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Smell your memories: Positive effect of odor exposure on recent and remote autobiographical memories in Alzheimer's disease

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ABSTRACT

Introduction: There is a burgeoning interest in the effects of odor exposure on autobiographical memory in Alzheimer's disease (AD). We pursued this line of research by assessing the effect of odor exposure on the retrieval of recent and remote memories in AD.

Method: Twenty-six patients with mild AD and 28 controls were tested in two conditions: with and without odor exposure. In each condition, participants were invited to retrieve two childhood memories, two adulthood memories, and two recent memories.

Results: Analysis showed that AD patients produced a higher number of and more specific childhood memories, adulthood memories, and recent memories after odor exposure than without odor.

Discussion: These findings demonstrate how odor exposure may alleviate anterograde and retrograde amnesia, at least when considering the ability of patients with mild AD to retrieve few recent or remote memories.

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Alzheimer's disease; autobiographical memory; odor; olfactory stimulation; retrograde amnesia

Autobiographical memory, or memory for personal experiences, has been found to be compromised in Alzheimer's disease (AD), leading to a diminished sense of the self and identity (Addis & Tippett, 2004; El Haj & Antoine, 2017; El Haj, Antoine, Nandrino, & Kapogiannis, 2015; Fargeau et al., 2010; Klein & Gangi, 2010). One main characteristic of autobiographical memory decline in AD is overgenerality—that is, low production of specific memories that occurred at a specific time and place (Barnabe, Whitehead, Pilon, Arsenault-Lapierre, & Chertkow, 2012; El Haj & Antoine, 2018; El Haj, Antoine, & Kapogiannis, 2015; Hou, Miller, & Kramer, 2005; Martinelli, Anssens, Sperduti, & Piolino, 2013; Muller et al., 2013). The difficulty to retrieve specific autobiographical memories in AD has been associated with a weak subjective experience of memories—that is, with a diminished ability to travel back mentally in subjective time (El Haj, Antoine, Nandrino, & Kapogiannis, 2015). Another core characteristic of autobiographical decline in AD is anterograde amnesia (i.e., the inability to form new memories). Supporting this assumption, a body of empirical research has shown better retrieval for remote memories than for recent memories in AD (Greene, Hodges, & Baddeley, 1995; Hou et al., 2005; Irish et al., 2018; Irish, Lawlor, O'Mara, & Coen, 2011; Leyhe, Muller, Milian, Eschweiler, & Saur, 2009; Meeter, Eijsackers, & Mulder, 2006; Piolino et al., 2003). Considering the difficulty of AD patients to retrieve recent memories, we investigated whether this difficulty would be alleviated using olfactory stimulation.

Generally speaking, there is a body of research on the effects of odor exposure on autobiographical memory in nonamnesic populations. In a seminal study, Rubin, Groth, and Goldsmith (1984) invited participants to retrieve memories after odor exposure; results showed that odors cued memories that had never been thought of or talked about previously. Further, Herz and Schooler (2002) reported that odor-evoked autobiographical memories were more emotional and evocative than those evoked by visual or verbal cues. Supporting this suggestion, research has suggested that odor-evoked autobiographical memories trigger strong feelings of being brought back in time to the occurrence of the events (Herz, 2004; Herz & Schooler, 2002). In a similar vein, Larsson and Willander (2009) suggested that emotion is a central aspect of odor-

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evoked autobiographical memories. One study also reported that odor-evoked autobiographical memories triggered mental time travel better than memories evoked by verbal or visual cues in healthy elderly subjects (Willander & Larsson, 2006). Interestingly, odor exposure has been found to trigger specific autobiographical memories. This issue was investigated by Chu and Downes (2002) who found that odor-evoked autobiographical memories are more unique and detailed than memories evoked by other sensory modalities.

The positive effect of odor exposure on autobiographical memory, as reported in the above-mentioned studies, was also reported in several studies on AD. Odor-evoked autobiographical memory in AD was assessed by El Haj, Gandolphe, Gallouj, Kapogiannis, and Antoine (2017) who invited patients with mild AD to retrieve autobiographical memories after odor exposure, after music exposure, and in an odor-and-music-free condition. Results demonstrated better specificity, emotional experience, mental time travel, and retrieval time in AD patients after odor and music exposure than in the control condition. Similar beneficial effects of odor and music exposure were observed in AD patients for specificity, emotional experience, and mental time travel, except for retrieval time, which was more improved after odor exposure than after music exposure. Analyses also demonstrated executive involvement in memories evoked in the control condition but not in those evoked after music or odor exposure. El Haj, Gandolphe, et al. (2017) suggested that odor-evoked autobiographical memories in AD are retrieved in an involuntary fashion; in other words, odor exposure might facilitate spontaneous retrieval of memories by reducing the deliberate effort (i.e., the executive demand) that is usually require to retrieve autobiographical memory. Positive effects of odor exposure on autobiographical memory in AD were also reported by Glachet, Gandolphe, Gallouj, Antoine, and El Haj (2018) who invited patients with mild AD to retrieve autobiographical memories when exposed to odor and, in a control condition, without odor. Compared to memories evoked without odors, odor-evoked autobiographical memories were more specific and were accompanied by more subjective experience in the patients. The latter experience was evaluated with a scale assessing mental time travel, visual and auditory imagery, emotion, and relationship between the retrieved memories and the self.

Inspired by the research reporting benefits of odor exposure on autobiographical memory in AD (El Haj, Gandolphe, et al., 2017; Glachet et al., 2018), the present study tested these benefits for anterograde amnesia in the disease. Because the difficulty to retrieve recent memories (i.e., anterograde amnesia) has been considered as a factor contributing to the diminished sense of self in AD (El Haj, Roche, Gallouj, & Gandolphe, 2017), any potential effect of odor exposure on anterograde amnesia would yield significant clinical benefits for patients. Anterograde amnesia, and memory decline in general, in AD can be associated with neurodegeneration in the medial temporal lobe and, more specifically, in the hippocampus. The relationship between anterograde memory and dysfunctions of the medial temporal lobe has been known since the description of the famous H.M. case (Scoville & Milner, 1957), thus establishing a key role for the medial temporal lobe in consolidation (Squire & Zola-Morgan, 1991).

Taken together, one core characteristic of autobiographical memory decline in AD is difficulties to retrieve recent memories (Greene et al., 1995; Hou et al., 2005; Irish, Hornberger, et al., 2011 ; Leyhe et al., 2009; Meeter et al., 2006; Piolino et al., 2003). Inspired by research reporting the benefits of odor exposure on autobiographical memory in AD (El Haj, Gandolphe, et al., 2017; Glachet et al., 2018), we investigated whether this exposure would ameliorate difficulties to retrieve recent memories in AD patients. To this aim, we invited patients with mild AD and healthy controls to retrieve childhood, adulthood, and recent memories without odor and after odor exposure. We expected that odor exposure would improve the number and specificity of memories, including recent ones, in AD patients.

Method

Participants

The study included 26 patients at the mild stage of AD and 28 healthy controls. AD patients were recruited from local retirement homes and were diagnosed with probable AD dementia by an experienced neurologist or geriatrician based on the National Institute on Aging–Alzheimer's Association clinical criteria (McKhann et al., 2011). The controls were independent, living in their own homes, and recruited from the local community. As shown in Table 1, controls and AD patients were matched according to age, sex, and educational level. Exclusion criteria for all participants were as follows: significant psychiatric or neurological illness (other than AD for the patients), history of alcohol or drug use, or major visual or auditory acuity limitations that would prevent patients completing the study tasks. Since our study dealt with olfactory stimuli, we excluded six participants with nasal congestion, upper respiratory infection, or allergic rhinitis symptoms (original sample = 32 AD patients). All participants provided written informed

Table 1. Demographic and cognitive characteristics of Alzheimer's disease and control participants.

	Alzheimer (n = 26)	Controls (n = 28)
Women/men	18/8^{ns}	20/8
Age in years	72.69 (6.63)^{ns}	70.82 (7.81)
Education in years	8.85 (3.05)^{ns}	9.36 (2.33)
General cognitive functioning		
Mini-Mental State Examination	22.50 (1.70)***	28.10 (1.49)
Episodic memory		
Grober and Buschke	5.69 (1.87)***	8.61 (1.64)
Working memory		
Forward span	4.86 (1.18)**	6.29 (1.68)
Backward span	3.58 (1.13)***	4.96 (1.42)
Depression		
Hospital Anxiety and Depression Scale	8.69 (1.12)***	7.07 (2.02)

Note. Standard deviations in parentheses. Performance on Mini-Mental State Examination refers to correct responses/30. Performance on Grober and Buschke (1987) task refers to correct responses/16. Performance on forward and backward spans refers to number of correctly repeated digits. Maximum score on depression scale was 21 points.
^{ns}Nonsignificant. **$p < .01$. ***$p < .001$.

consent, freely consented to participate, and could withdraw whenever they wish. The study was approved by the research ethics committee of the University of Lille.

Cognitive and clinical assessments

We administered tests of general cognitive functioning, episodic memory, working memory and depression. All scores are summarized in Table 1. We assessed general cognitive functioning with the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975), and the maximum (theoretical) score was 30 points. We assessed episodic memory with the task of Grober and Buschke (1987) on which we invited participants to retain 16 words. After immediate cued recall, there was a 20-s distraction phase during which participants were invited to count numbers aloud. This phase was followed by 2 min of free recall, and the score from this phase (out of a maximum of 16) was retained as the episodic score. As for working memory, we used the span tasks (Weschler, 1981), in which participants were invited to repeat a string of single digits in the same order (i.e., forward span) or in the inverse order (i.e., backward span). We assessed depression with the self-report Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983) consisting of seven items scored on a 4-point Likert scale from 0 (not present) to 3 (considerable). The maximum score was 21 points, and the cutoff for definite depression was set at >10/21 points.

Experimental procedure

Participants were tested individually in two sessions (within-subject design): after odor exposure and in a control condition. The order of sessions was counterbalanced, and there was approximately a 5- to 7-day interval between the two sessions. In the two sessions, participants were asked to recount, in detail, two events in their childhood, two events in their adulthood, and two recent events; the order of time periods was counterbalanced. Participants were informed that the childhood period was the period when they were 0–15 years, the adulthood period was the period when they were 16–30 years, and the recent period was the last five years. This temporal distribution replicated those proposed by tests of autobiographical memory such as the Episodic Autobiographical Memory Interview (Irish, Lawlor, O'Mara, & Coen, 2008), the Test Episodique de Mémoire du Passé (Piolino et al., 2006, 2007), and the Autobiographical Memory Interview (Kopelman, 1994). If participants could not spontaneously bring an event to mind, two cues were provided (i.e., family and trip, cues proposed by the Test Episodique de Mémoire du Passé). The participants were given 2 min to describe each memory, and were informed of this time limit so that they could structure their memories accordingly, in order to avoid bias from redundancy or distractibility.

In the odor exposure condition, one odor (i.e., coffee) was used for all time periods, this odor was used based on its familiarity in AD patients (El Haj, Gandolphe, et al., 2017). This odor was used based on its pleasantness as shown by studies on odor-evoked memories (Chu & Downes, 2002; Herz, 2004; Herz & Cupchik, 1995; Miles & Berntsen, 2011; Rubin et al., 1984). Participants were instructed that the experimenter was about to open a small bottle of essential oils (the coffee odor); afterwards, the experimenter moved the bottle under the participant's nose and asked them to close their eyes and mouth and breathe normally through the nose. Directly after each odor exposure, the autobiographical instruction was given. This procedure was repeated for each memory and for each time period. In the control condition, autobiographical instruction was also given twice for each time period, but with odor-free air. Prior to the session, rooms were aerated to provide an odor-neutral environment; similar precautions were also taken for the odor session.

The characteristics of memories

To test our hypothesis, two dependent variables were selected (i.e., the number of memories and their specificity). Specificity was evaluated with the Test Episodique de Mémoire du Passé, an instrument based on classic autobiographical evaluations and adapted in French. Ranging from 0 to 4 points, the specificity scale allows a comprehensive evaluation of autobiographical specificity (single vs. repeated memory) by evaluating

contextual characteristics such as the presence of spatio-temporal details, and internal characteristics such as the presence of phenomenological details (perceptions, thoughts, and feelings). Following this scale, we assigned 0 if the participant was unable to produce any memory or if she or he gave only general information about a theme (e.g., *my mother*); 1 point if the memory depicted a repeated or extended event (e.g., *my mother used to drink coffee*); 2 points if the memory was situated in time and/or in space (e.g., *my mother used to drink coffee early in the morning*); 3 points if the memory was specific, lasting less than 24 hours, and situated in time and space (e.g., *one morning a cat entered the garden and spilled the coffee*); and 4 points if the memory was specific, situated in time and space, and included internal sensory-perceptual-affective details (e.g., *my mother, who always disliked cat, was angry and kept yelling at the cat telling it to get out*). To prevent scoring bias, events were also rated and categorized by an independent rater who was blind to the hypotheses. Using Cohen's kappa coefficient (κ) (Brennan & Prediger, 1981), a high inter-rater agreement coefficient was obtained (κ > .87). Disagreements were discussed until a consensus was reached.

The specificity score, for each time period, referred to the mean of scores of the two memories, the maximum score being 4 points. Regarding the number of memories, we counted this number for each time period; we counted only memories with a score above 1 point on the specificity scale; as mentioned above, 0 points were attributed when patients provided no memories or general information about a theme (for the same scoring system, see (Piolino et al., 2003).

Results

We compared the number and specificity of memories between AD and control participants for each experimental condition (i.e., control condition and after odor exposure) and for each life period (i.e., childhood, adulthood, and recent life). The number of memories and specificity were analyzed with nonparametric tests, using the Kolmogorov–Smirnov test due to non-normal distribution of data. We also provided effect sizes by using Cohen's d criterion (Cohen, 1992; 0.20 = small, 0.50 = medium, 0.80 = large); the effect size was calculated for nonparametric tests following recommendations by Rosenthal and DiMatteo (2001) and Ellis (2010). For all tests, significance was set as $p \leq .05$, with p values between .051 and .099 being considered as trends.

In the following sections, we provide detailed analyses for each variable (i.e., the number and specificity of memory); however, two core findings can be highlighted. First, AD patients produced a higher number of and more specific childhood memories, adulthood memories, and recent memories after odor exposure than without odor. Also, the temporal gradient of memories evoked after odor exposure memories in AD patients was similar to that observed for memories evoked without odor.

Number of memories

The number of memories as evoked with and without odor, and for each life period, is provided in Figure 1. Regarding memories evoked with odor, Mann–Whitney U tests showed that, compared with controls, AD patients retrieved fewer childhood memories ($z = -2.40$, $p < .05$, $d = 0.69$) and recent memories ($z = -3.22$, $p < .01$, $d = 1.70$); however, no significant differences were observed for adulthood memories ($z = -0.55$, $p > .1$, $d = 0.15$). Regarding memories evoked without odor, and compared with controls, AD patients retrieved fewer childhood memories ($z = -3.19$, $p < .01$, $d = 0.96$) and recent memories ($z = -5.54$, $p < .001$, $d = 2.29$); however, no significant differences were observed for adulthood memories ($z = -1.61$, $p > .1$, $d = 0.32$).

In AD patients, and compared with the control condition, odor exposure resulted in more childhood memories ($z = -2.13$, $p < .05$, $d = 0.92$), adulthood memories ($z = -2.72$, $p < .01$, $d = 1.26$), and recent memories ($z = -2.74$, $p < .01$, $d = 1.27$). In control participants, and compared with the control condition, odor exposure yielded no significant results for childhood memories ($z = -1.51$, $p > .1$, $d = 0.44$), adulthood memories ($z = -1.13$, $p > .1$, $d = 0.43$), and recent memories ($z = -1.13$, $p > .1$, $d = 0.43$).

Friedman's tests demonstrated significant differences for the number of odor-evoked memories across the three life periods in AD patients, $\chi^2(2, N = 26) = 20.26$, $p < .001$, $d = 3.75$. Follow-up Wilcoxon's tests demonstrated that AD patients produced more adulthood memories than childhood memories ($z = -2.89$, $p < .01$, $d = 1.37$), more adulthood memories than recent memories ($z = -3.01$, $p < .01$, $d = 1.45$), and more childhood memories than recent memories ($z = -2.02$, $p < .05$, $d = 0.85$). Regarding memories evoked without odor, Friedman's tests demonstrated significant differences for the number of memories evoked with odors across the three life periods in AD patients, $\chi^2(2, N = 26) = 8.03$, $p < .05$, $d = 1.26$. Follow-up

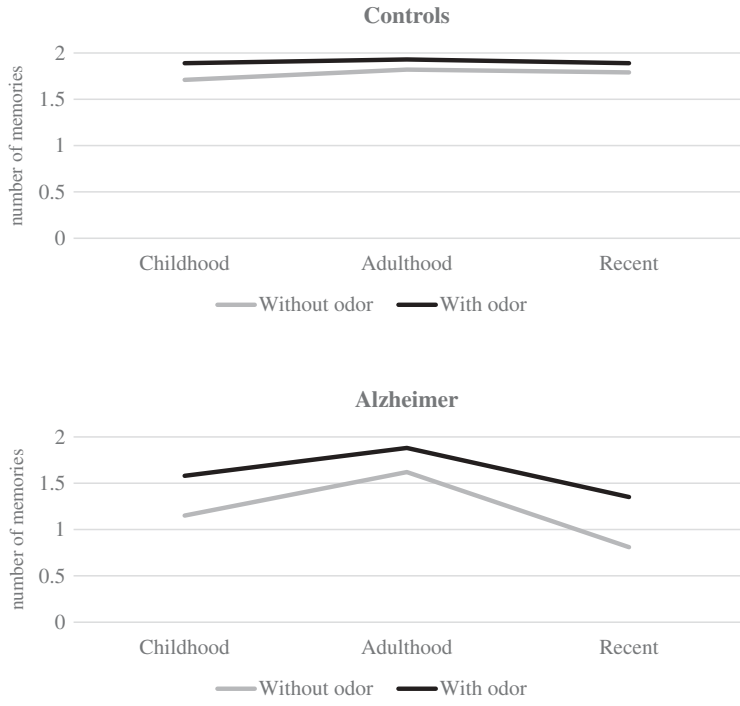

Figure 1. The number of childhood, adulthood, and recent memories evoked, with and without odor, by patients with Alzheimer's disease and control participants.

Wilcoxon's tests demonstrated that AD patients produced more adulthood memories than childhood memories ($z = -2.55$, $p < .05$, $d = 1.15$), more adulthood memories than recent memories ($z = -3.83$, $p < .001$, $d = 2.27$), and more childhood memories than recent memories ($z = -2.01$, $p < .05$, $d = 0.85$).

As for controls, no significant differences were observed across the three life periods for memories evoked with, $\chi^2(2, N = 28) = 0.87$, $p > .1$, $d = 0.35$, or without odor, $\chi^2(11, N = 28) = 0.88$, $p > .1$, $d = 0.33$.

The specificity of memories

Specificity scores are provided in Figure 2. Regarding memories evoked with odor, Mann–Whitney U tests showed that, compared with controls, AD patients retrieved less specific childhood memories ($z = -3.82$, $p < .001$, $d = 1.20$) and recent memories ($z = -6.00$, $p < .001$, $d = 2.82$); however, no significant differences were observed for adulthood memories ($z = -0.87$, $p > .1$, $d = 0.23$). Regarding memories evoked without odor, and compared with controls, AD patients retrieved less specific childhood memories ($z = -4.37$, $p < .001$, $d = 1.47$), adulthood memories ($z = -4.73$, $p < .001$, $d = 1.74$), and recent memories ($z = -3.21$, $p < .01$, $d = 0.98$).

In AD patients, and compared with the no-odor exposure, odor exposure resulted in more specific childhood memories ($z = -2.69$, $p < .01$, $d = 1.24$), adulthood memories ($z = -2.77$, $p < .01$, $d = 1.29$), and recent memories ($z = -2.88$, $p < .01$, $d = 1.33$). In control participants, and compared with the control condition, odor exposure yielded no significant differences for childhood memories ($z = -1.26$, $p > .1$, $d = 0.49$), adulthood memories ($z = -1.13$, $p > .1$, $d = 0.44$), and recent memories ($z = -1.03$, $p > .1$, $d = 0.40$).

Friedman's tests demonstrated significant differences for specificity of odor-evoked memories across the three life periods in AD patients, $\chi^2(2, N = 26) = 32.72$, $p < .001$, $d = 5.53$. Follow-up Wilcoxon's tests demonstrated that AD patients produced more specific adulthood memories than childhood memories ($z = -3.01$, $p < .01$, $d = 1.45$), more specific adulthood memories than recent memories ($z = -4.23$, $p < .001$, $d = 2.97$), and more specific childhood memories than recent memories ($z = -3.57$, $p < .001$, $d = 1.96$). Regarding memories evoked without odor, Friedman's tests demonstrated significant differences for the specificity of memories evoked with odors across the three life periods in AD patients, $\chi^2(2, N = 26) = 33.80$, $p < .001$, $d = 5.55$. Follow-up Wilcoxon's tests demonstrated that AD patients produced more specific adulthood memories than childhood memories ($z = -3.39$, $p < .01$, $d = 1.78$),

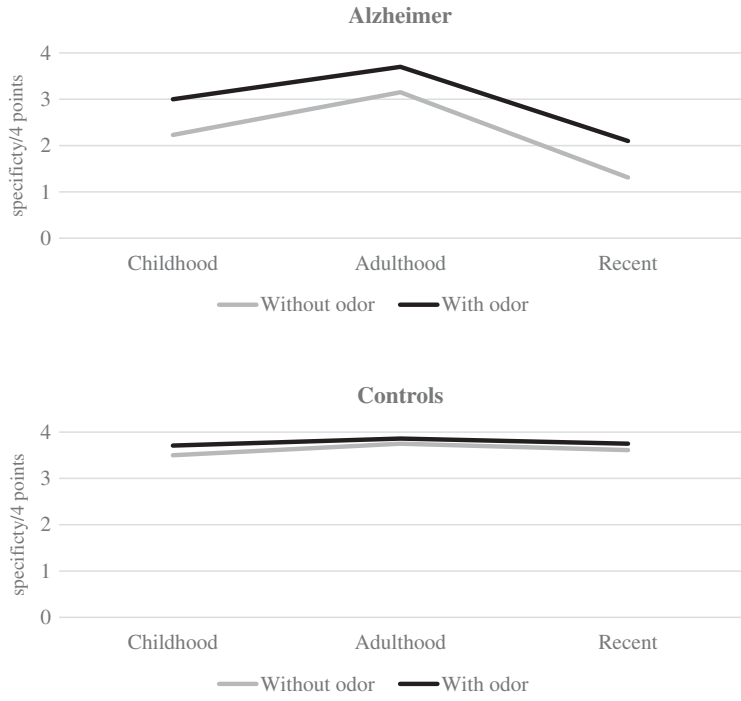

Figure 2. Specificity of childhood, adulthood, and recent memories evoked, with and without odor, by patients with Alzheimer's disease and control participants.

more specific adulthood memories than recent memories ($z = -4.34$, $p < .001$, $d = 3.24$), and more specific childhood memories than recent memories ($z = -3.09$, $p < .01$, $d = 1.53$).

As for controls, no significant difference were observed across the three life periods for memories evoked with, $\chi^2(2, N = 28) = 0.51$, $p > .1$, $d = 0.35$, or without odor, $\chi^2(11, N = 28) = 3.58$, $p > .1$, $d = 0.76$.

Discussion

We investigated the effects of odor exposure on the retrieval of recent memories in mild AD. Our analysis showed a positive effect for odor exposure on the ability of patients to retrieve childhood, adulthood, and recent memories. More specifically, AD patients produced higher number and more specific childhood, adulthood, and recent memories after odor exposure than without odor. Further, the temporal gradient of memories evoked after odor exposure memories in AD patients was similar to that observed for memories evoked without odor.

As mentioned in the introduction, two core characteristics of autobiographical memory in AD are overgenerality and anterograde amnesia. Considering overgenerality, research demonstrates a low production of specific autobiographical memories in AD (Barnabe et al., 2012; El Haj & Antoine, 2018; El Haj, Antoine, Nandrino, & Kapogiannis, 2015 ; Hou et al., 2005; Martinelli et al., 2013; Muller et al., 2013). Our findings replicate previous research demonstrating that autobiographical overgeneratilty in mild AD can be, to some extent, alleviated with odor exposure (El Haj, Gandolphe, et al., 2017; Glachet et al., 2018). However, our findings extend this previous research by demonstrating how odor exposure may enhance the specificity of autobiographical retrieval regardless of the life period. Considering anterograde amnesia, research demonstrates difficulties in retrieving recent memories in the disease (Greene et al., 1995; Hou et al., 2005; Irish, Hornberger, et al., 2011 ; Leyhe et al., 2009; Meeter et al., 2006; Piolino et al., 2003). We therefore investigated whether anterograde amnesia in AD would be alleviated with olfactory stimulation. Our findings demonstrated a better retrieval of recent memories, childhood memories, and adulthood memories after odor exposure in the AD participants.

The difficulty of AD patients to retrieve recent autobiographical memories has been associated with neurodegeneration of the hippocampus (El Haj, Antoine, & Kapogiannis, 2015 ; Irish, Lawlor, et al., 2011). Philippi et al. (2016) assessed the involvement of the hippocampal region in immediate and delayed memory in mild cognitive impairment. Delayed memory was evaluated with the Delayed Matching-to-Sample test, which included an implicit encoding phase during an immediate trial as well as a forced-choice recognition phase after one-hour delay. The authors found that the parahippocampal gyrus was significantly involved in the immediate trial, whereas

the hippocampus was solely involved in the delayed trial of the test. According to Philippi et al. (2016), the involvement of the hippocampus in memory is time dependent and triggered by long delay.

The difficulty of AD patients to retrieve recent and remote autobiographical memories can be associated with neurodegeneration of the hippocampus. This assumption is supported by a body of research demonstrating the involvement of the hippocampus in anterograde and retrograde amnesia (Nadel & Moscovitch, 1997; Squire & Zola-Morgan, 1991). This difficulty can also be associated with degeneration in the medial prefrontal cortex; further research has demonstrated that this brain region plays an important role in episodic memories processing. For instance, research has demonstrated increased activation of the medial prefrontal cortex during retrieval of memories stabilized through sleep or spaced learning (Sterpenich et al., 2007; Takashima et al., 2009). Furthermore, hippocampal activity has been shown to be more discriminable for remote autobiographical memories than for recent ones (Bonnici et al., 2012). Interestingly, research has demonstrated greater activation of connectivity between the medial prefrontal cortex and hippocampus for consolidated memories than for recently formed ones (Sterpenich et al., 2007, 2009; Sweegers & Talamini, 2014).

The evidence reviewed so far suggests a key role of the hippocampus in memory processing, and, not surprisingly, neurodegeneration of the hippocampus has been associated with memory decline in AD (McKhann et al., 2011). It is likely that the positive effect of odor on autobiographical memory, as observed in our AD participants, can be mediated by the positive effect of olfactory stimuli on functioning of the hippocampus. While we are aware that this hypothesis is speculative and requires rigorous evaluation, we would like to highlight that, compared to other sensory systems, olfactory stimuli have close neural connections between the hippocampus; the olfactory nerve is separated only by three synapses from the hippocampus (Herz & Engen, 1996). Also, the primary olfactory system is connected with the amygdala-hippocampal system, and the secondary olfactory cortex is connected with the left lateral prefrontal cortex (Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000). These findings demonstrate the intimate neural association between both the hippocampus and the prefrontal cortex, regions involved in autobiographical memory; this association may therefore support the positive effect of olfactory stimulation on autobiographical memory in AD.

Another core finding of our study was that odor exposure evoked more adulthood memories than childhood memories, and more childhood memories than recent memories in AD, and the same temporal gradient was observed for memories evoked without odor. This temporal gradient mirrors research demonstrating an asymmetric impairment of recent memories relative to remote ones in AD (Greene et al., 1995; Irish et al., 2006, 2014, 2011). The difficulty in retrieving recent memories in AD can be associated with negative changes in the sense of self in AD. According to Mograbi, Brown, and Morris (2009), the lack of updating of personal information can be associated with a difficulty to form new memories in AD patients, and this difficulty contributes to an outdated image of the self in the patients. Considering adulthood memories, our AD participants retrieved more adulthood memories than recent or remote memories (with or without odor). The high number of adulthood memories can be attributed to the fact that these memories were retrieved from the reminiscence bump. This bump refers to the high retention of memories for events that occurred between the ages of 10 and 30 years as these memories cover the most important events of people's lives (Pillemer, 2001; Rubin, 2005). According to the autobiographical memory in Alzheimer's disease model (El Haj, Antoine, Nandrino, & Kapogiannis 2015), the reminiscence bump provides AD patients with a significant portion of events that have defined their life stories. This assumption is supported by research demonstrating that most autobiographical memories retrieved by AD patients originate from the reminiscence bump (El Haj, Antoine, Nandrino, Gely-Nargeot, & Raffard, 2015; Fromholt et al., 2003; Martinelli et al., 2013). Taken together, another core finding of our study was that odor exposure has resulted in a temporal gradient similar to that observed in previous research on (odor-unrelated) autobiographical memory in AD.

Unlike AD participants, our control participants demonstrated odor exposure benefits neither for the number nor for specificity of memories. These findings can be attributed to the ceiling effect in these participants who seem to demonstrate no difficulties on retrieving only two memories for each life period. In our study, we did not wish to increase the burden on AD patients by asking participants to retrieve more than two memories per life period. While this choice resulted in a ceiling effect in the controls, future research should address this limitation by increasing the number of memories in these participants.

Overall, the decline of autobiographical memory in AD has been associated with negative effects on identity and the sense of self in patients. Our study

demonstrates how the decline of autobiographical memory in AD can be, to some extent, alleviated by odor exposure. While our findings are limited to mild AD as well as to the ability of patients to retrieve few (i.e., two) memories, we believe that these findings provide the groundwork for a novel therapeutic pathway in rehabilitation of autobiographical memory in AD. More specifically, by showing that odors are similarly potent cues, this study has potential clinical interest, since sensory cuing may alleviate, to some extent, the autobiographical decline in AD. In our view, olfactory stimulation should be implemented in clinical rehabilitation programs aimed at improving autobiographical retrieval (e.g., reminiscence program) in AD.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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