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Odor-Evoked Autobiographical Memories: Age and Gender Differences Along the Life Span

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Abstract

Odors are powerful in bringing back old and vivid memories bearing emotional content. This inherent hedonic property of olfactory stimuli makes this sensory modality particularly suitable for studying autobiographical memory. In the present work, adolescents (first experiment), young adults (second experiment), and elderly (third experiment) of both sexes were asked to smell 10 familiar odorants and to report if these odorants evoked personal autobiographical memories or referential memories (i.e., names and objects). The participants were then required to link these memories to triplets of words using the progressive elaboration method of the Loci mnemonic. The aim of the study was to investigate whether 1) odorants evoking autobiographical memories led to faster reaction times (RTs) and to a greater number of correct responses in the recall of the items associated to such memories than do odorants evoking referential memories, 2) females differed from males on the above tasks along with the life span, and 3) the preferential codes (i.e., autobiographical or referential) attributed to the odorants vary according to gender and age. In general, it was observed that the way in which the odorants were encoded affected the subsequent retrieval. Indeed, data analyses have shown that odorants evoking autobiographical memories lead to faster RTs (experiments 2 and 3) and that females outperform males (experiments 1 and 2). However, these effects are greatly age and gender dependent. Furthermore, females are more prone than males to code the odorants autobiographically (as shown by the higher amount of autobiographical experiences that they have provided at all ages relative to males). Results are discussed in terms of developmental differences and odor-emotion links and the possible role of odors and autobiographical memory in learning and retrieval of other items.

Key words: age-related changes, autobiographical odor memory, emotion, gender differences

Introduction

Odors have an extraordinary ability to remind us of a sometimes far distant past. These memories are often characterized by a strong emotive connotation and specificity, a property which makes the sense of olfaction particularly suitable for studying autobiographical memory (Laird 1935; Richardson and Zucco 1989; Herz and Cupchik 1992; Chu and Downes 2002; Maylor et al. 2002; Zucco 2003, 2007; Herz 2004; Larsson and Willander 2009). However, to investigate autobiographical memories, experimental research has been concerned mainly with autobiographical experiences triggered by verbal cues following the procedure proposed by Galton (1879) and reintroduced by Crovitz and Shiffman (1974) to investigate autobiographical memories. According to this technique, the participants are provided with cue words and for each word are asked to describe the first personal episode which comes to mind. On completing this task, the participants are requested to date each event, usually by giving their age at the time of the episode's occurrence. The participants can be requested also to provide various judgments, such as the pleasantness, vividness, and feeling of being brought back in time for each single episode retrieved. Results from extensive studies have consistently shown that autobiographical memories evoked by verbal cues are characterized by 3 distinct components, namely: childhood amnesia, reminiscence "bump," and recency (Rubin 1986; Conway 1990; Rubin and Wenzel 1996; Rubin et al. 1998; Conway and Haque 1999; Conway and Pleydell-Pearce 2000; see also, Williams and Scott 1988 as to the quality of autobiographical memories in psychiatric patients). The first effect refers to the

paucity of memories from the early childhood; the reminiscence bump in adults of 50 years old and above refers to the rise of memories for events that occurred when they were aged between 10 and 30 years; and recency refers to the better retrieval of events dated from the most recent decades of life.

At variance with these studies, empirical research on odor-evoked autobiographical memories is limited and sparse. Nevertheless, available evidence shows that personal life events cued by olfactory information reliably differ from those evoked by verbal and visual stimuli. In particular, it has been observed that the reminiscence bump—when older adults recall the most autobiographical life experiences—is situated in the first 10 years of life rather than in early adulthood (for an account of the reminiscence bump occurrence between 10 and 30 years, see Rubin et al. 1998), suggesting that autobiographical odor memory is older and more enduring compared with the memories evoked by other stimuli (e.g., Chu and Downes 2000; Willander and Larsson 2006, 2007). In addition, empirical outcomes indicate that personal odor-evoked life episodes are more evocative, affective, and emotional (e.g., Herz and Schooler 2002; Herz 2004), characterized by a stronger brought back feeling to the original event (e.g., Herz and Schooler 2002; Herz 2004; Willander and Larsson 2006, 2007), more vivid (Chu and Downes 2002), sensitive to semantic processing (Willander and Larsson 2007) and that they are memories that people retrieve and think of less often than memories in pictorial and verbal sensory formats (e.g., Rubin et al. 1984; Willander and Larsson 2006). These findings suggest that odors, at variance with other stimuli, are effective powerful reminders of past life episodes, a peculiarity usually attributed to their capability to trigger emotional reactions (see, e.g., Willander and Larsson 2007, who observed that olfactory stimulation per se affected the valence ratings of autobiographical evoked memories). Consistent with these outcomes, physiological records during the recall of autobiographical memories have clearly shown a significantly greater activation in the amygdala and hippocampal regions (respectively involved in emotion and memory). This phenomenon was only evoked by emotionally valenced olfactory stimuli compared with other cues, providing support to the behavioral data (Royet et al. 2000; Herz et al. 2004).

As pointed out above, the existing literature on autobiographical odor memory has mainly dwelled on the distribution of the memories elicited by odors along the life span and on the nature and qualities of such memories. As far as we are aware, no studies have explored the extent to which odor cues remind people of autobiographical or non autobiographical (i.e., referential) life experiences and to which extent this distribution depends on age and gender. In most other autobiographical memory tests, words or pictures of recognizable objects are used to evoke the memories. Odors are different. They are strongly linked to the situations or to the sources from which they emanate. When considered as objects in themselves (by identifying and naming them), they lose most of their specific situational memory power (Degel and Köster 1999; Degel et al. 2001). Willander and Larsson (2007) also showed that providing odors with their name had negative effects on the feeling of being brought back in time to the situation and on the emotionality. It might therefore be interesting to see whether the tendency to let odors evoke either autobiographical (situational) or referential (mere factual) memories is equally distributed over the 2 genders and how this distribution develops over life time.

At the same time, it may be interesting to see whether odor-evoked autobiographical memories differ from referential memories in the ease and tenacity with which they may bind themselves to other memory elements (e.g., to-be-learned words as in the mnemonic task used here, see below) and which of the 2 differently formed memory complexes (autobiographical or referential) is to be accessed fastest and/or most reliably. In some cases, odors have been used with success as memory cues for other learned material (Schab 1990), and the present experiment might also throw further light on that.

In addition, we are not aware of studies on autobiographical odor memory where gender differences were taken into account along with the whole life span. All of these topics will be examined in the present study. Three experiments were carried out, with participants from 3 different age groups. The design of the 3 experiments was a double factorial that crossed Kind of Encoding (autobiographical vs. referential) and Gender of participants. The rationale for not carrying out a single experiment adding age group as a factor was to simplify the design and the subsequent statistical analyses.

On these grounds, we have asked adolescents (first experiment), young adults (second experiment), and elderly (third experiment) of both sexes to smell 10 familiar odorants and to report if the odorants evoked general personal autobiographical memories or referential memories (i.e., names and objects). Then, the participants were required to associate these memories to triplets of words using the progressive elaboration method of the Loci mnemonic. At the experimental session, they were asked to say aloud the first or the second or the third item that they associated to the autobiographical or referential memory cued by the presented odor. Reaction times (RTs) were recorded and responses were scored for latency and accuracy. Our aim was to investigate whether 1) odorants evoking autobiographical memories led to faster RTs and to a greater number of correct responses in the recall of the items linked to such memories than do odorants evoking referential memories, 2) females differed from males on these tasks along the life span, and 3) the preferential code (i.e., autobiographical or referential) attributed to the odorants varied according to gender and age. On the basis of the literature examined above and that on gender differences in human odor perception (for reviews, see Brand and Millot 2001; Doty and Cameron 2009), we expected 1) that odorants that evoke autobiographical

memories can lead to faster RTs and to a better accuracy than odorants that refer to referential memories; 2) a better performance of females over males and a higher propensity of females to code the odors autobiographically. We would also expect the magnitude of these hypothesized effects to be specifically sensitive to age and gender.

Experiment 1 (adolescents)

Method

Participants

Two groups of adolescents (16 males and 16 females) aged on average 13.03 ± (standard deviation [SD]) 0.82 years (range: 12–14 years) and attending secondary school participated in the study.

None of them exhibited an acute or chronic impairment in olfactory function prior to the study. All participants and their parents gave informed consent to take part in the study. The experimental procedures were in accordance with the Declaration of Helsinki for experimentation with human subjects.

Materials

The following materials were used:

- Ten familiar olfactory stimuli of medium and comparable subjective intensities. The odorants were contained in small test tubes fitted with rubber plugs. Some of them were commonly found in the home, whereas others were essences and essential oils (Kart laboratories, Lausanne, Switzerland). To keep their concentration under control, the stimuli were replaced every 48 h. Odorants were: after shave, coffee, ink, mustard, shoe polish cream (i.e., household products), eucalyptus, fennel, rose (i.e., essential oils), strawberry, and vanilla (i.e., essences).
- Two series of 10 triplets of easy to imagine concrete words (e.g., tree-cow-bird; devil-hanky-watch; and cinema-ant-ship; see Appendix) provided by the experimenter.
- A voice key connected to a timer controlled by a computer.

Procedure

The participants were individually administered the experimental tasks in 3 steps.

Step 1 (odor-evoked memories). The participants were asked to smell the 10 odorants one at time and to say whether each of them evoked a general event of their life (i.e., an autobiographical memory) or a name and a visual object (i.e., a referential memory). All the memories provided by the participants were tape recorded.

Step 2 (study phase). The participants were asked to associate the triplets of items provided by the experimenter to the autobiographical or referential memory evoked by each odorant, using the progressive elaboration technique of the Loci mnemonic (see, e.g., Higbee 1988). This technique requires the creation of an interactive image between a "locus" and the items to be remembered. The items have to be added to the locus one after the other, so that the order itself can be memorized. The entire procedure is shown below.

The words comprising each word triplet of our study were reproduced on cards (10 × 20 cm) with the first word of the triplet printed on a first card, the first and the second word of the triplet on a second card, and all the 3 words of the triplet on a third card. The participants were instructed to smell each odorant of the series, and for each of them: 1) to build up an image of the autobiographical or referential memory (i.e., the locus) cued by the odorant; 2) to read the word printed on the first card and to generate an interactive image between the word and the autobiographical or referential memory evoked by the odorant; 3) to take the second card, to read the first word, and to build up again the previous interactive image; to read the second word printed on this card and to enclose it in the image; and 4) to take the third card, and, after having build up again the image comprising the first and second word, to read the third word printed on the card and to add it to this image. The participants were left alone during this phase. Based on prior pilot studies, they were given about 40 min to perform the task. All of them completed the task in due time and met the experimental demands.

Here, follows a concrete example of the final odorant (coffee)→ kind of recall (autobiographical)→ triplet (devil-hanky-watch) association, from the personal report by participant 7 (female, young sample): "I see myself in the old farm of my grandmother. I see her preparing, as usual, the coffee for me; a devil is looking at her preparing the coffee; the devil keeps a hanky in his hand; and the devil cleans a big watch with the hanky."

Step 3 (experimental session). The experimental test took place a few minutes after the study phase, with the participant sitting in front of a computer screen. Instructions were as follows: "Please, look at the center of the screen. You will hear an acoustic signal coming from the computer. At the same time, you will be required to sniff an odorant. Your task is to smell it until you hear (actually 2 s later) another acoustic signal coming from the computer. Immediately after this one of the following notices, "Item 1, Item 2, or item 3" will appear on the screen. You have to say aloud the first, or the second or the third item that you have associated during the study phase to the autobiographical or referential

memory cued by that odor. Please, try to respond as accurately and as quickly as possible."

The participants were given 8 s to provide their response. RT was recorded by means of the timer connected to the voice key. Responses were scored for latency and accuracy. The 2-s interval between the 2 acoustic signals was chosen as the most appropriate after having run various pilot trials. Order of odorant presentation was randomly chosen by the computer. Order of series presentation was counterbalanced among participants.

Results experiment 1

Two two-way mixed design analyses of variance (ANOVAs) were carried out on the data, RTs and percentages of correct responses, with Gender (males vs. females) and Kind of Encoding (autobiographical vs. referential) respectively as between and within factors (see Figure 1A,B).

Only the factor "Gender" reached a statistically significant level for both analyses. Females showed shorter RTs than males ($F_{1,30} = 30.17$, $P < 0.0001$; $\eta p^2 = 0.501$) and also produced more correct responses than males ($F_{1,30} = 12.17$, $P < 0.01$; $\eta p^2 = 0.289$). "Kind of Encoding" nonsignificant effects relative to RTs ($F_{1,30} = 0.017$, $P = 0.897$; $\eta p^2 = 0.001$) and to percentages of correct responses ($F_{1,30} = 0.860$, $P = 0.361$; $\eta p^2 = 0.028$).

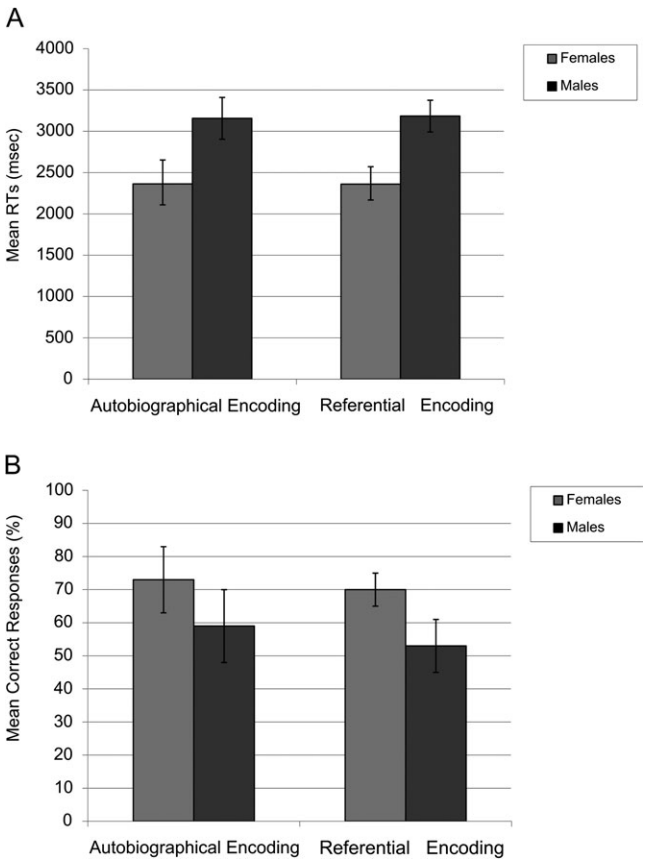

Figure 1 **(A)** RTs scores (Mean ± 95% confidence interval) for adolescent males and females as a function of encoding condition. **(B)** Percentages of correct recognition scores (Mean ± 95% confidence interval) for adolescent males and females as a function of encoding condition.

The 10 odorants gave rise to a total of 48 autobiographical and 112 referential memories for the male group and to a total of 70 autobiographical and 90 referential memories for the female group.

These frequencies were transformed in proportions. Statistical comparisons, by means of a proportions test for paired and unpaired samples, showed that odorants evoke significantly more referential than autobiographical memories both in males ($z = 7.15$, $P < 0.0002$) and in females ($z = 2.23$, $P < 0.02$). Furthermore, a comparison of the different forms of encoding between females and males showed that males made significantly less autobiographical ($z = 2.54$, $P < 0.01$) and significantly more referential encodings ($z = 2.53$, $P < 0.01$) than females.

Tables 1 and 2 summarize these data both for Experiment 1 and the 2 following experiments.

Summary conclusion experiment 1

Overall, females were faster and more correct than males, both for autobiographical and referential types of encoding. The latter result is consistent with the existing literature on gender differences showing a female superiority in verbal memory already during adolescence (cf. Denno 1982; Halpern 2000; Banich 2004, for reviews). With the arrival of puberty at the age of this group, females also start to be more sensitive to odors than males (Koelega and Köster 1974). Moreover, odors evoked more autobiographical memories for the female adolescent group than for the male adolescent group, although both groups preferentially use a referential code (probably due to a lack of meaningful personal experiences).

Experiment 2 (young adults)

Method

Participants

Two groups of young adults (16 males and 16 females) attending the University, aged on average 22.9 ± (SD) 1.6 years (range: 21–26 years), participated in the study.

None of the participants exhibited an acute or chronic impairment in olfactory function prior to the study. All participants gave their informed consent to take part in the study. The experimental procedures were in accordance with the Declaration of Helsinki for experimentation with human subjects.

The materials and procedures are the same as for Experiment 1.

Results experiment 2

Two two-way mixed design ANOVAs were carried out on the data, RTs and percentages of correct responses, with

Table 1 Percentages of odor evoked autobiographical and referential memories in 2 groups of male and female adolescents, 2 groups of male and female young, and 2 groups of male and female elderly

Groups	Autobiographical encoding %	Referential encoding %	Significance		Effect size
			z	*P*	*d*
Male adolescents	30 (16.3)	70 (16.3)	7.15	<0.0002	−1.04
Female adolescents	43.75 (19.9)	56.25 (19.9)	2.23	<0.02	−0.31
Male young	45.625 (18.2)	54.375 (18.2)	−1.56	0.11 (ns)	−0.22
Female young	58.125 (7.5)	41.875 (7.5)	2.90	<0.004	0.41
Male elderly	59.375 (8.5)	40.675 (8.5)	3.35	<0.001	0.47
Female elderly	61.875 (9.1)	38.125 (9.1)	4.24	<0.0002	0.60

Significance values refer to each group of participants on autobiographical versus referential encoding comparison. Standard deviations are reported in brackets. ns, not significant.

Table 2 Percentages of odor evoked autobiographical and referential memories in 2 groups of male and female adolescents, 2 groups of male and female young, and 2 groups of male and female elderly

Groups	Autobiographical encoding %	Significance		ES	Referential encoding %	Significance		ES
		z	*P*	*d*		*z*	*P*	*d*
Male versus female adolescents	30 versus 43.75	2.54	<0.01	−0.36	70 versus 56.25	2.53	<0.01	0.36
Male versus female young	45.625 versus 58.125	2.23	<0.03	−0.31	54.375 versus 41.875	2.23	<0.03	0.31
Male versus female elderly	59.375 versus 61.875	0.45	0.64(ns)	−0.065	40.675 versus 38.125	0.45	0.64(ns)	0.06

Significance values refer to autobiographical encoding by male versus female comparisons and referential encoding by male versus female comparisons for the 3 groups of participants. ns, not significant; ES, Effect size.

Gender (males vs. females) and Kind of Encoding (autobiographical vs. referential) respectively as between and within factors (see Figure 2A,B).

In the RTs analysis, only the interaction "Gender × Kind of Encoding" reached a statistically significant level: ($F_{1,30}$ = 4.54, $P < 0.05$; $\eta p^2 = 0.135$). *t*-Tests showed that females were faster on autobiographical encodings than males ($t_{30} = 2.83$, $P < 0.01$; $d = 0.70$) and were also faster on autobiographical than on referential encodings ($t_{15} = 2.65$, $P < 0.02$; $d = 0.50$). To control the family-wise error, the alpha level was set at 0.025 according to Bonferroni's correction.

The ANOVA on correct responses did not reach any significant effect: Gender ($F_{1,30}$ = 3.15, P = 0.089; ηp^2 = 0.095); Kind of Encoding ($F_{1,30}$ = 0.246, P = 0.624; ηp^2 = 0.008).

The 10 odorants gave rise to a total of 73 autobiographical and 87 referential memories for the male group and to a total of 93 autobiographical and 67 referential memories for the female group.

These frequencies were transformed in proportions. Statistical comparisons by means of a proportion's test for paired and unpaired samples showed that odorants evoke significantly more autobiographical than referential memories in females (z = 2.90, $P < 0.004$). Furthermore, a comparison of the different forms of encoding between females and males showed that males made significantly less autobiographical (z = –2.23, $P < 0.03$) and significantly more referential encodings (z = 2.23, $P < 0.03$) than females. Data are shown in Tables 1 and 2.

Summary conclusion experiment 2

The way in which odors were encoded during step 2 affected retrieval. Accordingly, odorants evoking autobiographical memories lead to faster RTs in the recall of items linked to such memories than do odorants which evoke referential memories. This effect is gender dependent, with females showing it more strongly than males. Odor-linked autobiographical memories, therefore, might have a higher emotional connotation for women than for men.

Experiment 3 (elderly)

Method

Participants

Two groups of healthy elderly (16 males and 16 females) living at home, aged on average 67.03 ± (SD) 1.8 years (range: 65–70 years), participated in the study.

None of the participants exhibited an acute or chronic impairment in olfactory function prior to the study. All participants gave their informed consent to take part in the study. The experimental procedures were in accordance with the Declaration of Helsinki for experimentation with human subjects.

The materials and procedure are the same as for Experiments 1 and 2.

Results experiment 3

Two two-way mixed design ANOVAs were carried out on the data, RTs and percentages of correct responses, with Gender (males vs. females) and Kind of Encoding (autobiographical vs. referential) respectively as between and within factors (see Figure 3A,B).

In the RTs analysis, the factor Kind of Encoding reached a statistically significant level. ($F_{1,30} = 11.89$, $P < 0.01$; $\eta p^2 = 0.284$) with autobiographical encoding being faster than referential encoding. No other comparisons reached significance. Gender nonsignificant effects relative to RTs: ($F_{1,30} = 0.176$, $P = 0.678$; $\eta p^2 = 0.006$).

The ANOVA on correct responses did not reach any significant effect: Gender ($F_{1,30} = 0.596$, $P = 0.446$; $\eta p^2 = 0.019$); Kind of Encoding ($F_{1,30} = 1.35$, $P = 0.254$; $\eta p^2 = 0.043$).

The 10 odorants gave rise to a total of 95 autobiographical and 65 referential memories for the male group and to a total of 99 autobiographical and 61 referential memories for the female group.

These frequencies were transformed in proportions. Statistical comparisons by means of proportion's test for paired and unpaired samples showed that odorants evoke significantly more autobiographical than referential memories both in males ($z = 3.35$, $P < 0.001$) and in females ($z = 4.24$, $P < 0.0002$). Data are shown in Tables 1 and 2.

Summary conclusion experiment 3

Interestingly, both elderly groups exhibited faster RTs on the recall of items associated with autobiographical memories compared those associated with referential ones. In addition, odors evoked more autobiographical memories than referential memories for both groups. Probably, this was due to the more extensive experience with odors the elderly had during

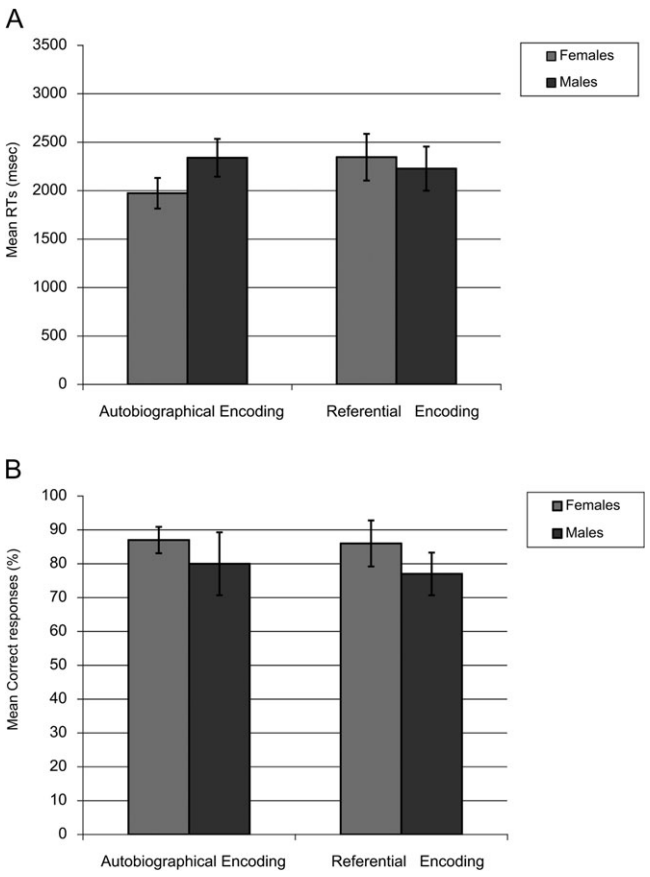

Figure 2 **(A)** RTs scores (Mean ± 95% confidence interval) for young males and females as a function of encoding condition. **(B)** Percentages of correct recognition scores (Mean ± 95% confidence interval) for young males and females as a function of encoding condition.

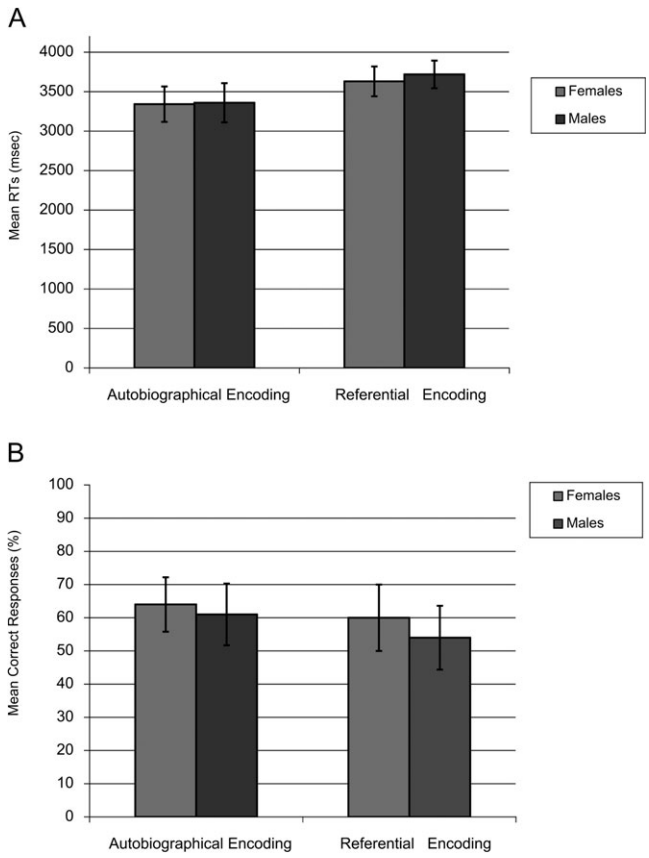

Figure 3 **(A)** RTs scores (Mean ± 95% confidence interval) for elderly males and females as a function of encoding condition. (**B)** Percentages of correct recognition scores (Mean ± 95% confidence interval) for elderly males and females as a function of encoding condition.

the course of their life compared with that of adolescent and young people. Accordingly, living longer increase the number of experiences that odors may be linked to, whereas the number of referential possibilities does not increase.

Both groups of elderly performed worse than adolescents and young in both tasks, being slower and less accurate to produce a response than the other groups. These outcomes are consistent with the literature which accounts for a reduced sense of smell and an age decline in memory retrieval in elderly (cf., e.g., Craik et al. 1995; Rubin and Schulkind 1997).

Effects of age differences

Finally, some statistical comparisons between the 3 studies have shown the following significant age effects (note that data to be compared refer to the whole groups, including both males and females):

1. With respect to RTs to autobiographical encodings, the adolescents were slower than the young: ($t_{30} = 3.64$, $P < 0.001$) but faster than the elderly ($t_{30} = 3.21$, $P < 0.003$), who in turn were slowest of all and much slower than the young ($t_{30} = 7.93$, $P < 0.0001$). The same pattern was found for RTs to referential encodings. Again the young were faster than both the adolescents ($t_{30} = 2.77$, $P < 0.009$) and the elderly ($t_{30} = 8.84$, $P < 0.0001$), whereas the adolescents were faster than the elderly ($t_{30} = 6.50$, $P < 0.0001$).
2. With respect to correct responses, the young do best in all cases (autobiographical: adolescents vs. young: $t_{30} = 2.71$, $P < 0.01$; young vs. elderly: $t_{30} = 3.73$, $P < 0.0008$ and referential: adolescents vs. young: $t_{30} = 4.17$, $P < 0.0002$; young vs. elderly: $t_{30} = 4.07$, $P < 0.0003$). There were no significant differences between the adolescents and the elderly.

Discussion

The present study aimed at exploring the extent to which odor cues remind people of autobiographical or non autobiographical life experiences depending on age and gender, and whether odors that evoke autobiographical memories are more effective cues than odors that remind one of non autobiographical referential memory in the recollection of associated items. We are not aware of studies on autobiographical odor memory that took this latter facet into account and also looked for gender differences along the whole life span.

The most striking feature of the results of these 3 experiments is the change in performance under the influence of age. Changes are observed in the numbers of autobiographical and referential memories evoked by the odors, in the ratio between the proportions of autobiographical memories evoked in males and females, and in the RTs and percentages correctness of the responses and their ratios both between types of encoding and between genders. These changes and their possible causes will be used to put the results in a theoretical perspective.

Evocation by odor: autobiographical versus referential

With age, the number of evoked autobiographical memories increases, and as a consequence, the number of evoked referential memories decreases, whereas the ratio between the genders (female autobiographical responses/male autobiographical responses) decreases from 1.46 at adolescence to 1.24 in adulthood or equality in the elderly. As pointed out above, the first finding is perhaps not very surprising because the number of possible autobiographical memories linked to an odor grows with age, whereas the number of referential memories does not or if it grows does so to a much lower degree. The second finding needs more detailed explanation. Why are young women clearly superior in producing autobiographical memories to odors and why do they loose this superiority later, although they produce more and more autobiographical memories with progressing age. The finding of gender differences in odor-evoked autobiographical memory is in itself not surprising, although such differences have not been established before. Gender differences in autobiographical memory in the same direction as the ones found here are a common phenomenon (Seidlitz and Diener 1998; Davis 1999; Fivush 2011) and seem even to be founded in the functional neuroanatomy (Piefke et al. 2005). The basic question is rather why such differences have not been found in earlier research on odor-cued autobiographical memory. The explanations are 3-fold: 1) In some cases (e.g., Willander and Larsson 2006), gender differences have not even been tested; 2) The autobiographical associations with the odors used (varying from predominantly male odors, e.g., whiskey, beer and red wine, and motor oil to predominantly female odors, e.g., hair products, detergents, etc.) are never specified. It may therefore be that their difference in frequency of occurrence in the life of men and women compensated for the existing gender differences in memory for odors in general. To demonstrate gender differences in odor-evoked memory one must either use odors with an equal frequency of occurrence for both genders (staple foods, such as bread or pasta or certain fruits) or specify the results per odor and relate this to the respective frequency of occurrence of the odor in the life of the 2 sexes. 3) Some of the methods used (e.g., Herz 2004) involved scaling of the characteristics of the autobiographical memories rather than the evocation of the autobiographical memories themselves. Such a procedure invokes a more distant and explicit cognitive attitude which might reduce the gender differences in odor-evoked autobiographical memories that seem closely related to the immediate emotion. Thus, the fact that gender differences are found here is not surprising even if others

have not found them, and it is more interesting to see what factors might be the principal reasons for them. A few possibilities present themselves. As pointed out above, women are more sensitive to odors than men from very early on (Doty 1986; Doty and Laing 2003; Doty and Cameron 2009), and this difference becomes much stronger around puberty (Koelega and Köster 1974). They also outperform men on odor identification, discrimination, and liking for perceived odor complexity (Jellinek and Köster 1979, 1983) and are at variance with men in assigning pleasantness ratings to the odorants. All of these factors probably contribute to the greater probability for women to associate odors with personal life events. Furthermore, these factors might result in a greater female involvement with odors from the early years on.

However, extensive recent data have indicated that with respect to odor identification, which depends on a combination of odor sensitivity, odor memory, and semantic (name) memory, female superiority remains stable from 35 years till at least over 80 years of age (Larsson et al. 2009), whereas female superiority in vocabulary performance was only found between 45 and 60 years in the same groups. This makes it at least improbable that the age-related gender differences in type of evoked memory are directly related to olfactory function or memory performance, but it may point in the direction of a possible influence of female verbal superiority, which seems to be lost around the same age as their advantage in the proportion of evoked autobiographical memories over men. Already from an early age and not just from 45 years on (see, Denno 1982; Halpern 2000; Banich 2004, for reviews), women outperform men at verbal tasks, and it is therefore possible that the gender difference in this experiment, which was carried out with common and therefore verbally identifiable odors, is based on or related to female verbal superiority.

Unfortunately, when well-known odors are used, as in most experiments on odor recognition, in all experiments on odor identification, and, as it is necessary, in experiments evoking autobiographical memories including the present one, it is not possible to separate the effects of the odors themselves from the effects of the verbal and semantic information linked to them. However, when uncommon and unnameable odors are used (Møller et al. 2004) or when a name-independent recognition paradigm is used (Köster et al. 2004; Møller et al. 2005, 2007), women loose their advantage over men, suggesting that the semantic (name or other) information might be a key element in female superiority in odor memory for well-known odors or flavors. This might also be the case in the evocation for the autobiographical memories in the present experiments. After all, describing such memories probably demands more semantic versatility than finding referential ones, and women might find it easier to have access via verbal channels to autobiographical memories that they have raised earlier in conversation. On the other hand, there are also strong indications that, with the exception of visuospatial processing (finding one's way), women are better than men in most episodic memory tasks and especially in those requiring little explicit verbal processing, such as familiar odor recognition (Herlitz and Rehnman 2008). Although it is not sure that verbal processing is not involved in the recognition of familiar odors, these authors seem to suggest that verbal processing is not a major factor in dealing with olfactory memory when no identification is demanded.

Maybe women evoke also more autobiographical memories because they are still more concerned with private and family matters, whereas men are more outward oriented and interested in factual information (work, sports, and politics). The fact that the men catch up with age and finally produce as many autobiographical memories as the women might be due to the fact that after retirement, they also start thinking more about the past and private matters than during their active periods in life, and it might also be possible that such a process occurs with a higher emotional connotation at old age than in other periods of the life. It is well known that midlife crises are more frequent and more severe among men and that "awareness of time passing," "life review or reevaluation," and "change in personal approach to life" are the most frequent events to which the crisis is attributed (Wethington 2000).

Although it is difficult to decide which or which combination of the mentioned alternative explanations of the female superiority in autobiographical memories should be favored, the results at least confirm that odors do invoke rather large numbers of autobiographical memories and do so more often in women than in men.

Memory test performance

The results of the final memory tests do not show the same rather continuous development with age that is found for the evocation of autobiographical memories. Thus, the RTs to both the autobiographically and the referentially encoded memories are shortest in the group of the young adults and longest in the elderly, and the correctness of the responses follows the same pattern (i.e., correct responses are highest in the young adult group and lowest for the elderly). This seems to indicate that the 2 measures are both the resultants of 2 competing effects, an increase in the speed of memory access and precision with age between adolescence and adulthood, on the one hand, and a quite strong slowing down and loss of memory between young adulthood and old age on the other hand. Furthermore, it is clear that especially with respect to memory correctness, the variability within the groups increases strongly with age, irrespective of the type of encoding. This indicates that the rate at which memory performance deteriorates is to a large extent dependent on factors of individual development.

With regard to speed, the same is true up to young adulthood, but at old age, the slowing down is rather

universal, especially in the case of referential encoding, where the well-known problems of elderly with name finding may be involved (Craik et al. 1995; Kester et al. 2002).

The slowing down and loss of memory correctness with old age are rather general phenomena that occur in many forms of intentional learning and explicit memory. They do not seem to be specifically dependent on the form of encoding. Thus, they seem not to be related to the fact that odors were used but may depend entirely on the difficulty elderly people have with intentional learning and explicit recollection, something they almost never do any more in normal everyday life. The superiority of the young adolescents may be explained perhaps along the same lines. They are all students and live in a phase of their life where explicit learning is a very frequent and important occurrence. Indeed, in 2 experiments on incidental versus intentional learning and recognition of respectively uncommon odors (Møller et al. 2004) and flavors of uncommon foods (Møller et al. 2007) with young adults (also students) and elderly, it was shown that elderly were at least as good, if not better, on incidental memory but that they did much less well than young adults on intentional memory. It was also shown that the superiority of the young in the first case was not due to better spontaneous naming and verbal memory. In the present experiments, all learning was intentional, and the results are well in line with general findings on memory losses and the slowing down of reactive processes with age.

Gender differences for the RTs to autobiographically encoded memories follow the same monotonic pattern as the one for the frequency of their evocation: Female adolescents and female young adults are faster than their male counterparts, but female elderly are not. With respect to correctness of the response, only the female adolescents do better than the males. With respect to referential encoded memories, only the adolescents show gender differences, the females being better than the males on both speed and accuracy of the response.

The female superiority in the evoking of and dealing with autobiographical memories and the fact that its course over age coincides with that of female superiority in olfactory performance (sensitivity and memory) suggests indeed that odor with its strong situational and emotional connotations plays a role in it. Autobiographically encoded odors, then, might have a greater emotional influence on females provoking in them more quickly than in males, the evocation, first of the autobiographical episode associated to an odor, and immediately after that of the items linked to it. Unfortunately, except from here, these aspects have not been tackled in the extant literature; but a few researchers have shown that women report higher ratings of distress and higher anxiety-related symptoms than men to aversive olfactory (Kirk-Smith et al. 1983) and visual (Kelly and Forsyth 2007) conditioning stimuli and to public speaking tasks (Grossman et al. 2001). These studies, although sparse, would suggest a higher proneness of females to the influence of emotional experiences than males in the years up to adulthood. Women, indeed, are subject to higher social contingencies than men for expressing emotional responses (Carey et al. 1988). In addition, functional imaging brain activation and electrophysiological studies have respectively shown 1) up to 8 times more activation in young women than in men in the frontal and temporal regions (these latter are involved also in emotion and memory; Yousem et al. 1999) and 2) larger olfactory evoked potential amplitudes (Evans et al. 1995). This field, however, needs to be more fully studied (Doty and Cameron 2009).

However, according to our results, at old age, the difference between the genders makes place for equality, both in the number of odor-evoked autobiographical episodes and in RTs for autobiographical responses. This might occur, as it was tentatively proposed above, because, when approaching the age of retirement, men start thinking more about the past and about private matters than during their active periods in life.

In conclusion, the present experimental studies have clearly shown that the way in which odors are encoded (autobiographically or referentially) affects the subsequent retrieval of associated items and that the paradigm we have chosen (based on the progressive elaboration method of the Loci mnemonic) is suitable and provides advantages to study both the accuracy and the latency of the responses to odor-evoked autobiographical life events. This extends the existing theoretical arguments about the differences between odor-cued and verbal- or picture-cued autobiographical memory into area of the use of odor-cued autobiographical memories in learning and remembering other materials such as the sets of different words in this experiment. Linking new facts and ideas to odors or to odor evoked autobiographical memories via the mnemonic method described here seems to be an effective way of facilitating retrieval of the learned material. The question whether such a mechanism must involve autobiographical memories to become effective or whether it is sufficient to establish a direct associative link between the learning situation and the remembrance situation by using the same odor on both occasions as in Schab's experiments (Schab 1990) should be resolved in future research. Perhaps, Schab's finding also involved autobiographical aspects (e.g., chocolate odor may have evoked autobiographical memories), but the formation of a direct emotional link between both situations by the odor itself seems a more parsimonious explanation. If odors are indeed more "emotional" than other cues as is generally assumed (see Introduction), they may open up channels of basically implicit memory that are faster and more effective than the rather explicit ones that are invoked by word cues or odor names. In the case of Schab's experiments, it may have helped to revive the learning situation and to get access to specific details of the learned material in much the same way as in Aggleton and Waskett's (1999) study. The results of the present study are well in line with the results of Schab and of Aggleton and

Waskett in showing the facilitation of retrieval by odors, but they also illustrate that this facilitation is not or at least less present when the odors lead to a referential memory. Contrary to what is often stated (e.g., Herz 2004), this not only strongly suggests that odors give good access to specific memory information but also that odors do so only or at least better when they are not "objectified" or named. This latter conclusion fits well with the earlier discussed finding of Willander and Larsson (2006) that when odors can be identified, they produce less autobiographical memories. It is also in line with the earlier mentioned findings of Degel et al. (1999, 2001) on the linking of unidentified, but not of identified odors, to the situations in which they occurred without being consciously noted by the person.

We have also shown that the observed effects—together with the number of odor-evoked autobiographical memories, are largely sensitive to age and gender, and we have indicated a number of the possible explanations in terms of the mechanisms that might be involved in the differences.

As a next step, it would be interesting to study the extent to which these effects can be observed when visual and verbal cues are used.

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Appendix

The 2 lists of verbal stimuli (in triplets) to be associated (by means of Loci mnemonic) to the odour evoked autobiographical or referential memories

List A	
1. Cinema-Ant-Ship	1. Cinema-Formica-Nave
2. Nail-Stick-Fireplace	2. Chiodo-Bastone-Camino
3. Bone-Fly-Gate	3. Osso-Mosca-Cancello
4. Orange-balcony-Truck	4. Arancia-Balcone-Camion
5. Box-Farm-Pen	5. Scatola-Fattoria-Penna
6. Devil-Hanky-Watch	6. Diavolo-Fazzoletto-Orologio
7. Chain-Spoon-Mill	7. Catena-Cucchiaio-Mulino
8. Tree-Cow-Bird	8. Albero-Bue-Uccello
9. Prison-Egg-Hammer	9. Carcere-Uovo-Martello
10. Mountain-Flag-Bride	10. Montagna-Bandiera-Sposa
List B	
1. Gate-Orange-Cow	1. Cancello-Arancia-Bue
2. Mill-Box-Hanky	2. Mulino-Scatola-Fazzoletto
3. Fly-Tree-Flag	3. Mosca-Albero-Bandiera
4. Armchair-Tower-Hut	4. Poltrona-Torre-Capanna
5. Sheep-Key-Giraffe	5. Pecora-Chiave-Giraffa
6. Hammer-Cinema-Garden	6. Martello-Cinema-Giardino
7. Tie-Sunset-Ant	7. Cravatta-Tramonto-Formica
8. Ship-Ring-Egg	8. Nave-Anello-Uovo
9. Coin-Car-Farm	9. Moneta-Automobile-Fattoria
10. Lamp-Prison-Cart	10. Lampada-Carcere-Carro