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The smell of my self: Odor exposure increases the number of self-defining memories in Alzheimer's disease

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Abstract

Self-defining memories (i.e., memories of self-relevant events) were found to be hampered by Alzheimer's Disease (AD). We therefore investigated whether this decline can be alleviated with odor exposure. We invited individuals with mild AD and healthy controls to choose a preferred odor and to retrieve three autobiographical memories after exposure to that odor as well as to retrieve three other memories without odor exposure. We analyzed the retrieved memories regarding their self-defining nature. Results demonstrated a retrieval of a higher number of self-defining memories in individuals with AD after odor-exposure than in the odor-free condition. Our study demonstrates positive effects of odor exposure on self-defining memories in AD but not in normal aging. We attribute the beneficial effect of odors in individuals with AD to their familiarity. At the clinical level, our findings contribute to the enhancement of autobiographical memory and the amelioration of diminished sense of self in AD.

Keywords Alzheimer's disease · Autobiographical memory · Olfactory stimulation · Odor · Self-defining memory

Introduction

Self-defining memories pertain to events that are vivid, emotionally intense, repetitively recalled, and focused on identity (Blagov & Singer, 2004; Singer & Blagov, 2002; Singer et al., 2013). The importance of self-defining memories can be summarized by the approach of Singer et al. (2013). Self-defining memories evoke the development of narrative scripts that serve as the components of "chapters" in one's life story (Singer et al., 2013). Because self-defining memories are impaired in Alzheimer's Disease (AD) (El Haj et al., 2015a; Martinelli et al., 2013), and because this impairment has been associated with a decreased sense of the self in individuals with AD (Ben Malek et al., 2018; El Haj & Allain, 2020; El Haj et al., 2015b), in this study, we investigated whether impaired self-defining memories in AD can be alleviated using olfactory stimulation. Our study was based on prior research suggesting negative effects of AD on self-defining memories as well as beneficial effects of odor exposure on autobiographical memory in AD.

A study by El Haj et al. (2015a) has attempted to alleviate decline in self-defining memories in AD by inviting individuals with AD and healthy older adults to retrieve autobiographical memories in two conditions: when listening to music and in silence. Retrieval was subsequently analyzed and results demonstrated an enhanced production of self-defining memories in persons with AD during exposure to music, especially when music was self-selected. Building on these prior results, in the present study, we investigated whether the diminished ability to retrieve self-defining memories in AD would be alleviated with odor exposure. Our aim was further based on research demonstrating positive effects of odor exposure on autobiographical memory in AD, which is detailed below.

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The positive effects of odor exposure on autobiographical retrieval in AD were first reported in a study by El Haj et al. (2017) who asked individuals with mild AD to remember autobiographical events after being exposed to odors, after being exposed to music, as well as in an odor-and-music-free condition. Analysis demonstrated higher specificity, mental time travel, emotional experience, and retrieval time in individuals with AD after being exposed to odor and music than in the odor-and-music-free condition. Analyses also demonstrated low involvement of executive function in memories retrieved in the odor-and-music-free condition. These results demonstrate that odor-evoked autobiographical memories in AD may require less cognitive effort to retrieve compared to non-cued autobiographical retrieval which typically requires effortful executive processes such as memory search. The positive effects of odor on autobiographical retrieval in individuals with AD were further reported in a study by Glachet et al. (2018) who invited participants with mild AD to remember autobiographical events after being exposed to odor as well as in an odor-free condition. Results demonstrated more specific retrieval, as well as enhanced subjective experience, after odor-exposure than in the odor-free condition. The positive effects of odor on autobiographical retrieval in participants with AD were also reported in a study by Glachet et al. (2019b) who asked participants with mild AD to remember childhood, adulthood, and recent autobiographical events, with and without odor exposure. Results demonstrated a higher number and more specific childhood, adulthood, and recent memories with than without odor-exposure in individuals with AD. These results demonstrate that odor exposure may alleviate both retrograde amnesia (i.e., the inability to retrieve remote memories) and anterograde amnesia (i.e., the inability to retrieve recent memories). The positive effects of odor exposure on autobiographical memory in AD were also reported by a study demonstrating higher arousal during the retrieval of odor-evoked autobiographical memories in individuals with AD (Glachet & El Haj, 2019).

Taken together, research has supported the benefits of odor exposure on autobiographical memory in AD (El Haj et al., 2017; Glachet & El Haj, 2019; Glachet et al., 2018; Glachet et al., 2019b). However, prior research has not investigated whether odor-exposure may alleviate the diminished sense of self in individuals with AD. Our hypothesis was that compared with an odor free condition, odor exposure would result in a retrieval of a higher number of self-defining memories in individuals with AD. Our hypothesis was based on research reporting benefits of odor exposure on general autobiographical retrieval in AD (El Haj et al., 2017; Glachet & El Haj, 2019; Glachet et al., 2018; Glachet et al., 2019b).

Method

Participants

The study included 30 individuals with mild AD (M age = 71.77 years, SD = 6.21, M education = 9.03, SD = 3.43 years, 20 female/10 male) and 30 healthy older adults (M age = 69.96 years, SD = 5.93, M education = 8.78, SD = 3.04 years, 18 female/12 male). We recruited individuals with AD from residential care facilities in the region of Lille-France based on the diagnosis of probable mild AD made by neurologists or geriatricians following the criteria of McKhann et al. (2011). The control participants were living in their own homes, independent, and recruited from the local community. We matched control participants and individuals with AD according to age [$t(58) = 1.16$, $p = .25$], sex [$\chi^2(1, N = 60) = .29$, $p = .59$] and educational level [$t(58) = .26$, $p = .79$]. The study was approved by the ethics committee of the University of Lille and all participants provided written informed consent. Participation was voluntary and participants could withdraw at any time.

General Cognitive Assessment

To ensure that individuals with AD were in the early stages of the disease and to ensure that the control participants had normal cognitive functioning, we assessed general cognitive functioning of participants as well as their episodic and working memory. We evaluated general cognitive functioning with the French translation of Mini Mental State Exam (Folstein et al., 1975) and the maximum score was 30 points [M AD = 23.21, SD = 1.82, M control participants = 28.14, SD = 1.21, $t(58) = 12.35$, $p < .001$]. We tested episodic memory with the test of Grober and Buschke (1987) on which participants encoded 16 words. After a 20-second distraction phase during which participants were asked to count numbers aloud, participants were allocated two minutes to retrieve the 16 words and this score was retained as the verbal episodic score [M AD = 5.53, SD = 1.62, M control participants = 8.76, SD = 1.43, $t(58) = 8.18$, $p < .001$]. Regarding working memory, we used the span tasks (Wechsler, 1981). We invited participants to repeat a string of single digits in the same order [M AD = 4.93, SD = 1.63, M control participants = 6.33, SD = 1.83, $t(58) = 3.23$, $p = .002$] or in a reverse order [M AD = 3.75, SD = 1.32, M control participants = 5.51, SD = 1.66, $t(58) = 4.54$, $p < .001$]. Performance was defined as the number of correctly repeated digits.

Exclusion Criteria

We defined exclusion criteria as any significant neurological or psychiatric disorders (other than AD for the AD participants) or major deficits of visual or auditory acuity that would

hamper testing. After applying these exclusion criteria, the original sample was 42 individuals with AD and 43 controls. Because our study dealt with olfactory stimuli, we excluded nine AD participants with nasal congestion, allergic rhinitis symptoms or upper respiratory infection. We also excluded three individuals with AD as they obtained scores below 20 points on the Mini Mental State Exam, following the validated French version the test (Kalafat et al., 2003). Regarding controls, we excluded five participants from the original sample due to nasal congestion, four participants who scored below 28 points on the Mini Mental State Exam, and four who performed below the norms on the task of Grober and Buschke (1987). Consequently, and as reported in the "participants" section, the final sample was 30 individuals with AD and 30 controls.

Procedures

In general, directly after the cognitive assessment, participants were invited to determine their preferred odor. After a delay of five to seven days, they were tested in two conditions (within-subject design): with and without odor. The order of the two conditions was counterbalanced in the two groups and there was approximately a delay of five to seven days between the two conditions. In the odor condition, we invited participants to retrieve three autobiographical memories after odor exposure, whereas, in the odor-free condition, we invited them to retrieve three autobiographical memories without odor exposure; all memories were later analyzed regarding their self-defining nature.

Choice of the Odors

Following cognitive assessment, we exposed participants to a set of seven odors (i.e., lemon, chocolate, orange, coffee, peach, cinnamon, coconut), displayed in small bottles of scented-oil. Bottles with oils in them were not labelled with their scents; this reduced language-based cues as to what each oil was. We selected these odors based on previous research suggesting that these odors can be easily detected by individuals with AD and healthy older adults (Tabert et al., 2005). Also, these odors were found to trigger self-related knowledge in general populations (Rubin et al., 1984). In our study, we invited participants to move the bottles containing the odor under their nose and to breathe normally through the nose. We asked participants to rate familiarity of each of the seven odors on a five-points Likert-type scale ranging from: 0 = not at all familiar, 1 = a little familiar, 2 = moderately familiar, 3 = familiar, 4 = very familiar. For each participant, we used the odor that was rated as the more familiar. Among the seven odors, most participants rated at least one odor as familiar or very familiar. Two individuals with AD, however, rated all odors as not at all or a little familiar; in this case, we asked them if they have any other choice and we provided them with that odor (i.e., lavender). When two or more odors were rated at the same high level (e.g., if a participant rated two or three odors as very familiar), they were asked which one they liked most and we used this odor for the subsequent autobiographical cuing.

Autobiographical Retrieval

As mentioned above, we asked participants to retrieve three autobiographical memories with and without odor exposure. In the odor and odor-free conditions, we invited participants to recount in detail three events in their lives. Using the same instructions as in our previous research (Glachet & El Haj, 2019, 2020a, 2020b; Glachet & El Haj, 2021; Glachet et al., 2018; Glachet et al., 2019a), we instructed the participants to be precise and specific, so events had to have lasted no more than a day and spatiotemporal details had to be provided, such as time and place at which the events had occurred. We also requested that participants describe their feelings and emotions during these events. Memory recall was limited to two minutes for each event and the duration was stated from the outset so participants could plan their time accordingly. When memory description ended before the two-minutes-interval, participants were encouraged to provide further details to fill the time available. In the odor condition, the experimenter explained that he will open a small bottle of essential oils; afterwards, he moved the bottle under the participants' nose and invited the participants to breathe normally through the nose. After breathing, the experimenter provided the autobiographical instruction and this procedure was applied for each of the three memories. In the odor-free condition, the autobiographical instruction was also given three times, without olfactory stimuli. Prior to the two conditions, rooms were aerated to provide an odor-neutral environment.

Analysis of Self-Defining Memories

We analyzed the retrieved memories following the definition of Singer et al. (2007) which was also applied to a research on self-defining memories in AD (El Haj et al., 2015a; Martinelli et al., 2013). More specifically, we considered a memory as a self-defining memory if it described an event situated in time and space with phenomenological details (e.g., emotion, thoughts), and also if the event contributed to the way the participant saw her/himself, and/or if the event was related to personality construction, concerns or unresolved conflicts. Consider the following example of a memory retrieved by Participant#4 (an AD patient), and considered as a self-defining memory: "*I can remember the holiday in St-Nazaire (a French city), I was fourteen years old and it was a shiny morning. I much wanted to swim but my mother didn't allow me as the waves were relatively high. I waited till she*

was busy talking to my aunt and I went to swim, but after a while the waves got more and more fierce and the wind got stronger. My mother began to scream and, to be honest, I was a bit scared, probably because she was yelling at me. My cousin got me out of the water…mum was so angry…I can clearly see her red face. I didn't understand her attitude until I was myself a dad and experienced how much parents may worry about their kinds… perhaps that's why my own kids think that I am a strict dad". To avoid any scoring bias, two independent raters rated the self-defining memories. These raters were not affiliated with the project, and were blind to the hypotheses. Using Cohen's Kappa coefficient (K) (Brennan & Prediger, 1981), a high inter-rater agreement coefficient was obtained (K = .91).

Results

To test our hypothesis (i.e., that compared with an-odor free condition, odor exposure would result in more self-defining memories in individuals with AD), we evaluated the differences between individuals with AD and controls regarding the number of self-defining memories in the odor and odor-free conditions. Thus, the dependent variable of our study was the number of retrieved self-defining memories. We used Chi-square tests because data were categorical. Data are summarized in Table 1.

Odor Exposure Increases Autobiographical Retrieval in AD

Compared to controls and regardless of the self-defining nature of memories, individuals with AD produced fewer total memories [$\chi^2(1, N = 144) = 10.40$, $p = .001$], as well as fewer memories in the odor-free condition [$\chi^2(1, N = 61) = 4.74$, $p = .03$] than controls; however, no significant differences were observed between the two populations in the odor condition [$\chi^2(1, N = 83) = .59$, $p = .44$]. In other words, whereas fewer memories were produced by individuals with AD than by controls in the odor-free condition, odor exposure significantly improved memory retrieval in individuals with AD. Furthermore, more memories were produced in the odor than in the odor-free condition in individuals with AD [$\chi^2(1, N = 60) = 4.27$, $p = .03$] but not in controls [$\chi^2(1, N = 84) = .43$, $p = .51$].

Odor Exposure Increases Self-Defining Memories in AD

More self-defining memories were produced by individuals with AD in the odor than in the odor-free condition [$\chi^2(1, N = 36) = 7.11$, $p = .007$], but no significant differences were observed between these two conditions in the controls [$\chi^2(1, N = 50) = .72$, $p = .39$]. Furthermore, while fewer self-defining memories was produced by individuals with AD than by controls in the odor-free condition [$\chi^2(1, N = 32) = 4.50$, $p = .003$], no significant differences were observed between the two populations in the odor condition [$\chi^2(1, N = 54) = .07$, $p = .78$].

Discussion

We investigated the effects of odor-exposure on the retrieval of self-defining memories in AD. Results demonstrated the production of a higher number of self-defining memories in individuals with AD after odor-exposure than in the odor-free condition.

The increased number of self-defining memories after odor-exposure in AD, as observed in our study, extends research demonstrating beneficial effects of odor-exposure on autobiographical memory. This previous research has demonstrated beneficial effects of odor-exposure on the ability of individuals with AD to retrieve a specific memory, as well as on their ability to subjectively relive the past (El Haj et al., 2017; Glachet & El Haj, 2019; Glachet et al., 2018). These prior studies have even demonstrated beneficial effects of odor-exposure on the ability of individuals with mild AD to retrieve both recent and remote memories (Glachet et al., 2019b). Our current study extends this research by demonstrating that odor-exposure may yield positive effects on memories highly related to the self in AD. Our findings are important as they demonstrate how decline in self-defining memories in mild AD can be alleviated due to odor exposure. Research has demonstrated a diminished ability to retrieve self-defining memories in mild AD (El Haj et al., 2015a;

Table 1 The number of self-defining memories as produced by persons with and without Alzheimer's disease in the odor and odor-free conditions

	Alzheimer's disease		Controls	
	Total number of produced memories=60		Total number of produced memories=84	
	Odor *n*= 38 memories	Odor-free *n*= 22 memories	Odor *n*= 45 memories	Odor-free *n*= 39 memories
Self-defining memories	26	10	28	22

Martinelli et al., 2013), and this diminished ability has been associated with the decreased sense of the self in the disease (Ben Malek et al., 2018; El Haj et al., 2015b). Our current study therefore provides valuable information to researchers and clinicians on the enhancement of production of self-defining memories in individuals with AD.

Our findings contribute to the rehabilitation of self-defining memories and sense of self in general in AD. Self-defining memories are intimately associated with self-images as these memories are retrieved to provide motivation to pursue personal goals (Conway et al., 2004; Moffitt & Singer, 1994; Sutin & Robins, 2008). These memories thus provide us with a sense of self-continuity and meaning, as well as with a better understanding of both the self and the world (Blagov & Singer, 2004). Self-defining memories serve to update our self-concept by integrating important experiences in our life story, and this "meaning-making" process allows us to learn from past events and to stand back from the past to realize how we have evolved in our understanding of ourselves, others, and the world (Blagov & Singer, 2004; Moffitt & Singer, 1994; Singer & Moffitt, 1992). Consequently, the decline in self-defining memories in individuals with AD can result in a weakened self-concept and ability to extract meaning from the past and to integrate important events into their life story (Ben Malek et al., 2018; El Haj et al., 2015b). AD has been generally associated with a weakened sense of the self (Addis & Tippett, 2004; Mograbi et al., 2009) as well as with a weakened ability to remember the past to support and maintain self-images and self-continuity (El Haj & Antoine, 2017; El Haj et al., 2019). Taken together, by demonstrating an increased number of self-defining memories after odor-exposure in AD, our findings can be considered as a tool to alleviate the diminished sense of self in AD.

The positive effects of odor-exposure on self-defining memories in AD, as observed in our study, can be attributed to several factors. In general, research has demonstrated that odors function as a potent cue for autobiographical retrieval in the general population (Herz, 2004; Larsson et al., 2014; Saive et al., 2014) and that effect is consistent with the hypothesis of encoding specificity (Tulving & Thomson, 1973). This hypothesis suggests that salient sensory elements (e.g., odors, images) are encoded along with the target information and these sensory elements may later serve as a retrieval cue for the target information when the same encoding context is reinstated at retrieval. This hypothesis has been supported in studies using odors. For instance, Cann and Ross (1989) exposed subjects to photographs in the presence of odors, followed by a memory test. The authors found higher memory of the photographs when the odors present during encoding and retrieval were matched than when they mismatched. Similar findings were reported by a study demonstrating that odors presented during both encoding and retrieval enhanced recall of a list of words compared to a no-odor control condition (Schab, 1990). Thus, odors in our study might serve as cues for the retrieved memories as these odors might reinstate a retrieval context similar to that during memories encoding. This assumption can be supported by the familiarity of odors, which might facilitate reinstatement, or simply retrieval, of familiar events during the odor-exposure condition compared to the odor-free condition. That being said, some self-defining memories may not have any particular odors associated with them, as in the case of memories cued in the odor-free condition. Clinicians may thus manipulate not only the presence or lack of odors, but also their familiarity, during stimulation on self-defining memories.

Unlike for individuals with AD, odors yielded no significant effects on self-defining memories in controls. Healthy older adults typically demonstrate no difficulties, and even a tendency, to retrieve self-defining memories. This assumption can be supported by a study demonstrating that compared to younger adults, older adults rate self-defining memories as more vivid and important (Singer et al., 2007). The same study also demonstrated that self-defining memories were positive and associated with meaningful topics such as achievements, illnesses, and deaths. Other studies reported high specificity of self-defining memories in normal aging (El Haj et al., 2015a; Martinelli et al., 2013). This line of research suggests a preservation of self-defining memories in normal aging, which is not surprising as normal aging has been associated with a stable sense of self. In general, middle and later adulthood are considered as a time of self-maintenance, often in the face of substantial losses (Brandtstädter & Greve, 1994; Caspi & Roberts, 2001; Pals, 1999). Aging is also accompanied by a strong sense of self that resists variation (Charles & Pasupathi, 2003). Together, the non-significant effects of odor exposure on self-defining memories in healthy older adults, as observed in control subjects in our study, may be attributed to the preservation of these memories in normal aging.

A potential limitation of our study is the lack of a subjective assessment of self-relatedness of the retrieved memories. In other words, it might be interesting to ask participants to rate how much the retrieved memories were related to their life-story. While in the present study, we adopted an objective assessment of self-defining memories, a subjective assessment, as provided by the participants, might allow for a better understanding of the self-relatedness of memories. Another issue to be considered is that, in our study, participants with AD were living in residential care facilities whereas control participants were living independently. Although this might have influenced memory retrieval, it is difficult to recruit participants with AD who live independently because the disease decreases participants' autonomy. In contrast, it is difficult to recruit control participants who live in institutions because institutionalization decreases autonomy in healthy older adults.

To summarize, while clinically relevant, little research has been focused on the effects of odor exposure on memory in AD. Our study addresses this challenge by adding to the burgeoning literature demonstrating beneficial effects of odor-exposure on autobiographical memory in AD. Critically, our study demonstrates how odor exposure may improve the ability of individuals with AD to retrieve memories highly-related to the self, at least when individuals with mild AD are invited to retrieve self-defining memories after exposure to a familiar odor. At the clinical level, these findings might contribute to the rehabilitation of autobiographical memory and diminished sense of self in AD.

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Authors'Contribution MEH & OG supervised data collection, all authors contributed to data interpretation and the writing of the article.

Data Availability Statement Data is available upon a reasonable request by email to the first author.

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Declarations

Ethical Approval The study was conducted in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the ethical board of the University of Lille.

Informed Consent Informed consent was obtained from all individual participants included in the study (the sample included no participants with AD who were unable to provide consent).

Conflict of Interest The authors declare no conflict of interests.

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