. Six "control" patients (CP) had lesions not involving vMPFC (three male participants; mean age = 59.9 years; range = 31–76 years; mean education = 13.5 years, range: 5–18 years). These were caused by ischemic or hemorrhagic stroke and were in the left hemisphere in two cases and in the right hemisphere in four cases. Lesion sites mainly included temporoparietal cortex, extending into the occipital area (one case) and subcortical regions (four cases). Included patients were in the stable phase of recovery (at least 7 months postmorbid). The HC group comprised 21 participants without neurological or psychiatric history (HC—10 male participants; mean age = 55.9 years, range = 50–65, mean education = 12.5 years, range = 8–13), who were matched to patients on age, education, $F(2, 33) < 2.84$; $p \geq .07$ in both cases, and gender balance ($\chi^2 < .94$, $p \geq .63$ in all cases).

Based on the results of a previous study using the "think aloud" method (D'Argembeau & Mathy, 2011), we estimated that a minimum sample size of $n = 6$ participants was necessary to replicate an effect size of $\eta_p^2 = .45$ for the main effect of the *level of abstraction* (critical $F = 3.49$), with a significance level of $\alpha = .05$ and a desired power $(1 - \beta)$ of 0.95, and therefore, data collection ended as soon as we recruited at least six individuals per group (i.e., CP group $n = 6$; vMPFC group $n = 9$; HC group $n = 21$). These sample sizes are also in line with those in previous lesion studies on event construction in vMPFC patients (e.g., Bertossi, Aleo, et al., 2016; Bertossi, Tesini, et al., 2016).[1]

Participants gave informed consent to participate in the experiment, which was performed in agreement with the 2013 World Medical Association Declaration of Helsinki and approved by the bioethical committee of the University of Bologna and the Area Vasta of Emilia Romagna ethics committee.

Neuropsychological Assessment

Patients received an extended neuropsychological assessment, aimed at specifying their cognitive profile (HC did not receive a neuropsychological assessment). Table 1 displays the standardized mean scores of the two patient groups on individual tests. Their general cognitive functioning, as indicated by the scores attained in tests assessing reasoning and attentional skills (i.e., the *Raven Standard Matrices* and *Attentional Matrices*; Spinnler & Tognoni, 1987), was, on average, within the normal range. Patients also attained normal scores in tests assessing verbal and spatial short-term memory (Digit Span, Orsini et al., 1987; Corsi Test, Spinnler & Tognoni, 1987), long-term memory (Prose Passage Recall Test, Spinnler & Tognoni, 1987; Novelli et al., 1986), Rey Complex Figure–Recall (Caffarra, Vezzadini, Dieci, Zonato, & Venneri, 2002), and executive abilities (Phonemic and Semantic Fluency, Stroop's Test, Caffarra et al., 2002; Tower of London, Keith Berg & Byrd, 2002; Novelli et al., 1986). The only exceptions were impaired performance in the Wisconsin Card Sorting Test (Grant & Berg, 1948), indicating weak cognitive flexibility in both groups of patients, and impaired copy performance in CP. There were no significant differences in test scores between patient groups across tests (Itl < 2.097; $p \geq .09$ in all cases).

Table 1. Patients' Clinical Data

	CP	*vMPFC Patients*
Measure	*Mean (SD)*	
Raven's Matrices	22.9 (6.15)	28.78 (7.17)
Digit Span	5.75 (1.17)	5.39 (1.51)
Corsi Block Tapping	4.08 (0.89)	4.57 (1.11)
Attentional Matrices	40.83 (3.78)	49.03 (10.95)
Prose Passage Recall	10.34 (5.32)	8.51 (5.11)
Rey complex figure		
Copy	27.85 (3.96)*	33.39 (13.79)
Recall	14.80 (9.86)	15.40 (7.10)
Fluency		
Phonemic	30.40 (9.46)	28.44 (15.69)
Semantic	39.80 (10.87)	40.22 (12.97)
Stroop		
Errors	0.96 (5.23)	2.50 (1.16)
Interference (sec)	28.54 (20.88)	29.67 (19.93)
Tower of London		
Total move score	72.00 (25.63)	87.33 (9.93)
Rule violation score	71.00 (23.58)	91.11 (22.00)
WCST		
Errors	79.75 (20.42)*	77.63 (33.73)*
Perseverations	74.00 (25.39)*	83.75 (46.95)*

Raven's Progressive Matrices, black/white version (cutoff ≥ 15); Digit Span (cutoff ≥ 3.75); Corsi Test (cutoff ≥ 3.75); Attentional Matrices (cutoff ≥ 30); Prose Passage Recall (cutoff ≥ 10th percentile); Rey Complex Figure–Copy (cutoff ≤ 28.9), Recall (cutoff ≤9.5); Phonemic Fluency (cutoff ≥ 17) and Semantic Fluency (cutoff ≥ 25); Stroop's Test–Errors (cutoff ≤ 4.24), Interference (cutoff ≤ 36.92); TOL = Tower of London–Total Moves (cutoff ≤ 70), Rule Violation (cutoff ≤ 70); WCST = Wisconsin Card Sorting Test–Errors, Perseverations (cutoff ≥ 10th percentile). An impaired performance is indicated by an *.

Lesion Mapping

We derived patients' individual lesions from the most recent MRI or CT scans. They were manually drawn by two trained neuroscientists directly on each slide of the normalized T1-weighted template MRI scan from the

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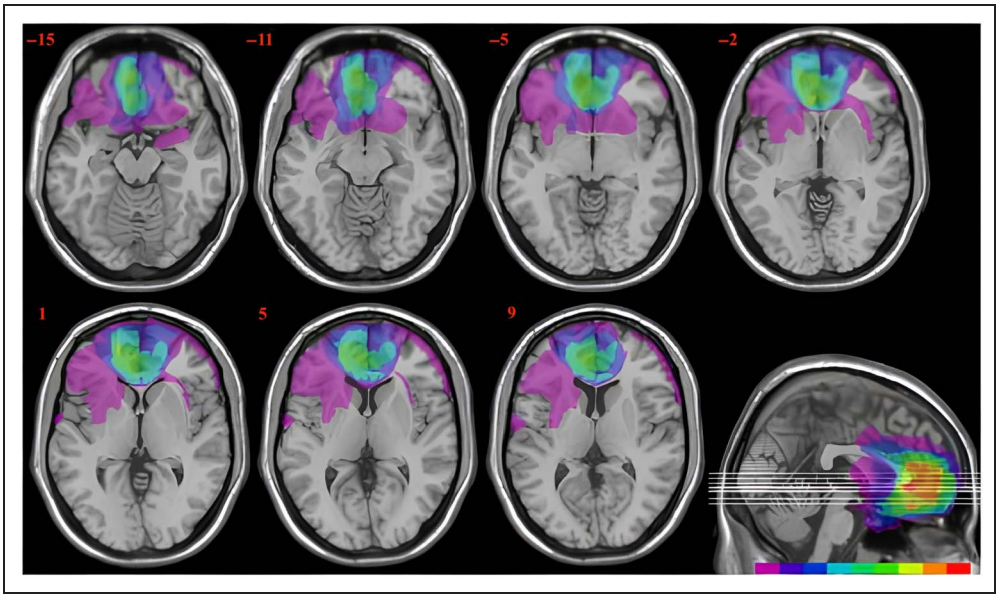

Figure 1. Location and overlap of vmPFC patients' brain lesions. This figure displays the brain lesions of the nine patients with vMPFC damage, all projected onto the same seven axial slices and the mesial view of the standard Montreal Neurological Institute brain. The level of each axial slice is marked by white horizontal lines on the mesial view and the corresponding *z* coordinates. The color bar represents the number of overlapping lesions, with the greatest overlap occurring in BA 11, BA 10, and BA 32 of vMPFC. In the axial slices, the left hemisphere is shown on the left.

Montreal Neurological Institute distributed with MRIcro (Rorden & Brett, 2000). The MRIcro software was used to estimate lesion volumes (in cc) and generate lesion overlap images. Figure 1 shows the extent and overlap of brain lesions in vMPFC patients. The region of maximal lesion overlap occurred in Broadmann area (BA) 11 (mean = 17.59 cc, $SD = 10.686$), BA 10 (mean = 9.08 cc, $SD = 7.23$), and BA 32 (mean = 5.88 cc, $SD = 5.66$). There was no significant difference in total lesion volume between vMPFC patients and CP, $t(13) = 0.56$, $p = .59$, Cohen's $d = 0.29$.

Materials and Procedure

The experimental procedure comprised two computerized tasks, distributed into three separate sessions: a personal semantic interview (Session 1) and an event construction task (Sessions 2 and 3). Session 1 assessed participants' ability to access personal semantic information, whereas Sessions 2 and 3 evaluated their ability to construct past and future events using lifetime periods or words as cues. The order of Sessions 2 and 3 was counterbalanced across participants. The data on event construction using word cues are not reported here, as they were analyzed using a different approach and will form the basis of a separate study.[2]

During the event construction session, for three of the four lifetime periods (*childhood, recent past*, and *near future*), we asked participants to retrieve or to imagine a specific event that happened/could happen in that period. Patients' relatives attended all sessions to verify the truthfulness or plausibility (for future events) of patients' statements.

Personal Semantic Interview

During Session 1, participants were told that we were interested in investigating semantic facts from four lifetime periods in their lives: "*childhood*" (0–18 years), "*adulthood*" (18–30 years), "*recent past*" (last 10 years), and "*near future*" (next 10 years). The personal semantic semistructured interview was adapted from the semantic section of the Autobiographical Memory Interview (Kopelman, Wilson, & Baddeley, 1989). For each time period, participants were required to provide semantic information regarding their knowledge of four types of facts, that is, (1) the names of three people they frequently met/will meet, (2) three places they frequently visited/will visit, (3) up to three schools they attended or the job they had/will have, and (4) up to three past/future home addresses (see Supplement A). For the near future time period, participants were encouraged to think about the people they foresee they will frequently meet or would like to meet (e.g., "my golf buddy"; "my doctor"), the places they will frequently visit or would like to visit (e.g., "the gym"; "Rome"), jobs that they will have or would like to have (e.g., "same job as now but promoted"; "I will be retired"), and addresses where they could or would like to live (e.g., "25 Aprile street, where my son currently lives"; "same as now but renovated").

For each time period, we also asked participants to produce five culturally shared personal events that are expected to be experienced by individuals within a given society in that lifetime period (i.e., *cultural life scripts*, Berntsen & Rubin, 2004). The duration of this session was about 1 hr.

Event Construction Task

The event construction task was a modified version of the Crovitz method (Crovitz & Schiffman, 1974) and was programmed on Qualtrics. Participants were required to recall specific events that happened in their past and to imagine specific events that might reasonably happen in their future, in response to three time periods ("*remote past*

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(0–18 years)," "*recent past (last 10 years)*," and "*near future (next 10 years)*"). Participants performed two trials per time condition (blocked), with the order of time conditions counterbalanced across participants. Participants were instructed to recall/imagine specific events, that is, a unique event taking place in a precise place at a specific time and lasting no more than a day (see D'Argembeau & Mathy, 2011). They were provided with some examples to illustrate what would or would not be considered a specific event. The instructions further specified that the event should refer to personal experiences and that future events should be plausible (something that could reasonably happen in the context of their lives) and novel (something that was not experienced in the past). Crucially, we asked participants to "think aloud," namely, to say aloud everything that came to their minds while trying to retrieve or to imagine the specific event (i.e., the "think aloud" method; see also D'Argembeau & Mathy, 2011), starting from the time they read the cue stimulus (the lifetime period) until they considered their description of the event to be complete, for a maximum of 3 min. This procedure allowed us to delineate the entire temporal progression of memory structures in participants' constructed experience (from abstract semantic structures to specific events). In line with the AI (Levine et al., 2002), if the participant was unable to generate an event, general probes were provided to clarify the instructions or elicit more details (e.g., "*Is there a specific event you can think of?*"). If general probing did not work, we cued participants with one of the typical life-events (e.g., "wedding") or with a frequently attended place they provided in Session 1. After the generation of each event, participants were asked to rate the event, using a 5-point Likert scale, for emotional valence (1 = very pleasant, 5 = very unpleasant), personal importance (1 = a life-changing event; 5 = an irrelevant event), and relation to personal goals (1 = highly related to personal goals; 5 = not related to personal goals at all).

Scoring Procedure

Personal semantic interview. Each of the four categories explored during the personal semantic interview was scored separately. Participants were assigned 1 point to each piece of information they provided. For the *people* and *places* categories, participants were required to indicate three items per category (three people and three places) and were required to provide two pieces of information about each item. The scores were summed, resulting in a maximum score of 6 for each category. In the *address* and *work* categories, participants could indicate up to three items per category (people differ in the number of houses or work activities they have had, or plan they will have), and they were required to provide four pieces of information about each item. The scores about each item were summed, and the scores about different items were averaged, leading to a maximum score of 4 for each category. Thus, within each time period, the total score ranged from 0 to 20 (six for people and places, four for address and work; for further details, see Supplement A).

Knowledge structures. The scoring procedure was adapted from D'Argembeau and Mathy (2011). Participants' reports were recorded and transcribed (example reports are provided in Supplement B). The information provided was segmented and classified into five types of knowledge structures with different levels of abstraction: general semantics, personal semantics, repeated events, extended events, specific events, and an extra nothing in mind category.

We defined *general semantics* as general world knowledge shared among people and that applies to everyone (e.g., "A friend is seen in times of need" or "The best restaurants are sometimes not the most expensive ones"). With *personal semantics*, we meant the semantic information specific to the speaker, including his/her characteristics, tastes (e.g., "I actually prefer to eat at home rather than at the restaurant"), personally known people and places (e.g., "My best friend at that time was my classmate Roberta"), and information about main lifetime periods (e.g., "I attended high school in Milan"). We considered *repeated events* any personal event that happened more than once (e.g., "I spent every afternoon studying before that exam") or personal habits (e.g., "every Saturday my wife and I go to the restaurant"). Personal events that are unique but extended in time (over days or weeks, e.g., "I imagine myself going on holiday with my cousin in the near future"), and/or unique but sparsely detailed (e.g., "I remember when I bought my house") were scored as *extended events*. Finally, we defined as *specific events* all the unique, personal experiences contextualized in space and time and accompanied by numerous contextual details (e.g., "Last week I went to the beach all day with my sister. It was very hot and we got stuck in traffic in the morning. I felt very nervous"). Finally, the extra-category *nothing in mind* included hesitations, nonspecific or abstract expressions and repetitions of the cues, or any expression indicating that the elaboration of the instructions was still in progress or could not be processed at that time (e.g., "I find myself in a bit of difficulty with respect to this lifetime period … ."). This category identified parts of the reports that lacked meaningful content and was not considered in the analyses.

Progressive units. Because the main purpose of this study was to examine the temporal progression of knowledge structures during event construction, we segmented participants' discourses into temporally ordered "units" (see also D'Argembeau & Mathy, 2011). According to this procedure, the type of knowledge structure characterizing the first element (or elements) of participants' discourse was considered as the first description unit (Unit 1). A unit

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could comprise multiple elements all referring to the same type of knowledge structure. We noted a distinct (successive) description unit when participants shifted forward to another, lower-level knowledge structure (e.g., from repeated events to specific events; see also D'Argembeau & Mathy, 2011), which would be called Unit 2. By analogy, the following (forward) shifts toward lower-level knowledge structures would be called Unit 3, Unit 4, and Unit 5 (as in D'Argembeau & Mathy, 2011). By contrast, if a knowledge structure was activated (e.g., specific events) in Unit n and it was followed by a "backward" shift to higher-level memory structure (e.g., repeated events), that shift would not determine the creation of Unit n + 1, as only forward transitions from higher- to lower-level knowledge structures let the unit count progress. In total, there could be a maximum of five description units for each trial, with each unit corresponding to one of the five knowledge structures described earlier (general semantics, personal semantics, repeated events, extended events, and specific events).

To examine the type of knowledge structure that was most accessed first (i.e., in Unit 1), for each period (remote past, recent past, and near future), we calculated the frequency of general semantics, personal semantics, repeated events, extended events, and specific events described in Unit 1 across participants. We then adopted the same procedure to compute the frequency of knowledge structures reported in the following units (except for trials in which a specific event had been generated in Unit $n - 1$, and therefore, Unit n did not exist; those trials were not included in the analysis; see also D'Argembeau & Mathy, 2011). Even though five units are possible in principle (because participants can access five types of knowledge structures), Unit 4 and Unit 5 were not analyzed because, in fact, they were not covered by participants. This is because (1) general semantics were produced extremely infrequently across groups and therefore were not considered in the analyses (which made only four units actually possible) and (2) participants in most cases (n = 33/36) accessed a specific event by Unit 3, and therefore Unit 4, in most cases, did not exist. Unit 1 (n = 36/36), Unit 2 (n = 36/36), and Unit 3 (n = 25/36) were covered by most participants and, therefore, were analyzed.

Transitions among knowledge structures. After segmenting the participants' reports into different knowledge structures, we studied participants' transitions between knowledge structures. First, to quantify the tendency to transit forward (from higher- to lower-level) and backward (from lower- to higher-level) across knowledge structures, we computed Lag-Conditional Response Probability (CRP) profiles for each participant. Transition lag was defined as the numerical difference in position between the target and source knowledge structure, such that positive lags reflected forward transitions toward lower-level knowledge structures (e.g., from personal semantics to repeated events, lag = +1), whereas negative lags indicated backward transitions toward higher-level knowledge structures (e.g., from extended events to personal semantics, lag = −2). For each participant, the frequency of each lag was normalized by the total number of transitions, resulting in an individual-level CRP distribution. Group-level means were then calculated for each lag value (ranging from −3 to +3) separately for the HC, CP, and vMPFC groups, enabling direct comparisons of transition patterns across groups.

In addition, we qualified all the possible transitions among knowledge structures, including both "forward" transitions (from higher- to lower-level knowledge structures; e.g., personal semantics to extended events, extended events to specific events) and "backward" transitions (from lower- to higher-level knowledge structures; e.g., extended events to personal semantics, specific events to extended events), which may point to iterative retrieval attempts. For each pair of knowledge structures and each participant, we counted the number of—forward and backward—transitions between knowledge structures, corrected by the sum of the two types of knowledge structures in the pair [e.g., n° transitions between repeated events and personal semantics/ (n° repeated events + n° personal semantics)]. This correction was applied to control for the fact that not all the possible transitions between knowledge structures were equally probable, because different groups accessed a different number of higher- and lower-level knowledge structures.

Internal and external details. We also assessed the episodic (vs. semantic) richness of participants' reports according to the AI segmentation and categorization procedure (Levine et al., 2002). Briefly, for each trial, the central event was identified and, if more than one event was mentioned, the event described in more detail was considered the main event. Each event was divided into distinct details (unique bits of information), and these details were classified as internal (episodic, context-rich details) or external (semantic information, repetitions, and information not specific to the main event).

Authors G. C., D. S., and A. P. jointly established the scoring methods based on prior literature (see D'Argembeau & Mathy, 2011; Levine et al., 2002; Kopelman et al., 1989) and trained coauthors M. C. and E. P. (blind to the study hypotheses) by assisting them in scoring the first 10 participants. Both M. C. and E. P. scored independently 20% of the reports, and the remainder were divided evenly between them. Any scoring uncertainty was flagged, brought to the attention of G. C., and resolved through discussion. Interrater agreement (calculated on the reports scored by both raters), assessed with intraclass correlations (ICCs), was good: internal details (ICC = 0.86), external details (ICC = 0.76), general semantics (ICC = 0.79), personal semantics (ICC = 0.77), repeated

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events (ICC = 0.76), extended events (ICC = 0.76), specific events (ICC = 0.72).

RESULTS

Unless noted otherwise, the data were analyzed using repeated-measures ANOVAs with Group (HC, CP, vMPFC patients) as a between-subject factor and Time (remote past, recent past, and near future) and Knowledge Structure (general semantics, personal semantics, repeated events, extended events, and specific events) as within-subject factors. To test our main hypotheses on the distribution and temporal unfolding of knowledge structures across groups (see the Introduction section), we conducted planned contrasts comparing the vMPFC group with each control group for every knowledge structure. These contrasts were corrected according to their numerosity using the Holm–Bonferroni method. For the remaining (exploratory) post hoc comparisons, we applied a full Holm–Bonferroni correction.

Personal Semantic Interview

Because the distribution of the scores at the interview violated the assumption of normality, the scores underwent a logarithmic transformation (see Supplement C for raw scores). To compare personal semantic knowledge across groups, we conducted a repeated-measures ANOVA on transformed personal semantic memory scores, with Group as the between-subject factor and Time (childhood, adulthood, recent past, and near future) and Semantic Information (people, places, address, and work) as within-subject factors. Because the assumption of sphericity (Mauchly's test) was violated, we applied the Greenhouse–Geisser correction.

The analysis yielded a main effect of Semantic Information, $F(2, 75) = 147.39$; $p < .001$; $\eta_p^2 = .82$, and a main effect of Group, $F(2, 33) = 7.75$; $p = .002$; $\eta_p^2 = .32$, which were qualified by a significant interaction Group × Semantic Information, $F(5, 51) = 3.13$; $p = .010$; $\eta_p^2 = .16$: Post hoc comparisons showed that vMPFC patients attained lower scores in the personal semantic category *places* compared with HC ($p = .013$) and CP ($p = .040$), with no difference between the control groups ($p = .99$). The same pattern emerged for personal semantic scores related to the category *work*, with vMPFC patients showing lower scores than the other groups (HC: $p = .005$; CP: $p = .037$), with no difference between the control groups ($p = .99$). No group differences emerged for scores related to the categories *people* and *addresses* (all $ps > .99$; see Figure 2).

Regarding life scripts, we ran a repeated-measures ANOVA on the frequency of correctly reported life scripts (based on Berntsen & Rubin, 2004) with Time (childhood, adulthood, recent past, and near future) as a within-subject factor and Group (HC, CP, and vMPFC patients) as a between-subject factor. Results revealed a main effect of Group, $F(2, 33) = 5.23$, $p = .011$, $\eta_p^2 = .24$: Post hoc comparisons indicated that vMPFC patients reported significantly fewer cultural life scripts than HC ($p = .001$) and marginally fewer life scripts than CP ($p = .069$), with no significant difference between CP and HC ($p = .83$; see Figure 3). A significant effect of Time, $F(2.80, 92.44) = 3.05$, $p = .036$, $\eta_p^2 = .08$, also emerged, with a marginal trend toward reporting more of cultural life scripts related to the adulthood (18–30) compared with the childhood (0–18) life period ($p < .06$) across groups, and no significant differences among the remaining lifetime periods (all $ps \geq .22$). The interaction Group × Time was not significant, $F(5.60, 92.44) = 1.26$, $p = .28$.

This set of analyses shows that vMPFC patients exhibited impairments in accessing personal semantic information, particularly related to attended places and jobs, and in explicitly acknowledging culturally relevant life events, regardless of the lifetime period considered.

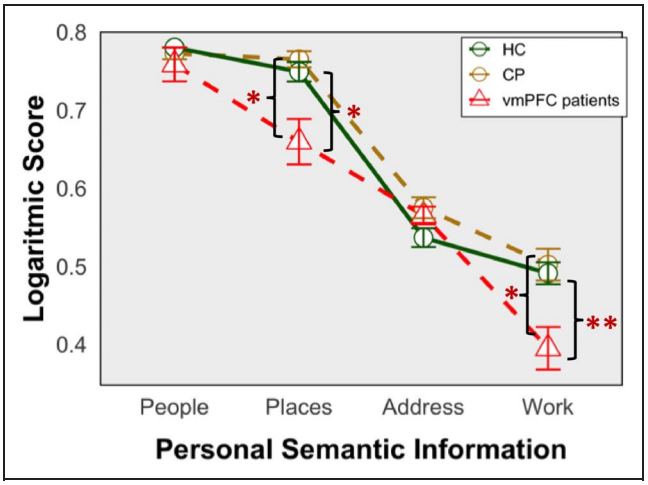

Figure 2. Personal semantic interview. Logarithmically transformed mean scores at the personal semantic interview by *group* (HC, CP, and vMPFC patients) and *semantic information* (people, places, address, work). Data are collapsed across time conditions. Error bars indicate the standard error of the mean. *$p < .05$, **$p < .01$, ***$p < .001$.

Event Construction Task

Distribution of Knowledge Structures

To compare the general frequencies of different knowledge structures across groups, we ran a repeated-measures ANOVA on the number of times each participant produced a given knowledge structure on each trial, with Group as a between-subject factor and Knowledge Structure and Time as within-subject factors.

We found a main effect of Group, $F(2, 33) = 7.59$; $p = .002$; $\eta_p^2 = .32$, and a main effect of Knowledge Structure, $F(2, 31) = 28.67$; $p < .001$; $\eta_p^2 = .23$, which were qualified by a significant interaction Group × Knowledge structure, $F(5, 32) = 13.78$; $p < .001$; $\eta_p^2 = .46$ (Figure 4). Planned

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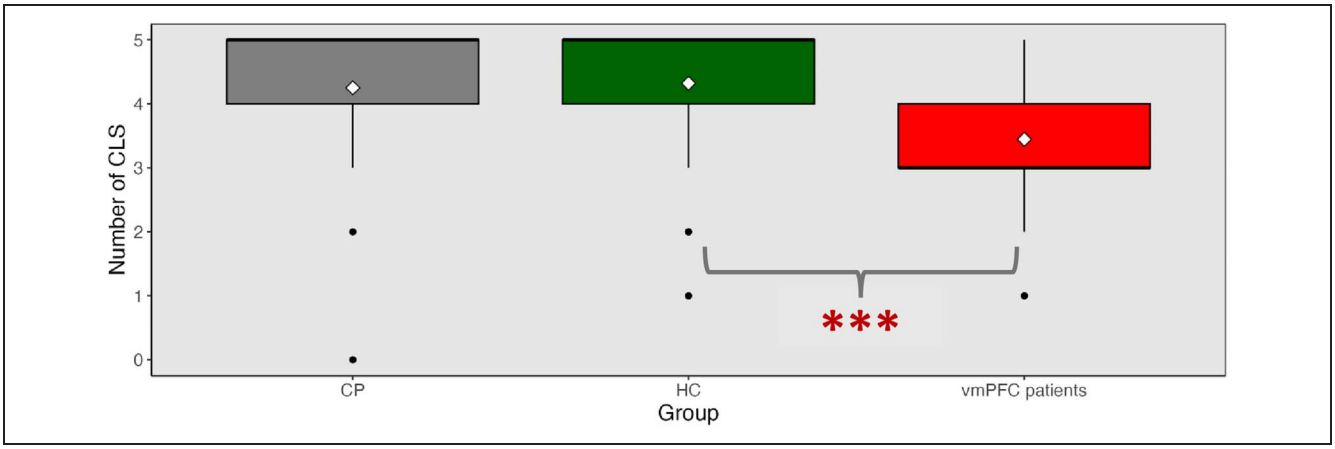

Figure 3. Number of cultural life scripts (CLSs). Mean number of correctly reported CLSs by *group* (HC, CP, and vMPFC patients). Data are collapsed across time conditions. Error bars indicate the standard deviation from the mean. *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

between-group contrasts revealed that vMPFC patients reported significantly more personal semantics, repeated events, and extended events than HC (*personal semantics:* $p = .010$; *repeated events:* $p = .010$; *extended events:* $p = .010$), but not CP (all $ps \geq .075$). By contrast, vMPFC patients reported fewer specific events than both HC ($p = .010$) and CP ($p = .010$). No significant differences among groups emerged for general semantics (all $ps > .99$). No other comparisons were significant ($p > .99$). The results also showed a significant interaction Time × Knowledge Structure, $F(5, 91) = 6.75$; $p < .001$; $\eta_p^2 = .17$: All groups reported more extended events in the future (mean = 4.59, $SD = 1.98$) compared with the remote past (mean = 2.32,$SD = 1.76$, $p < .001$). Due to the low frequency of general semantics (7%), this knowledge structure was excluded from all subsequent analyses.

This analysis revealed that vMPFC patients accessed specific events less frequently than healthy and brain-damaged controls and tended to access higher-order knowledge structures instead.

Temporal Unfolding of Units

For Units 1, 2, and 3, the frequencies of knowledge structures were then subject to repeated-measures ANOVAs with Group as a between-subject factor and *time* and Knowledge Structure (personal semantics, repeated events, extended events, and specific events) as within-subject factors.

With respect to Unit 1, we found a main effect of Knowledge Structure, $F(1, 95) = 8.27$; $p < .001$; $\eta_p^2 = .20$, indicating that more personal semantics and extended events were accessed in the first part of the reports rather than repeated events (all $ps \leq .001$) or specific events (*personal semantics:* $p = .029$; *extended events:* $p = .016$; see Figure 5). No other factors or interactions were significant ($p > .28$).

Turning to Unit 2, we found a main effect of Knowledge Structure, $F(1, 95) = 28.464$; $p < .001$; $\eta_p^2 = .46$, and a significant interaction Group × Knowledge Structure, $F(3, 89) = 9.22$; $p < .001$; $\eta_p^2 = .36$: Planned contrasts revealed that vMPFC patients produced more repeated events and fewer specific events compared with HC (repeated events: $p = .008$; specific events: $p = .008$), but only numerically more when compared with CP (repeated events: $p = .072$; specific events: $p = .110$). No differences emerged among groups in the remaining types of knowledge structures (all $ps \geq .110$; see Figure 5).

In Unit 3, the results showed a main effect of Knowledge Structure, $F(3, 66) = 19.51$; $p < .001$; $\eta_p^2 = .470$, qualified by a significant triple interaction Group × Time × Knowledge Structure, $F(12, 132) = 2.59$; $p = .004$; $\eta_p^2 = .191$. Planned contrasts revealed that, for the future period,

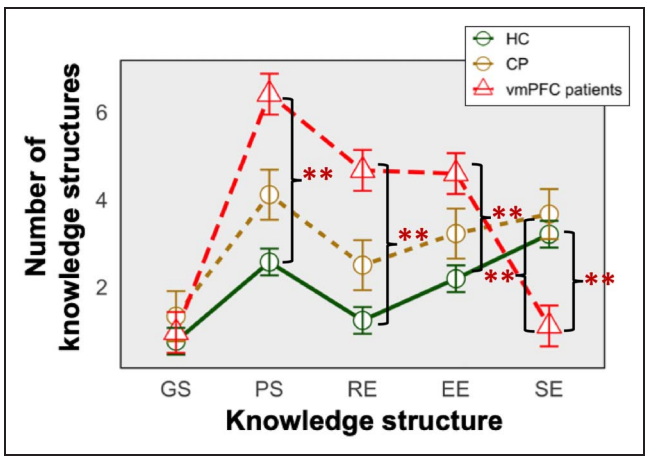

Figure 4. Distribution of knowledge structures. Mean number of knowledge structures produced by Group (HC, CP, and vMPFC patients) and type of Knowledge Structures (GS = general semantics; PS = personal semantics; RE = repeated events; EE = extended events; SE = specific events). Data are collapsed across time conditions. Error bars indicate the standard error of the mean. *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

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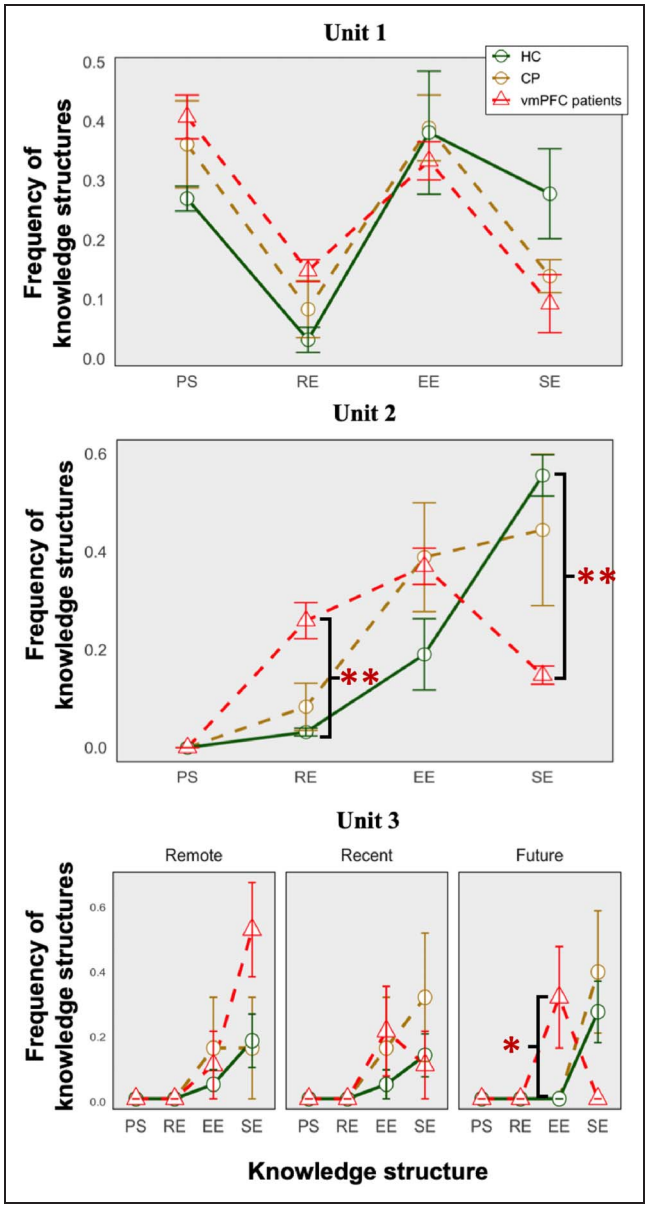

Figure 5. Top and middle. Mean frequency of knowledge structures (PS = personal semantics; RE = repeated events; EE = extended events; SE = specific events) by Group (HC, CP, and vMPFC patients). Data are collapsed across time conditions. Bottom (Unit 3): Mean frequency of knowledge structures by Group and Time (remote past, recent past, and near future). Error bars indicate standard error of the mean. *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

vMPFC patients accessed more extended events compared with HC ($p = .024$). No other contrasts were significant ($p > .165$; see Figure 5).

This set of analyses showed that all groups, including vMPFC patients, began (Unit 1) the event construction process mainly by activating personal semantics or extended events, while rarely accessing directly specific events, confirming D'Argembeau and Mathy's (2011) findings. In Unit 2, vMPFC patients still tended to access high-level knowledge structures (repeated events) as opposed to specific events, a tendency that persisted in Unit 3 (extended events), especially for future events.

Transitions between Knowledge Structures

Figure 6 displays the group-level Lag-CRP curves as a function of transition lag (−2 to +2). Positive lag values reflect forward transitions toward lower-level knowledge structures, whereas negative lag values reflect backward transitions toward higher-level knowledge structures. Lag values of −3 and +3 were infrequent across participants and were therefore excluded from the analysis.

To assess group differences in transition patterns, we conducted a repeated-measures ANOVA on CRP values with Group as a between-subject factor and Lag (−2, −1, +1, +2) as a within-subject factor. The analysis revealed a significant main effect of Group, $F(2, 28) = 5.86, p = .007, \eta_p^2 = .064$, that configured in the significant interaction Group × Lag, $F(4.48, 62.66) = 3.20, p = .015, \eta_p^2 = .161$: Post hoc comparisons showed that at lag −1 vMPFC patients had significantly higher CRP values than both HC ($p < .001$) and CP ($p = .001$), indicating that vMPFC patients tended to show backward transitions between adjacent knowledge structures (see Figure 6). No significant group differences were observed at lag −2 (all ps = .99), lag +1 (all ps ≥ .20), or lag +2 (all ps ≥ .62), although CRP values at lag +2 were numerically higher for HC compared with vMPFC patients. The effect of Lag failed to reach significance, $F(2.24, 62.66) = 0.53, p = .61$.

This analysis shows that vMPFC patients were more likely to move backward toward more abstract memory structures during event construction and particularly between knowledge structures that were adjacent (i.e., lag = −1) in the memory hierarchy.

To qualify the types of transitions exhibited by the participants' groups, for each pair of knowledge structures and each participant, we analyzed the corrected number of—forward and backward—transitions between knowledge structures. For conciseness, we report the analyses on backward transitions only, because those on forward transitions are reported in Supplement C (as the findings confirm largely those reported in the previous section).

The corrected number of backward transitions from repeated events to personal semantics was subject to a beta generalized linear mixed model (GLMM), with Group (HC, vMPFC patients, and CP) and Time (remote past, recent past and future) as fixed effects and Participant as a random effect. The results showed a significant main effect of Group, Wald $\chi^2(2) = 46.23; p < .001$ (see Figure 7), with vMPFC patients showing significantly more backward transitions from repeated events to personal semantics compared with both HC ($p < .001$) and CP ($p < .001$), with no difference between HC and CP ($p = .19$). No other effect or interaction were significant ($p > .75$).

The corrected number of backward transitions starting from extended events was subject to a beta GLMM with Group, Target Knowledge Structure (the ending point of

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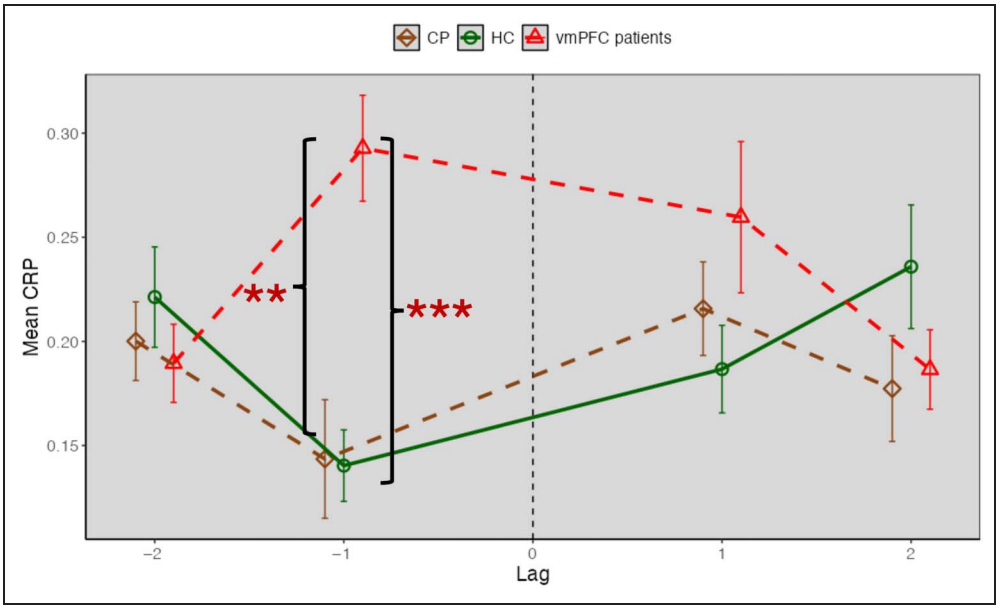

Figure 6. Lag-CRP. Mean CRP values by group (HC, CP, and vMPFC patients) as a function of transition lag (−2 to +2). *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

the transition, i.e., personal semantics and repeated events), and Time as fixed effects and Participant as a random effect. The results yielded a main effect of Group, Wald $\chi^2(2) = 42.60$; $p < .001$; Target Knowledge Structure, Wald $\chi^2(2) = 12.04$; $p < .001$; and Time, Wald $\chi^2(2) = 19.46$, $p < .001$, which were qualified by a Group × Time × Target Knowledge Structure interaction, Wald $\chi^2(4) = 12.01$, $p = .02$ (see Figure 8). Planned contrasts showed that, for the remote past period, vMPFC patients showed more backward transitions from extended events to personal semantics compared with both CP ($p = .01$) and HC ($p < .001$), with no difference between CP and HC ($p = .53$). For the future period, vMPFC patients ($p < .001$) and CP ($p < .001$) showed more backward transitions from extended events to personal semantics compared with HC, with no difference between vMPFC patients and CP ($p = .89$). No significant differences among groups emerged in the recent past (all $ps > .06$). For backward transitions from extended events to repeated events, vMPFC patients showed more transitions compared with both HC ($p < .001$) and CP ($p < .001$) for the future period, with no difference between HC and CP ($p = .85$). For the recent past period, vMPFC patients showed more transitions compared with HC ($p = .02$), but not CP ($p = .46$), with no difference between CP and HC ($p = .46$). No significant differences among groups emerged relative to the remote past period (all $ps \geq .99$; see Figure 8).

Turning to the number of backward transitions from specific events, we conducted a beta GLMM with group, target knowledge structure (i.e., personal semantics, repeated events, and extended events), and time as fixed effects and participant as a random effect. We found a main effect of Target Knowledge Structure, Wald $\chi^2(2) = 6.95$; $p = .03$. All participants showed more backward transitions from specific events to personal semantics (mean = 0.03; $SD = 0.02$) than from specific events to extended events (mean = 0.01; $SD = 0.01$, $p = .022$). The remaining factors were not significant (all $ps \geq .06$).

These findings show that, compared with the control groups, vMPFC patients exhibited more backward transitions from relatively lower- to higher-level memory structures and, in particular, from repeated events to personal semantics. Differences in backward transitions starting from extended events were instead time dependent, emerging selectively in the remote past period (from extended events to personal semantics) and in the future period (from extended events to repeated events).

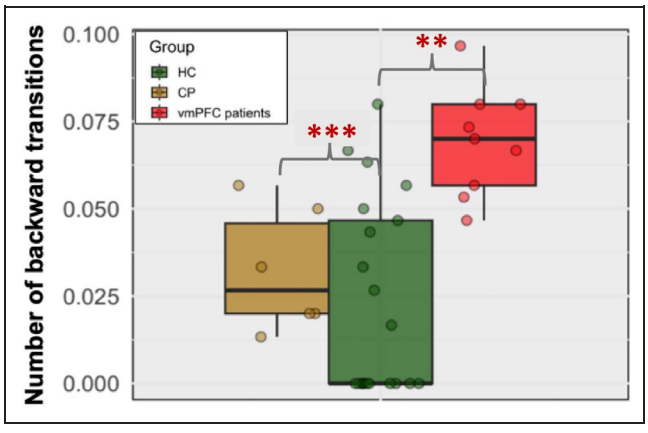

Figure 7. Backward transition between knowledge structures. Corrected number of backward transitions from repeated events (REs) to personal semantics (PS) by Group (HC, CP, and vMPFC patients). Data are collapsed across time conditions. Error bars indicate standard error of the mean. *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

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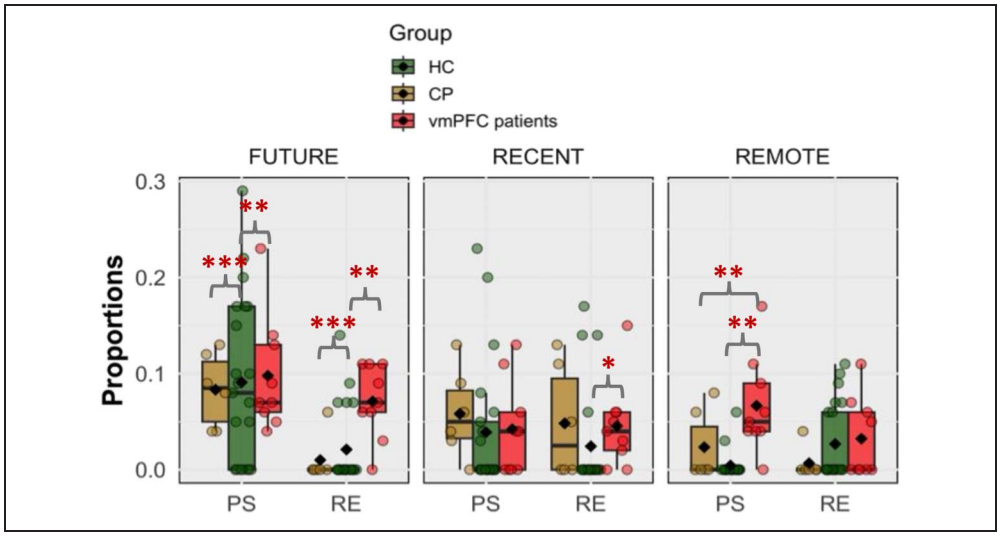

Figure 8. Backward transition from extended events. Corrected number of backward transitions from extended events to personal semantics (PS) and from repeated events (RE) by group (HC, CP, and vMPFC patients) and time (remote past, recent past, and near future). Black diamonds indicate the mean values, with error bars reporting the standard error of the mean. *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

Internal and External Details

We conducted a repeated-measures ANOVA on the number of details with Time and Type of Detail (internal and external) as within-subject factors and Group as a between-subject factor.

The analysis revealed a significant main effect of Type of Detail, $F(1, 33) = 8.40, p = .007$; $\eta_p^2 = .20$, and a significant main effect of *time,* $F(2, 66) = 11.73, p < .001$; $\eta_p^2 = .26$, which configured in a significant Time × Type of Detail interaction, $F(1.602, 52.882) = 7.90, p = .002$; $\eta_p^2 = .19$: Participants produced more internal compared with external details in the recent past ($p < .001$), whereas no difference in internal and external details emerged in the remote past and the future (all ps $\geq .99$). The effect of group was not significant, $F(2, 33) = 1.296, p = .287$, but there was a significant Type of Detail × Group interaction, $F(2, 33) = 6.49, p = .004$; $\eta_p^2 = .28$: Post hoc comparisons showed that HC produced more internal than external details ($p < .001$), but this difference was not significant in CP ($p = .41$) and numerically opposite in vMPFC patients ($p = .99$). Indeed, vMPFC patients reported significantly more external details compared with HC ($p = .024$) but not with CP ($p = .99$), with no difference between HC and CP ($p = .99$). No group differences emerged in the number of internal details (all ps $\geq .99$; see Figure 9). No other effects or interactions were significant (all ps $\geq .77$).

Qualitative Ratings

We conducted repeated-measures ANOVAs on the qualitative ratings of emotional valence, importance, and relationship with personal goals, with Group (HC, vMPFC patients and CP) as a between-subject factor and Time (remote past, recent past, and near future) as a within-subject factor.

Emotional Valence

We found a main effect of Time, $F(2, 66) = 18.696$; $p < .001$; $\eta_p^2 = .362$, suggesting that imagined future events (mean = 1.64) were rated as more positive than events

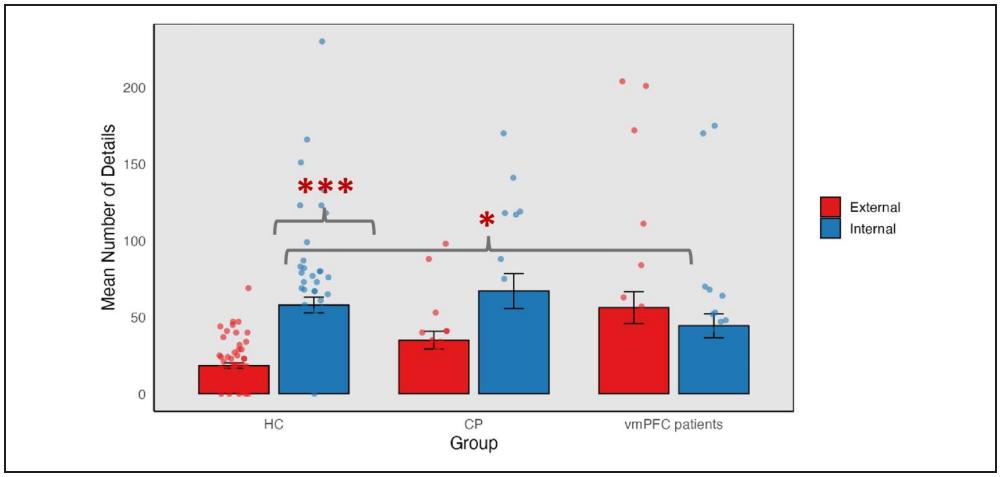

Figure 9. Number of details. Mean number of details produced by Group (HC, CP, and vMPFC patients) and Type of Detail (internal and external). Data are collapsed across time conditions. Error bars indicate the standard error of the mean. *$p < .05$, **$p \leq .01$, ***$p \leq .001$.

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that happened in the recent (mean = 2.96; $p < .001$) and the remote past (mean = 2.79; $p < .001$). The factor *group,* $F(2, 33) = 2.457$; $p = .101$, and the interaction Time × Group, $F(4, 66) = 1.082$; $p = .373$, were not significant.

Importance

The analysis yielded a main effect of Time, $F(2, 66) = 9.441$; $p < .001$; $\eta_p^2 = .222$, revealing that events in the remote past were rated as less important (mean = 2.57) than events in the recent past (mean = 1.83; $p = .002$) and the future (mean = 1.72; $p < .001$), with no differences between the recent past and the future ($p = .50$). The factor Group, $F(2, 33) = 0.502$; $p = .610$, and the interaction Time × Group, $F(4, 66) = 1.624$; $p = .179$, were not significant.

Relationship with Personal Goals

We found a main effect of Time, $F(2, 66) = 4.937$; $p = .010$; $\eta_p^2 = .130$, whereby imagined future events were rated as significantly more related to participants' personal goals (mean = 2.60) compared with events in the recent (mean = 3.19; $p = .017$) and remote past (mean = 3.36; $p = .026$), with no differences between the remote and the recent past ($p = .76$). The factor Group, $F(2, 33) = 1.826$; $p = .177$, and the interaction Group × Time, $F(4, 66) = 1.071$; $p = .378$, were not significant.

DISCUSSION

The present study aimed to investigate the role of vMPFC in personal semantic memory and in guiding the temporal progression in the activation of hierarchical memory structures during episodic memory and future thinking (MTT). To this aim, we had vMPFC patients, CP, and HC undergo a personal semantic interview. Moreover, we noted the progression in the activation of memory structures at different levels in the memory hierarchy while participants recalled and imagined events. Crucially, we used a "think aloud" method, in which participants uttered whatever came to their mind while constructing past and future events, allowing us to note the activation of all types of knowledge structures during MTT, from the more abstract (personal semantics) to the more concrete (specific events). As predicted, we found that vMPFC patients produced less correct personal semantic information than the control groups during the personal semantic interview. However, contrary to our expectations, they did initiate MTT by accessing higher-order memory structures (personal semantics and repeated events) and in fact tended to resort to these memories even more frequently than the control groups during MTT. vMPFC patients, however, produced more repeated events and fewer specific events than HC during MTT. Notably, vMPFC patients showed a marked alteration of retrieval dynamics: They showed atypical, backward transitions from lower- (e.g., extended and repeated events) to higher-level memory structures (e.g., personal semantics). We discuss each of these findings in turn.

First of all, we found impaired personal semantic memory in vMPFC patients. At the personal semantic interview, indeed, vMPFC patients showed reduced access to personal semantic information, particularly regarding places attended in the past and previous schools attended/job positions held. The reduction in personal semantics following vMPFC damage supports previous evidence that vMPFC is engaged while processing personal semantic memory (Stendardi, Giacometti Giordani, Gambino, Kaplan, & Ciaramelli, 2023; Verfaellie et al., 2019; D'Argembeau, 2013; Renoult, Davidson, Palombo, Moscovitch, & Levine, 2012; Wheeler & Stuss, 2003). Notably, this impairment was more pronounced for places and schools/jobs, which, we argue, are fundamental cues for event construction. Event construction, indeed, requires integrating episodic and semantic memories (Schacter, 2012; Schacter, Addis, & Buckner, 2008) within coherent spatial contexts (Hassabis & Maguire, 2009). Spatial contexts (as opposed, e.g., to information about people) are most effective retrieval cues that significantly enhance memory vividness (Robin et al., 2015; Robin & Moscovitch, 2014; Burgess, Becker, King, & O'Keefe, 2001). Schools/jobs, on the other hand, may relate to personal goals, which are even more effective than person and place information in driving the mental construction of future events (D'Argembeau, 2016; Schacter et al., 2012; D'Argembeau, Renaud, & Van der Linden, 2011; D'Argembeau, Ortoleva, Jumentier, & Van der Linden, 2010). vMPFC patients also proved less aware of the typical, culturally shared events that constellate lifetime periods compared with HC and, marginally, CP. In a previous report (Pisani et al., 2025), we also found that vMPFC patients had a reduced capacity to place typical life events in the appropriate position on an imaginary lifeline compared with HC and brain-damaged controls, which, too, points to a deficit in personal semantic memory. Life scripts are important drivers to the construction of specific events (Koppel & Berntsen, 2014), and, therefore, poor knowledge of life scripts may underlie MTT deficits in vMPFC patients. The finding that vMPFC damage disrupted personal semantic memory is in line with the proposal that vMPFC is implicated in activating high-level (semantic or schematic) knowledge during event construction (Ciaramelli, Anelli, & Frassinetti, 2021; Giuliano, Bonasia, Ghosh, Moscovitch, & Gilboa, 2021; Ciaramelli et al., 2019; McCormick et al., 2018; Moscovitch et al., 2016; Ghosh et al., 2014).

Contrary to our expectations, even though personal semantic information was degraded in vMPFC patients, they still did use it to initiate the retrieval process. In fact, we found that vMPFC patients generated higher-order knowledge structures, such as personal semantics, repeated events, and extended events, even more frequently than HC, while they accessed specific events

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less frequently than the control groups, consistent with previous reports (e.g., De Luca et al., 2018; Bertossi et al., 2017; Bertossi, Aleo, et al., 2016; Bertossi, Tesini, et al., 2016). Thus, although vMPFC patients showed a preserved retrieval dynamic with respect to the early activation of higher-order memory structures, they then struggled to descend in the retrieval hierarchy and activate specific events. One possibility, compatible with the results of the personal semantic interview, is that, although vMPFC patients can activate personal semantic memories to initiate MTT, the available personal semantic memories are fewer or less detailed in vMPFC patients than in the control groups (in our data, spatial locations and job information were scant), and therefore are less likely to successfully guide the construction of specific events.

Another possibility relates to retrieval dynamics across groups. The results of the event construction task using the think-aloud method in healthy participants confirm those originally highlighted by D'Argembeau and Mathy (2011; see also Conway, 2009; Conway & Pleydell-Pearce, 2000): For both past and future events, event construction is frequently a protracted generative process in which personal semantic knowledge is accessed before episodic details. Our results show that healthy participants constructed mental events either directly (i.e., activating specific events in Unit 1; 28% of cases) or, more frequently, indirectly (i.e., activating personal semantics or extended events in Unit 1, followed by specific events in Unit 2; 72% of cases). During the indirect path, they initiated event construction relying on personal semantics or extended events, reinforcing the view of autobiographical knowledge as a framework for retrieving, integrating, and interpreting episodic details while constructing specific events (D'Argembeau, 2020; D'Argembeau & Mathy, 2011). The dynamics of event construction were not completely subverted in vMPFC patients as we had originally thought. Indeed, as anticipated, even vMPFC patients initiated MTT by activating personal semantics or extended events in Unit 1. However, instead of accessing specific events in Unit 2, they more frequently accessed, and somehow got stuck in, repeated events (i.e., collections of the common features of similar episodes; e.g., my holidays at the beach as a kid; Renoult et al., 2016; Neisser, 1981). Repeated events tend to be recalled less vividly and are rated lower in personal significance and emotional intensity compared with specific events (Holland, Addis, & Kensinger, 2011; Addis et al., 2004; Levine et al., 2004). These differences have been confirmed in fMRI studies (Holland et al., 2011; Addis, Moscovitch, Crawley, & McAndrews, 2004; Levine et al., 2004; see also Martinelli, Sperduti, & Piolino, 2013) reporting higher activity in the MPFC for specific events and in right inferior temporal cortex for repeated events. Our finding of an increased tendency to converge on repeated events in vMPFC patients makes contact with the findings from Serra and colleagues (2014) and from Ciaramelli (2008) in patients with confabulation, the tendency to produce false memories for unhappened events commonly associated with vMPFC damage (Schnider, 2008). Confabulating patients, too, often mistakenly report and experience habits and repeated occurrences as unique, currently relevant events (Serra et al., 2014; Ciaramelli, 2008; see also Dalla Barba, Brazzarola, Marangoni, Barbera, & Zannoni, 2017; Dalla Barba & Boisse, 2010). In addition to an abnormal tendency, on the vMPFC patients' part, to converge on repeated events, these patients showed another marked anomaly in retrieval dynamics, namely, "backward" transitions from repeated events and extended events to more abstract memory structures, such as personal semantics, a tendency that was not observed in the control groups. Backward transitions may relate to an inability to use extended and repeated events to cue specific events down the retrieval hierarchy, leading to a regression toward more abstract representations, possibly in an attempt to trigger the retrieval cascade again. Of course, backward transitions may account for vMPFC patients' higher rates of personal semantics and lower rates of specific events. During both past and future MTT, vMPFC patients were not capable of accessing specific events; they reached extended events at best. This is not because they failed to comply with the task's demands. Indeed, across groups, constructed future events were perceived as more emotionally engaging, important, and connected to one's goals than past events, suggesting that all groups, including vMPFC patients, were able to follow the task instructions and impart a temporal direction to their constructed events. The fact that vMPFC patients accessed fewer specific events than the control groups confirms previous evidence of impaired MTT following vMPFC damage, a state of consciousness anchored to the present moment (De Luca et al., 2018; Bertossi et al., 2017; Bertossi, Aleo, et al., 2016; Bertossi, Tesini, et al., 2016; Levine et al., 2004; Moscovitch & Melo, 1997). As anticipated, we argue that, in vMPFC patients, access to specific events is prevented, at least in part, by the degradation of semantic memory structures that normally guide event construction, such as personal semantics (Renoult et al., 2012, 2016; Preston & Eichenbaum, 2013). These help frame the search of episodic details and monitor the output of memory search (e.g., McCormick et al., 2018; Moscovitch et al., 2016; Cabeza & St Jacques, 2007; Svoboda, McKinnon, & Levine, 2006). Note, however, that unlike these previous studies, here, we did not find that vMPFC patients produced fewer internal (episodic) details than the control groups (Bertossi, Aleo, et al., 2016; Bertossi, Tesini, et al., 2016). We found that, compared with the control groups, vMPFC patients produced a similar number of internal details and more external details. One possibility is that the think-aloud procedure we adopted, requiring to utter whatever comes to the participants' mind, placed relatively less emphasis on the production of internal details than the most typical procedures that encourage to report only specific events, and result indeed in typically low rates

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of external details. In addition, lifetime periods may be more effective cues to specific events than single words (Bertossi, Aleo, et al., 2016). Alternatively, these findings may suggest that vMPFC damage impairs the early stages of event construction—as reflected in the lower number of specific events vMPFC patients accessed—but that once an event is constructed, the capacity to elaborate it with episodic detail is relatively intact, confirming a more pronounced role of vMPFC in initiating event construction (D'Argembeau, 2020; Ciaramelli et al., 2019). Future studies using the think-aloud procedure but using minimal cues (e.g., words) will help clarify this issue.

In summary, the present study reveals that vMPFC damage impairs personal semantic memory and disrupts the normal temporal progression in the activation of memory structures during event construction, highlighting anomalous "attractor" memory structures (repeated events; Ciaramelli, 2008) and backward transitions from lower- to higher-level memory structures, resulting in reduced access to specific events. Taken together, our findings confirm the role of vMPFC as a supervisor (McCormick et al., 2018) and an integration hub (D'Argembeau, 2020) during event construction, which warrants memory search and monitoring of autobiographical knowledge along the retrieval hierarchy.

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Data Availability Statement

We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all data manipulations, and measures of the study. Experimental data that support the findings of this study are available upon request from the corresponding authors. Supplemental Material can be accessed on this article's homepage: https://doi.org/10.1162/JOCN.a.2422.

Author Contributions

Giovanni Cantarella: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing—Original draft; Writing—Review & editing. Angelo Pisani: Data curation; Formal analysis; Writing—Original draft; Writing—Review & editing. Debora Stendardi: Conceptualization; Methodology; Writing—Review & editing. Matteo Cetraro: Data curation; Formal analysis; Investigation. Emma Pasquini: Data curation; Formal analysis; Investigation. Elisa Ciaramelli: Conceptualization; Funding acquisition; Methodology; Project administration; Resources; Supervision; Writing—Review & editing.

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Diversity in Citation Practices

Retrospective analysis of the citations in every article published in this journal from 2010 to 2021 reveals a persistent pattern of gender imbalance: Although the proportions of authorship teams (categorized by estimated gender identification of first author/last author) publishing in the *Journal of Cognitive Neuroscience* (*JoCN*) during this period were M(an)/M = .407, W(oman)/M = .32, M/W = .115, and W/W = .159, the comparable proportions for the articles that these authorship teams cited were M/M = .549, W/M = .257, M/W = .109, and W/W = .085 (Postle and Fulvio, *JoCN*, 34:1, pp. 1–3). Consequently, *JoCN* encourages all authors to consider gender balance explicitly when selecting which articles to cite and gives them the opportunity to report their article's gender citation balance.

Notes

1. We also conducted a sensitivity analysis for a one-way ANOVA including three groups, a total sample size of 36, $\alpha = .05$, and power $(1 - \beta) = 0.95$. Results indicated that the smallest between-groups effect size that could be reliably detect corresponded to a critical F value of 3.28. All F values we observed exceeded this threshold, indicating that the reported between-groups effects were above the detection limit of our design.
2. It is important to note that if we analyze the data using words as cues with the scoring method used here, we obtain findings similar to those observed with life-period cues. Namely, we found that participant groups accessed high order knowledge structures before specific events, while both remembering the past and imagining the future (replicating again D'Argembeau & Mathy, 2011, who also used words as cues). Moreover, we found that vMPFC patients tend to access fewer specific events and more high-level knowledge structures than healthy controls, although in the case of word-cues these were mainly repeated events (and not personal semantics, as was the case for the main investigation using life-period cues), which we attribute to the peculiarity of different cues. Finally, we found that vMPFC patients tended to access specific events in later units compared with healthy controls.

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