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Similarity between remembering the past and imagining the future in Alzheimer's disease: Implication of episodic memory

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ABSTRACT

Recent studies suggest that common cognitive processes and neuroanatomical substrates underlie the ability to remember the past and imagine the future. We studied these cognitive processes in patients with Alzheimer's Disease (AD). We asked 27 participants with AD and 30 older controls, matched by age, sex, and educational level, to generate past and future autobiographical events. Autobiographical generation was analyzed with respect to theme, general autobiographical performance, contextual performance, self-defining memories, and autonoetic reliving/re-experiencing. Unlike older controls, most AD participants evoked similar themes when generating past and future events (n=23/30 participants). These participants also showed similar autobiographical and contextual performance, similar amount of self-defining memories, and similar autonoetic states when generating past and future events. Further, significant correlations were detected between hippocampal-dependent memory decline in AD participants and their ability to relive past and future events. These outcomes suggest striking similarities between remembering the past and imagining the future in AD. Due to their memory decline, imagining the future in AD patients is likely to draw heavily from the little amount of available information from past episodes, resulting in striking similarities between remembering the past and imagining the future. Finally, and unlike AD participants, older controls mentally "try out" alternative approaches to upcoming situations without replicating the same schemes of past events.

A growing body of literature has been documenting striking similarities between remembering the past and imagining the future. Both abilities have been found to employ common cognitive processes and neuroanatomical substrates. In regard to cognitive processes, projecting oneself into the past or into the future may trigger similar phenomenological experiences. According to the work of Tulving (1985, 2005), subjective experience of the past and future involves autonoetic consciousness, "the kind of consciousness that mediates an individual's awareness of his or her existence and identity in subjective time extending from the personal past through the present to the personal future" (Tulving, 1985, p. 1). Accordingly, the subjective experience associated with both remembering the past and imagining the future is determined by similar factors, such as combination of sensory features within a specific temporal and spatial reference system, retrieving of contextual details, mental simulation and imagery, and attribution of personal significance (D'Argembeau et al., 2012, 2008). In regard to neuroanatomical substrates, fMRI studies indicate that both remembering the past and imagining the future activate the default mode network, which includes medial prefrontal and medial parietal nodes, such as the retrosplenial, posterior cingulate and precuneus cortices (e.g., Addis et al., 2007; Okuda et al., 2003; Viard et al., 2012).

Interestingly, the hippocampus (e.g., Laakso et al., 1998; Rauchs et al., 2007), as well as the posterior nodes of the default mode network, such as the retrosplenial/posterior cingulate/precuneus cortex (Seeley et al., 2009), are preferentially targeted by Alzheimer's Disease (AD) neuropathology. Therefore, one may expect that, besides their well-known impairment in remembering the past, patients with AD are proportionately impaired in their ability to imagine the future. This issue was investigated by Addis and associates (Addis et al., 2009) who asked AD patients to generate past and future autobiographical events. Autobiographical generation was further separated into episodic (i.e., unique occurrences of specific events or thoughts) and semantic components (i.e., general or repeated events). Results showed deficits in

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remembering the past and imagining the future. Moreover, these abilities were closely related, as significant correlations were detected between past and future episodic, as well as semantic, autobiographical generation. Further evidence of the close linkage between past and future autobiographical generation was provided by Addis et al. (2009) who observed no significant differences between both generations in terms of personal significance, temporal distance, or emotional intensity.

The aim of the present study was to further investigate the similarities between past and future autobiographical generation in AD. Although the distinction of autobiographical recall into episodic and semantic components, in the work of Addis et al. (2009), may be conceptually appealing, it does not evaluate core aspects of episodic recall, such as the ability to retrieve contextual information which is involved in both remembering the past and imagining the future (D'Argembeau et al., 2008). Moreover, episodic memory has been related to autonoetic consciousness, which is defined as subjective feeling of reliving/re-experiencing or mental time travel into the past of future (Tulving, 1985, 2005). Thus, imagining the future may trigger retrieval of contextual details and autonoetic consciousness, similar to remembering the past.

We also investigated whether remembering the past and imagining the future contribute to the construct of self in AD patients. Although Addis et al. (2009) found that past and future events were of personal significance to AD patients, it is unknown whether imagining the future triggers self-defining memories in AD. The latter memories refer to events that are associated with self-discovery, self-understanding, and self-images, contributing to a life story and sense of identity (Blagov and Singer, 2004; Singer and Salovey, 1993; Thorne et al., 2004; Wood and Conway, 2006). The default mode network, which is the main target of AD pathology (Seeley et al., 2009), is the neuroanatomical substrate for projection of the self to the past and future or, perhaps, the basis of "ego" itself (Carhart-Harris and Friston, 2010). Self-defining memories are prone to degradation in AD and a relationship between autobiographical memory impairment and weakened sense of self exists in AD (Addis and Tippett, 2004; Fargeau et al., 2010; Massimi et al., 2008; Orona, 1990). More specifically, Martinelli et al. (2013) found difficulties in retrieving self-defining memories in AD patients, which they attributed to impaired reconstruction of episodic autobiographical memories. However, the study assessed self-defining memories in AD based solely on generation of past events, leaving open whether the same difficulties may be observed in generation of future events.

The similarities between remembering the past and imagining the future and the degradation of both in AD patients may be interpreted in the terms of the "constructive episodic simulation hypothesis". According to this hypothesis, imagining the future requires retrieving details from episodic memory and flexibly recombining them into a coherent simulation (Schacter and Addis, 2007a, 2007b). The "constructive episodic simulation hypothesis" hence suggests episodic memory as a common cognitive function that unifies past and future thinking. If this is the case, any decline in past and future thinking in AD should be related to the decline in episodic memory, a hypothesis that we pursued in the present study.

Taken together, a body of literature has suggested intimate relationships between past and future thinking. With this study, we extend and complement this literature by assessing whether AD participants mentally "try out" alternative approaches to future situations without replicating the same schemes as in past events. In that regard, we compared AD patients to control older adults in terms of contextual details, consciousness states, and self-implication in past and future thinking. Specifically, we assessed contextual similarities in terms of spatio-temporal and affective contextual conceptualization by Tulving (1985, 2005); consciousness state was assessed with a reliving assessment [(an adaptation of the Remember/know paradigm (Gardiner, 2001)]; and self-defining memories were defined as memories contributing to a life story and sense of identity (Blagov and Singer, 2004; Singer and Salovey, 1993; Thorne et al., 2004; Wood and Conway, 2006). In accordance with the literature suggesting common cognitive (D'Argembeau and van der Linden, 2004, 2006; D'Argembeau et al., 2008) and neuroanatomical mechanisms (see, Schacter et al. (2012a)) for remembering the past and imagining the future, we hypothesized that both abilities trigger generation of similar themes, with the same amount of contextual details, similar phenomenological experience, and self-defining memories. Another objective of our work was to provide support for the "constructive episodic simulation hypothesis" (Schacter and Addis, 2007a, 2007b), suggesting episodic memory as a common underpinning of past and future thinking. Following this view, we hypothesized that difficulties in both remembering the past and imagining the future would be related with memory deterioration in AD.

1. Method

1.1. Participants

We tested 27 participants with a clinical diagnosis of probable AD at the mild stage (17 women and 10 men; M age = 71.85 years, SD = 7.01; M years of formal education = 8.67, SD = 2.73) and 30 control older adults (19 women and 11 men; M age = 72.47 years, SD = 7.04; M years of formal education = 9.92, SD = 2.99). The AD participants were recruited from local retirement homes. The patients were diagnosed with probable AD dementia of the amnestic form by an experienced neurologist or geriatrician based on the National Institute on Aging-Alzheimer's Association clinical criteria (McKhann et al., 2011). The fact that all patients had the amnesic form of AD is confirmed by their performance on the neuropsychological battery. The control participants, who were often spouses or companions of AD patients, were independent and living at their homes. These participants were matched with the AD patients according to age [$t(55) = .33$, $p > .10$], sex [X^2 (1, $N = 57) = .01$, $p > .10$], and educational level [$t(55) = 1.53$, $p > .10$].

Exclusion criteria for both AD patients and control participants were: significant psychiatric or neurological illness, history of clinical depression, alcohol or drug use. All participants presented no major visual or auditory acuity difficulties that would have prevented completion of study tasks. They freely consented to participate and were able to withdraw whenever they wished. Of the 35 AD participants originally recruited, three participants leaved the study for personal reasons, four due to health problems, and one participant was excluded for ensuing visual impairment associated with recent eye surgery. Of the 35 control participants originally recruited, five participants were excluded for severe executive dysfunction raising doubts about their classification as controls.

1.2. Neuropsychological characteristics

Neuropsychological characteristics of all participants were evaluated with a battery tapping general cognitive functioning, episodic memory, working memory, inhibition, set-shifting, and depression. General cognitive functioning was assessed with the Mini Mental State Exam (MMSE) Folstein et al. (1975). Non-associative hippocampal-dependent verbal memory was evaluated with the task of Grober and Buschke (1987); in its French adaptation (Van der Linden et al., 2004) the participants had to retain

16 words, each of which describes an item that belongs to a different semantic category. After immediate cued recall, the participants proceeded to a distraction phase, during which they had to count backwards from 374 in serial 20 s. This phase was followed by 2 min of free recall and the score from this phase (out of a maximum of 16) provided a measure of hippocampal-dependent verbal memory, which is closely linked to episodic memory. For working memory assessment, participants had to repeat a string of single digits in the same order (i.e., forward span) or in the inverse order (i.e., backward span). Inhibition was assessed with the Stroop task, which was scored as completion time for the interference condition minus the average completion time for the word reading and color naming conditions. Shifting was assessed with the Plus–Minus task, and the score referred to the difference between the time for List 3 (shifting between addition and subtraction) and the average times for Lists 1 (addition) and 2 (subtraction) (for more details about the inhibition and shifting assessment, see, El Haj et al. (2012a, 2013a)). For assessment of depression, the Hospital Anxiety and Depression Scale (HADS, Zigmond and Snaith, 1983) was administered. This self-report scale consists of seven items on a four-point scale from 0 (not present) to 3 (considerable). As recommended by Herrmann (1997), the cut-off for definite depression was set at $>10/21$ points. Neuropsychological and clinical scores for study participants are summarized in Table 1.

1.3. Procedures

1.3.1. Autobiographical and reliving assessment

Participants were tested individually in their homes or their rooms/apartments (in retirement homes) during 2 sessions, one dedicated to remembering past events and one to imagining future events. Sessions were counterbalanced and separated by approximately 1 week. Participants were informed that they were taking part in a study examining their cognitive performance.

In each session, participants were asked to "recount in detail an event in their lives" or "imagine in detail a future event", regardless of when the event occurred or will occur. This instruction has been widely used to cue autobiographical generation for past events (El Haj et al., 2012b, 2012c, 2013b; Fromholt et al., 2003; Piolino, 2008 Piolino et al., 2000) and future events in AD patients (Addis et al., 2009). Participants were allowed 3 min to describe their memories, and the duration was stated from the onset so that they could structure, so far as possible, their memories accordingly. This time limit was adopted to avoid bias introduced by any attention deficits and concomitant distractibility and is sufficient for autobiographical recollection for most AD patients (Addis et al., 2009; El Haj et al., 2012b, 2012c, 2013b). For future events, the investigator explained that participants had to imagine events that might reasonably happen in the future. For all past and future events, we clarified that participants had to be precise and specific, that is, events had to have lasted/last no more than a day and details had to be provided, such as time and place at which events had/will have occurred, as well as to describe their feelings and emotions during those events. Some examples were also provided to illustrate what would be considered as a specific event. Subsequently, participants were briefed about the reliving paradigm, and the investigator explained: "If the event involves a specific place and time, as well as specific feelings, thoughts, or emotions, then you can provide a "Relive/Re-experience" response. If the event is taking place without involving such specific information, then you must provide a "Recognize" response. Finally, if you are not sure whether you relive or not the event, than you can provide "I Do not Know" response". This reliving paradigm and its instructions were an adaptation from the Remember/Know paradigm (Gardiner, 2001), the only difference being that the terms "Remember", "Know", and "Guess" were replaced by "Relive/Re-experience", "Recognize", and "I Do not Know", respectively. This modification was due to the fact that imagined events cannot be either remembered or known. In order to ensure that participants understood the reliving instructions, they were asked to repeat them using their own words. When failing to do so, which was the case of 4 AD participants, further clarifications were provided by the experimenter (for the same procedures, see, El Haj et al. (2014)). In addition, we provided participants with detailed written instructions about what constitutes specific information, as well as few exemplar reliving responses, to which participants were able to refer throughout the study, as needed (using black Times New Roman 48-point font on a white A4 sheet of paper). Also, after each autobiographical generation, the experimenter briefly repeated the reliving instructions. The participants' autobiographical generation narratives were recorded using a smartphone and were transcribed at a later time.

Table 1
Neuropsychological and clinical characteristics of Alzheimer's disease (AD) patients and control participants.

Task		AD $n=27$	Older adults $n=30$
General Cognitive functioning	Mini-Mental State Examination (MMSE)	21.89 (1.50)***	28.30 (1.25)
Verbal memory	Grober and Buschke	5.63 (2.32)***	11.17 (3.08)
Working memory	Forward span	5.37 (1.42)*	6.43 (1.79)
	Backward span	3.74 (1.16)***	5.27 (1.41)
Inhibition	Stroop	64.04 (7.39)***	36.07 (9.76)
Shifting	Plus-Minus	12.41 (7.17)***	6.17 (3.40)
Depression	HADS	7.07 (2.30)**	4.77 (2.66)

Note: Standard deviations are given between brackets; the maximum score on MMSE was 30 points; the maximum score on the Grober and Buschke's (1987) task was 16 points; performances on the forward and backward spans referred to number of correctly repeated digits; scores on the Stroop and Plus-Minus tasks referred to reaction time; the cut-off on the HADS (Hospital Anxiety and Depression Scale) was $>10/2$ points; differences between groups were significant at: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$; after checking for normality of distributions, comparison for the MMSE, plus-minus task, and forward span was established with Mann–Whitney's *U* test (abnormal distribution) and comparisons for remaining tasks were established with Student's *t*-test (normal distribution).

1.3.2. Processing of autobiographical transcriptions

From the autobiographical transcription of each event (114 events in total), we extracted a central theme and Relive/Recognize/Do not know answers, identified self-defining memories, and generated scores for general autobiographical performance and contextual performance. Appendix A depicts example of how each transcription was done.

Theme. The main theme of each event was defined. When events described more than one theme, which was the case of 11 events, the theme taking most time in the narrative was selected as the central theme.

General autobiographical performance. General autobiographical performance (in terms of general as opposed to specific recall) was scored with the TEMPau scale (Test épisodique de mémoire du passé, Piolino et al., 2000, 2006, 2007), an autobiographical evaluation instrument adapted in French. For each event, we provided no points, if there was no memory or only general information about a theme. We provided one point for a repeated or an extended event; two points for an event situated in time or/and space; three points for a specific event lasting less than 24 h and situated in time and space; and four points for a specific eventsituated in time and space with the presence of phenomenological details (e.g., feelings, perceptions, thoughts, or visual imagery). Thus, the maximum autobiographical score for each participant was four points.

Contextual performance. To expand the TEMPau scoring system, which was built according to the principles of episodic conceptualization by Tulving (1985, 2005), contextual performance was assessed by counting the number of spatiotemporal details, that is, pieces of information about "when, where, and who" (for the same procedures, see, Ivanoiu et al. (2006)). Following the TEMPau scoring system, we also assessed contextual performance in terms of affective details.

Self-defining memories. An event was considered as a self-defining memory if it contributed to the way participants viewed themselves; if it was related to their personality construction; and/or if it referred to chronic concerns or unresolved conflicts. Self-defining memories were also defined as events significantly contributing to life story and sense of identity (for a similar definition, see, Blagov and Singer (2004), Martinelli et al. (2013), Singer and Salovey (1993), and Wood and Conway (2006)).

Reliving/Re-experiencing. Here we counted the number of "Relive/Re-experience", "Recognize", and "Do not know" responses, as provided by each participant (a total of 114 responses).

Inter-rater agreement. To avoid bias in scoring, events were rated and categorized by both the investigator that administered the task and an independent rater who was blind to the study hypotheses and to individual participants' group membership (patients with AD vs. controls). Using Cohen's Kappa coefficient (κ) (Brennan and Prediger, 1981), high inter-rater agreement coefficients were obtained as to theme defining (κ=.89), general autobiographical performance (κ=.91), contextual performance (κ=.82), and self-defining memories (κ=.84). In cases of disagreement, events were discussed until a consensus was reached.

Statistical analysis. To address our first hypothesis, we assessed similarities between past and future generation in terms of 1) theme similarity of past and future events 2) general autobiographical performance 3) number of contextual details 4) number of self-defining memories and 5) distribution of "Relive/Re-experience", "Recognize", and "Do not know" responses. Due to the fact that some variables were categorical and some scalar, and also due to the abnormal distribution of the number of contextual details, we conducted non-parametrical tests. Differences in theme, self-defining memories, and "Relive/Re-experience", "Recognize", and "Do not know" responses were assessed with Chi-square tests. Differences in autobiographical and contextual performance between past and future generation, and between AD participants and older adults, were assessed with the Wilcoxon signed rank and Mann–Whitney's *U* tests, respectively.

Regarding our second hypothesis, we tested the "constructive episodic simulation hypothesis" by conducting non-parametric Spearman correlations between delayed free recall, as assessed with the task of Grober and Buschke, and past and future autobiographical generation. Correlations were computed only for AD participants since most older adults showed ceiling effects in general autobiographical performance. To assess whether correlation coefficient for memory performance and past generation is greater than for memory performance and future generation, a Fisher transformation (Zr) was performed for both correlation coefficients.

1.4. Results

Table 2 depicts performances on both conditions.

1.4.1. Same theme for past and future events in AD participants

Twenty/27 AD participants evoked the same theme while generating past and future events, a number that was significantly higher than that of participants evoking a different theme (n=7) [X^2 (1, N=27)=4.48, $p<.05$]. The reverse pattern was observed in controls, since only 7/30 evoked the same theme while generating past and future events, a number that was significantly lower than that of participants evoking different themes (n=23) [X^2 (1, N=30)=8.53, $p<.01$]. The number of AD participants (n=20) evoking the same theme while generating past and future events was significantly higher than that of older adults (n=7) [X^2 (1, N=27)=6.26, $p<.05$], and the reverse pattern was observed for the number of AD participants (n=7) and controls evoking different themes (n=23) [X^2 (1, N=30)=8.53, $p<.01$].

1.4.2. Similar autobiographical performance for past and future events in AD participants

Wilcoxon signed rank tests showed no significant differences between autobiographical performance, as assessed with the TEMPau scale, for past and future generation, in AD participants ($Z=-.71$, $p>.01$), and controls ($Z=-.57$, $p>.01$). However, Mann–Whitney's *U* tests showed lower autobiographical performances in AD participants compared to controls for past ($Z=-5.45$, $p<.001$), and future events ($Z=-4.14$, $p<.001$). Significant positive correlations were detected between TEMPau scores for past and future generation in AD participants, r=.45, $p<.05$.

1.4.3. Similar amount of contextual details for past and future events in AD participants

Wilcoxon signed rank tests showed no significant differences between number of contextual details for past and future events in AD participants ($Z=-1.07$, $p>.01$), and controls ($Z=-1.22$, $p>.01$). However, Mann–Whitney's *U* tests showed fewer contextual details in AD participants than in older adults for past ($Z=-3.40$, $p<.01$), and future events ($Z=-2.09$, $p<.05$).

1.4.4. Similar production of self-defining memories for past and future events in AD participants

AD participants showed similar production of self-defining memories during generating past and future events [X^2 (1, N=27)=1.53, $p>.10$], whereas controls produced significantly more self-defining memories during generating past than during

Table 2
Similarity between past and future autobiographical generation, as observed in Alzheimer's Disease (AD) and control participants.

	AD n=27		Older adults n=30	
	Past	Future	Past	Future
Theme	20 participants evoked the same theme		7 participants evoked the same theme	
General autobiographical performance	2.81 (.83)$^{n/s}$	3.87 (.35)	3.97 (.18)$^{n/s}$	3.93 (.25)
Number of contextual details	11.96 (6.04)$^{n/s}$	10.19 (5.78)	17.63 (5.14)$^{n/s}$	15.43 (8.98)
Number of self-defining memories	8$^{n/s}$	6	15*	12
Number of "Reliving", "Recognizing", and "Do not know" responses	12 Rel+14 Rec+ 1 D$^{n/s}$	10 Rel+15 rec+2 D	18 Rel+7 Rec+5 D$^{n/s}$	15 Rel+9 Rel+6 D

Note: Standard deviations are given between brackets; the maximum score of general autobiographical performance was 4 points; $^{n/s}$ the difference between past and future generation was no-significant; * the difference between past and future generation was significant at $p<.05$; after checking for normality of distributions, comparison was established with Wilcoxon signed rank tests (abnormal distribution).

generating future events [X^2 (1, N=30)=5.00, $p<.05$]. AD participants produced significantly less self-defining memories than controls during generating past [X^2 (1, N=57)=21.14, $p<.001$], as well as future events [X^2 (1, N=57)=27.31, $p<.001$].

1.4.5. Similar consciousness states during generation of past and future events in AD participants

No significant differences were detected between distribution of "Reliving", "Recognize", and "Do not know" responses during generation of past and future events in AD participants [X^2 (2, N=54)=.55, $p>.10$], and controls [X^2 (2, N=60)=.61, $p>.10$]. The distribution of "Relive/Re-experience", "Recognize", and "Do not know" responses was significantly different between AD participants and older adults for past events [X^2 (2, N=57)=6.06, $p<.05$]. No significant differences were detected between AD participants and older adults in the distribution of each response while evoking past events [for "Relive/Re-experience", X^2 (1, N=30)=1.20, $p>.10$; for "Recognize", X^2 (1, N=21)=2.33, $p>.10$; and for "Do not Know", X^2 (1, N=6)=2.67, $p>.10$]. Regarding future events, AD participants and older adults also showed similar distribution of "Relive/Re-experience", "Recognize", and "Do not know" responses [X^2 (2, NT=57)=4.35, $p>.10$].

1.4.6. Significant correlations between memory performance and past and future autobiographical generation in AD participants

In AD participants, significant positive correlations were detected between scores on the Grober and Buschke's task and TEMPau scores for past, r=.55, $p<.01$, and future events, r=.45, $p<.05$. Hence, the autobiographical decline in these patients was related to their memory difficulties. Fisher transformation showed no significant differences between the correlation coefficients of memory performance and past generation, and memory performance and future generation (Zr=.46, $p>.1$). In other words, there was no evidence that memory performance was better correlated with past than with future generation in AD patients.

2. Discussion

The aim of the present study was to investigate the phenomenological similarities between remembering the past and imagining the future in AD. In line with our first hypothesis, most AD participants evoked similar themes when generating past and future events, demonstrated similar autobiographical and contextual performance, generated similar amounts of self-defining memories, and experienced similar consciousness states during generating past and future events. Another objective of our work was to provide evidence for the constructive hypothesis, suggesting episodic memory as a common cognitive underpinning for past and future thinking. In line with this hypothesis, significant correlations were detected between memory performance in AD patients and their ability to generate past and future events.

The close link between past and future projection in AD participants can be related to their hippocampus-dependent memory decline. As stated by the "constructive episodic simulation hypothesis", a critical function of episodic memory is to make information available for simulation of future events (Schacter and Addis, 2007a, 2007b). According to this hypothesis, past and future projections draw from similar representations provided by episodic memory. Since AD is characterized by profound episodic memory deterioration, precious little amount of information may be available when future scenarios are scripted. Due to this constraint, future projection may draw heavily from a limited amount of information with no possibility to retrieve more details and, consequently, construct varied future scenarios. The combination of hippocampus-dependent episodic memory impairment and frontal-executive impairment seen in AD may also result in a tendency to perseveration. The impaired cognitive flexibility seen in AD due to frontal dysfunction may result in patients drawing repeatedly from few past episodes in scripting new episodic scenarios, resulting in greater similarity between past and future projection.

We suggest that episodic memory decline deprives AD patients from access to large pools of information when projecting themselves into the future, resulting in them having to draw from a limited range of themes derived from past events. Therefore, our findings provide further support to the "constructive episodic simulation hypothesis" (Schacter and Addis, 2007a, 2007b). Relatively to cognitively normal older adults, AD participants showed poor past and future autobiographical performance on the TEMPau scale, a performance that was reliably correlated with their poor recall, evaluated with the classic verbal memory task by Grober and Buschke (1987). Our work thus contributes to the "constructive episodic simulation hypothesis" by providing statistically solid empirical evidence on the relationship between memory and the ability to imagine the future.

The decline in past and future thinking in AD may be attributable to hippocampal and default mode network involvement by the disease. Several studies suggest that patients with hippocampal damage exhibit not only deficits in remembering past events but also difficulties in imagining future scenarios (Andelman et al., 2010; Hassabis et al., 2007; Race et al., 2011). Furthermore, using fMRI, Weiler et al. (2010) related activity in posterior hippocampus with both past and future thinking and interpreted it as evoking similar combinational processes. According to this interpretation, the hippocampus is mainly engaged in recombination of information extracted from various past events whether encountered together in reality or rearranged during imagining the future or simply for scene construction (Addis and Schacter, 2012; Hassabis and Maguire, 2007). Interestingly, and at odds with the literature about hippocampal engagement in future thinking, Mullally et al. (2012) examined the case of a patient who could construct future scenes despite dense amnesia and 50% bilateral hippocampal volume loss. Using fMRI, the authors found a relationship between the intact future thinking in this patient and activation in medial temporal, and default mode region nodes in retrosplenial, and posterior parietal cortices, as well as increased activity of the right hippocampus. According to the authors, intact scene construction, as observed in some hippocampal-damaged patients, may be supported by residual function in their damaged hippocampus.

The region in the default mode network that may underlie decline of past and future thinking in AD is the posterior cingulate/retrosplenial/precuneus cortex. This region is normally involved in imagery, retrieving of contextual details, and attributing personal significance (Andrews-Hanna et al., 2010; Szpunar et al., 2009), and has been implicated in deficits in both past (Greicius et al., 2004) and future thinking in AD (Irish et al., 2012).

Relatively to cognitively normal older adults, AD participants showed poor autobiographical performance when imagining future events, in agreement with the small body of literature investigating future thinking in AD (Addis et al., 2009; Irish et al., 2012). In addition, AD participants also showed poor autobiographical performance for past events, in agreement with the substantial body of literature about autobiographical decline in AD (e.g., Addis and Tippett, 2004; El Haj et al., 2012a, 2012b, 2013b; Irish et al., 2010; Meulenbroek et al., 2010; Piolino, 2008). According to this literature, autobiographical decline in AD compromises social interactions, (Donix et al., 2010), sense of identity (Addis and Tippett, 2004), as well the ability to relive past events (El Haj et al., 2014; Rauchs et al., 2007). Our findings contribute to this literature by showing poor contextual performance in AD when remembering past and imagining future events. Our findings fit with the scene construction theory, according to which future construction involves the binding of contextual elements into a spatially coherent scene (Hassabis and Maguire, 2007). Moreover, our data may be particularly valuable for assessing the validity of this theory, since we collected information on various contextual elements on our scale that may be differentially altered in AD. Future studies can use our scale to investigate contextual elements of past and future events (i.e., "when, where, and who" or affective dimension) that may be preferentially prone to degradation in AD and reveal their neuroanatomical correlates.

Similar to their poor autobiographical and contextual performance, AD participants produced less self-defining memories than cognitively intact older adults during generating past and future events. This outcome agrees with the findings by Martinelli et al. (2013), showing difficulties in retrieving self-defining memories in AD patients. Our work extends these findings to the patients' thinking about the future. Another difference of AD participants compared to cognitively intact older adults was their impairment of autonoetic consciousness during past and future thinking. This impairment has been studied extensively using the Remember/Know paradigm (El Haj et al., 2014; Hudon et al., 2009; Piolino et al., 2003; Rauchs et al., 2007). According to these studies, impairment of recollection of contextual details results in decline in the subjective feeling of reliving in AD, a suggestion that originated in the work of Tulving (1985, 2005) who linked subjective experience to the amount of retrieved contextual details. In light of the view of Tulving (1985, 2005), the poor contextual retrieval observed in AD may be responsible for the decline in past and future autonoetic reliving/re-experiencing.

Unlike AD participants, cognitively intact older adults tended to produce different themes when generating past and future events. This outcome is of particular interest since it suggests retained mental flexibility in older adults, allowing them to disengage from experienced past events and generated new themes for imagined future events. In this sense, older controls mentally "try out" alternative approaches to upcoming situations without replicating old schemes. This is a heartening finding, since research tends to overemphasize impairments of past and future thinking (and overall cognitive function) with normal aging (for a review, see, Schacter et al. (2012b)). Another difference between past and future generation in cognitively intact older adults was seen in the production of self-defining memories, with fewer such memories being observed during past than during future thinking.

One limitation of our study was the assessment of only one autobiographical event per participant, preventing us from assessing similarities between past and future thinking across a large spectrum of life events and autobiographical periods. Future research should balance this need with clinical and experimental constraints such as AD patients' fatigability. Another limitation of our study may have been ceiling effects for cognitively intact older adults on the TEMPau scale, which prevented us from assessing correlations between past and future general autobiographical performance and episodic memory in these participants. However, we have addressed this limitation by assessing a wide variety of autobiographical indexes (e.g., number of contextual details) that enriched the four-point scale of the TEMPau.

In conclusion, very few empirical investigations have examined the ability to imagine the future in AD. Our work contributes to this literature by showing striking similarities between remembering the past and imagining the future in AD. Our work also highlights a previously overlooked consequence of the memory decline in AD, which deprives patients from the capacity to mentally "try out" novel scenarios when imagining the future. Future neuroimaging studies should elucidate the neural correlates of this impairment, which we hypothesize to be due to combined of frontal, hippocampal and default mode network dysfunction.

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Appendix A

To provide an example of how theme, general autobiographical performance, contextual performance, and self-defining memories were analyzed, we provide an extract from past event generation in one Alzheimer's Disease participant and its analysis.

"I grew up in the countryside… in the south… (general information, zero point)… we had a tiny black dog with which I used to play… I always took care of it… (extended event, one point)… my dog used to sleep under my bed (event situated in space, two points)… until one summer day the dog disappeared… (specific event situated in time, three points)… I was really upset (specific event situated in time with affective details, four point)… perhaps that's why I decided to work in a veterinary clinic… contact with animals has always been a dream of mine (memory contributing to life story, self-defining memory).

Note: The autobiographical score for this participant was four points. One affective contractual detail (i.e., the word "upset")+eight "when, where, and who" contextual information were extracted from this speech (i.e., the words "I", "countryside", south", "dog", "bed", "summer day", "clinic", "animals"). The theme of this speech was defined as "animals". On the reliving paradigm, this participant indicated that this was a "reliving/re-experiencing" response.

An extract from the same participant's future generation:

"I imagine myself living in a big farm… with many animals to take care of… (extended event, one point)… I would like to wake up early to feed the animals… (event situated in space, two points) … I imagine myself with my grandchild walking the dog on an afternoon, my grandchild will be glad to go with me (specific event situated in time with affective details, four point)… I really love animals and that' why I decided to work in a veterinary clinic (memory contributing to life story, self-defining memory).

Note: The autobiographical score for this participant was four points. Two affective contractual details (i.e., the words "glad" and "love")+eight "when, where, and who" contextual information were extracted from this speech (i.e., the words "I", "farm", "animals", "early", "grandchild", "dogs", "afternoon", clinic"). The theme of this speech was defined as "animals". On the reliving paradigm, this participant indicated that this was a "reliving/re-experiencing" response.

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