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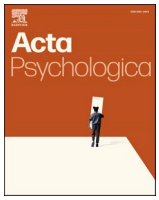

Odor-evoked memories: The importance of choosing the right odor

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ABSTRACT

Odors are known to entertain a special link with memory. However, the scientific literature investigating odors as powerful reminders of past experiences shows mixed results. This can be partly due to poor consistency in methodological approaches, especially concerning stimuli choice. Here, we presented 64 odorants to 130 young adults and asked them to freely report what each odor evoked to them. Responses were sorted in 1) mere odors' identification attempts and 2) any other memory-based verbal content, whose phenomenological properties were analyzed quantitatively and qualitatively. As expected, only a limited number of odors managed to spontaneously trigger high-quality autobiographical memories. In most cases, people engage in an odor identification task or evoke unspecific memory contents. We finally selected a pool of 20 odors as a function of the memory contents they're more likely to trigger. This enabled us to formulate recommendations for professionals (researchers or practitioners) performing olfactory-based memory stimulation.

Odors are effective reminders of past experiences due to the special link they entertain with memory. Olfactory responses (i.e. psychological reactions and/or behaviors) are indeed acquired through associative learning from the earliest moments of life and are shaped by culture and experience across life-span (see Herz, 2012 for a review).

A large part of the scientific literature investigating the evocative power of odors has focused on autobiographical memory, which has been defined as personal events from one's life (Conway & Pleydell-Pearce, 2000) underlying the sense of self and helping to regulate individuals' current and future behaviors (Conway, 2005; Pillemer, 2003; Rathbone, Moulin, & Conway, 2008). Autobiographical information is organized at many levels of abstraction, from sensory details to conceptual lifetime periods (Williams, Conway, & Cohen, 2008). In line with the encoding specificity principle – according to which matching the encoding contexts of information at recall assists in the retrieval of episodic memories (Tulving & Thomson, 1973) – sensory cueing can favor autobiographical event retrieval and odors in particular have been considered excellent cues.

Odor-evoked autobiographical memories (AMs) are indeed claimed to be different from other memory experiences particularly because of their enhanced specificity, emotional charge, vividness (i.e. the clarity and detail of visual imagery in a memory), rarity (i.e. the fact that they're rarely thought of compared to other memories), feeling of "being brought back in time" and age (i.e. memories from early life) (see Herz, 2012 or Larsson, Willander, Karlsson, & Arshamian, 2014 for a review). However, the results from the literature are somewhat inconsistent: whilst some studies have suggested enhanced emotions or vividness in memories evoked by odors as compared to those evoked by verbally, visually or auditory cues (e.g. Bonfigli, Kodilja, & Zanuttini, 2002; Herz, 1998, 2004; Willander & Larsson, 2007), several other authors failed to observe any differences across cue modalities (e.g. Toffolo, Smeets, & van den Hout, 2012; Willander & Larsson, 2006).

These findings have direct applications in clinical frameworks, especially for care professionals performing sensory-based cognitive stimulation with memory-impaired patients, namely dementia patients (see Herz, 2016 for a review). In these patients, memory retrieval is problematic and AMs lose their quality: they are less specific and vivid, and more like abstract summaries of extended and repeated events (e.g., Piolino, Desgranges, Benali, & Eustache, 2002; for a related general theory, see Park & Reuter-Lorenz, 2009). As a result, dementia patients have limited access to memories that shape their sense of self (Addis & Tippett, 2004; EL Haj, Antoine, Nandrino, & Kapogiannis, 2016; Morris & Mograbi, 2013) which ultimately favors the development of psycho-behavioral and affective disorders (Addis & Tippett, 2004; Morris & Mograbi, 2013).

To enhance memory performances in these patients, sensory-based

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cognitive training are frequently proposed, aiming at stimulating episodic – usually autobiographical – and/or semantic memory by exposing dementia patients to a set of sensory stimuli before asking them to perform some cognitive tasks (e.g. autobiographical memory retrieval, identification tasks, semantic networking; see Pinto, Dores, Geraldo, Peixoto, & Barbosa, 2020 for a review on sensory stimulation programs in dementia). Yet, little is known about the scientific rationale underlying these activities and the "olfactory stimulation kits" marketed to conduct them. It is therefore of great interest to improve our understanding of the psychological processes underpinning olfactory-based memory stimulation.

Research data discrepancies related to odor-evoked AMs retrieval are likely linked to poor consistency in methodological approaches. Beyond differences in task instructions and rating methods, the number and type of olfactory stimuli used as cues vary significantly across studies. Participants are generally cued a certain number of times (mostly ranging between 2 and 20, depending on studies) using odorants related to a different range of olfactory categories (see D'Andrea, Tischler, Dening, & Churchill, 2022 for a review). As for the rationale behind the choice of stimuli, selections are based either on physical and physiological effects reported by previous studies or on participants' odor preferences assessed pre-intervention (D'Andrea et al., 2022). While it is unlikely that all odors are equally evocative, previous preliminary testing of odorants' evocativeness in experiments is infrequent.

One may suppose that the evocative power of odors targets different memory contents: odors' perception can evoke simple objects (i.e. the odor source), people, or random situations not necessarily nested in autobiographical episodes. Odor naming – also called odor source naming (i.e. naming the object from which the odor emanates) – is known as a particularly difficult task (Olofsson & Gottfried, 2015). Correct naming performance for a set of common everyday odors rarely exceeds 50 % and this number is considerably lower for more uncommon odors (see Jönsson & Olsson, 2012 for a review). Interestingly, however, the struggling search for the right label leads to the activation of semantic memory contents, i.e. the semantic network supposed to encompass the targeted word (Koriat, Levy-Sadot, Edry, & de Marcas, 2003).

Semantic knowledge about odors also affects memory retrieval processes. Specifically, it has been shown that when odors are presented together with their congruent names as retrieval cues, the phenomenological qualities of the evoked memories (such as perceived pleasantness, emotionality, and feelings of being brought back in time) are lower as compared to when only an odor was presented (Willander & Larsson, 2007). Olfactory-evoked events have also been found to be older than verbal-evoked ones (Chu & Downes, 2000; Willander & Larsson, 2006).

The unique psychological experience that each odorant causes to a single individual is hardly predictable, still, it is possible that some categories of odorants are more strongly evocative than others or more likely to target specific memory contents. Following an empirical, exploratory, approach we tested the evocative power of 64 odorants pertaining to seven different categories. A sample of young participants freely reported what each odor evoked to them before evaluating their own productions (in terms of phenomenological properties) and trying to identify the odor source. All the verbal contents were analyzed both quantitatively (with basic, inferential statistics and multivariate analyses) and qualitatively (textual analysis). To the best of our knowledge, this is the first attempt to provide an extensive characterization of the verbal contents evoked by a large set of odors.

Our first aim was to determine whether all the stimuli share a similar evocative power (i.e. presence of a memory-based verbal content cued by the olfactory stimulation). We aimed at characterizing the evoked memory-content to better understand the psychological process tapped by each olfactory stimulation. We hypothesized that, although most of the stimuli will evoke a memory-based verbal content, only a small percentage of them will give rise to specific AMs. Also, we expected that all the odors would evoke objects, i.e., participants will spontaneously engage in an odor source naming task. However, general identification of the odor source (i.e. the recollection of a broader term to designate the odor) will be more frequent than specific identification (Olofsson & Gottfried, 2015). Our long-term, applied goal is to initiate a validation process of a limited selection of olfactory stimuli for dementia care professionals. Here, we used Principal Component Analysis and Hierarchical Cluster Analysis to summarize the information contained in participants' responses and generate different clusters of odorants addressing different memory contents.

1. Materials and methods

1.1. Participants

One hundred and thirty French volunteer participants (44 males and 84 females, mean age = 36.8, age range = 21–66) were recruited among the university of Bourgogne-Franche-Comté students and staff. Participants who self-reported olfactory impairments (e.g., symptoms of cold) were not included. All participants gave written informed consent in accordance with the Declaration of Helsinki.

1.2. Odorants and design

Sixty-four odorants related to seven different categories (i.e. "Alert", "Food", "Fruits", "House Hygiene", "Nature", "Spice Aromatics" and "Vegetables"; see Appendix A for the complete list of odorants) were developed by International Flavors & Fragrances Inc. (IFF). The categories were selected among a variety of every-day odors deemed to be meaningful for the French population. The odorants were specifically created to correspond to real-life odors. For the study, 1.5 mL of each odorant were placed in a 60 mL brown glass vial on squares of cotton (3 × 3 cm). The glass vials were open one hour before the first test of the day. An incomplete block design was used to avoid olfactory fatigue. Each participant was presented with 10 odors so that each odorant was rated by 20 different participants. The odorants' presentation was randomized.

1.3. Procedure

Testing was undertaken in a well-ventilated and quiet room. Participants were tested individually. The odors were presented sequentially. For each stimulus, the evaluation required participants to open the vial and smell the odor before answering the questions. Participants were free to smell the vial as often as they wanted while answering the questions related to it. No specific information was provided on smelling procedure and duration to preserve the spontaneity of the task. Between each odor, participants took a break of approximately 10 s. All questions were presented in the same order for each odor and participant.

The first two questions were open-ended: participants were asked "*What does this odor evoke to you?*". In cases where a personal memory was recalled, participants were asked to report it by giving "as much details as possible".

An accurate evaluation of the personal memory then followed. Participants were asked to report (1) to what period of life does their memory refer and (2) if each memory was "specific" (i.e. related to a unique event, e.g. "my wedding day") or vague (i.e. the memory of a repeated event over lifetime, e.g. "Christmas holidays in grandmother's house"). Three memory dimensions were also evaluated: emotional intensity, vividness, and feeling of "being brought back in time" during the retrieval process. Participants were asked "*How emotionally intense/vivid is this memory?*" and "*How strong is your feeling of being brought back to the time of the occurrence of the event?*". These ratings were done on a 7-point Likert scale, labelled at each end from not very much to very much.

Lastly, participants were asked if they could identify (i.e. attach any label to) each odor. The experimenter was instructed to note if the

participant already spontaneously mentioned the right label during his/her previous responses in order to avoid asking this final question.

The whole experimental session lasted about 30 min for each participant and was audio recorded for later transcription and textual analysis.

1.4. Scoring protocol

For close-ended questions related to the personal memory evaluation, participants were encouraged to provide a qualitative label (i.e. respectively "Childhood / Teenagerhood / Adulthood / Don't remember" / "Specific/Vague"). Questions related to memory dimensions (emotional intensity, vividness and feeling of "being brought back in time") were coded using numerical values ranging from 1 to 7.

Attempts to give each odor a label were categorized as: wrong label or no response, correct generic label (e.g. cleaner, food, sweet) and correct specific noun label (e.g. dissolvent, coffee, strawberry). For each correct label (either generic or specific), we reported whether it came spontaneously or on request.

1.5. Analysis

1.5.1. Variables of interest

To characterize the evoked memory contents, we computed for each stimulus ten different variables that we grouped into two distinct categories: verbal contents originating from mere odor identification attempts (in short, "Identification variables") and any other verbal content evoking subject's past experience with the odor, i.e. memory-based verbal contents (in short, "Memory variables").

Memory variables were: (1) the mean % of *evocations* (%EVOC), i.e. the percentage of times that a memory-based verbal content cued by the olfactory stimulation was evoked, (2) the mean % of personal memories among evocations (%MEM), (3) the mean % of "specific" personal memories, (4) average emotional intensity, (5) average vividness, (6) average feeling of "being brought back in time", (7) the % of memories from Childhood and Adulthood. As memories from "Teenagerhood" were scarce, we did not consider this variable in the analyses.

Identification variables were (8) the mean % of correct generic identification (generic label), (9) the mean % of correct specific identification (specific noun label) and (10) the mean % of spontaneous correct identification (both for generic and specific label).

1.5.2. Descriptive and inferential statistics

To better understand the psychological process tapped by each odor – and thus determine whether they share the same evocative power – we performed some basic statistics on each "Memory" and "Identification" variables for each of our stimuli. Then, to further explore the relationships between these psychological processes, we performed across-stimuli Pearson correlations between our variables (except for the mean % of spontaneous correct identifications due to the scarcity of their occurrence).

Moreover, to test whether some categories of odorants are more strongly evocative than others or more likely to target specific memory contents, we conducted across-stimuli repeated measures ANOVAs with "Category" as between-subjects factor on all the variable of interest. Partial Eta-squared (η^2_p) are reported as effect size indexes. As suggested by Cohen (1988), we considered effect sizes as being small for $\eta^2_p < 0.06$, medium for $0.06 \leq \eta^2_p < 0.14$, and marked for $\eta^2_p \geq 0.14$. Planned comparisons were performed using bilateral Fisher's LSD test when a main effect was observed with α set at 5 %. For significant comparisons, Cohen's d was used to determine effect size with $d < 0.3$ corresponding to a small effect, $0.3 < d < 0.8$ to a medium effect and $d > 0.8$ to a large effect (Cohen, 1988).

To pursue our long-term applied goal of starting a validation process of a limited selection of olfactory stimuli, we performed a Principal Component Analysis (PCA) followed by a Hierarchical Cluster Analysis (HCA) to visualize the data and identify specific clusters of odorants. To simplify this analysis, we kept only the 39 odorants (out of 64) that had evoked a memory-based verbal content in at least 80 % of the trials (i.e. %EVOC $\geq$80) and a personal memory in at least 70 % of the trials (i.e. %MEM $\geq$ 70). The HCA was performed on the dimensions of the PCA with an eigenvalue >1 (Kaiser law), using Euclidean distance and Ward's agglomeration criteria. A specificity analysis was then carried out to characterize the identified clusters in terms of memory and identification variables. This was done by comparing each cluster average memory and identification scores with the overall average scores using *t*-test at α = 5 % (Lebart, Morineau, & Piron, 1995). PCA and HCA were performed with the SPAD 9.3 software (Coheris).

1.5.3. Textual analysis

To provide a deeper semantic analysis of our stimuli selection, a textual analysis of the whole verbal material (identification attempts and memory-based verbal contents) generated for the selected odors was carried out using the SPAD 9.3 Text mining procedure (Coheris). The combined corpuses were lemmatized (i.e., the terms were reduced to their simplest form) and non-informative words (tool words such as link words) or expressions removed. Word counts were then computed for each odor and represented as word clouds. The analysis was carried out in French and the terms retained translated in English to build the word clouds.

2. Results

Please refer to Appendix B for the complete descriptive statistics.

Overall, all the stimuli generated the evocation of a verbal content in at least 65 % of the trials (mean %EVOC = 90.4 ± 9.3 %; min = 65 %; max = 100 %). For 58 stimuli out of 64 (91 %), this verbal content was a personal memory in at least half of the cases (mean %MEM for the overall sample = 64.2 ± 14.1 %; min = 28,5 %; max = 94.7 %). These personal memories were deemed to be "Specific" in 26.7 ± 14.7 % of the cases in average (min = 0 %; max = 54.5 %) and they were overall rated as mildly emotional, vivid, and causing a "feeling of being brought back in time" (respectively, m = 4.3 ± 0.5; m = 4.9 ± 0.5 and m = 4.5 ± 0.5). In approximately half of the cases, they originated from childhood and/or adulthood (respectively, mean occurrence = 52.8 ± 16.3 % and mean occurrence = 45.1 ± 15 %).

As for identification scores, correct *generic* labels were recollected in 29 ± 20 % of the cases in average while the mean of *specific* labels recollection was 22.8 ± 22.7 %. Spontaneous generic labelling concerned 61 out of 64 stimuli and occurred in 22.2 ± 26.2 % of the cases on average. However, interestingly, specific labelling was more frequently spontaneous, occurring 77 ± 32 % of the cases on average in 53 out of 64 stimuli.

Intercorrelations of our variables of interest are reported in Table 1. The results revealed distinct associations. Noteworthy, we observed a positive correlation between the % of correct generic identification and the %MEM evoked (r = 0.39, p = .001). The % of correct specific identification was, in turn, positively correlated with the magnitude of the vividness of the memory (r = 0.41, p = .001). Interestingly, the % MEM correlated positively only with the emotional intensity (r = 0.41, p = .001), even though the scores related to all the memories' dimensions (i.e. emotional intensity, vividness and "feeling of being brought back in time") strongly and positively correlated with each other (all the r > 0.55, all ps = 0.000).

Lastly, the ANOVA revealed a main effect of the "Category" exclusively on the mean % of correct generic identification ($F_{(6,56)} = 2.29$, p = .04; $\eta^2_p = 0.19$). Fisher's LSD *post-hoc* comparisons showed that the odors pertaining to the categories of "Alert", "Food" and "House hygiene" were more frequently identified than the odors related to the categories "Spice aromatics" and "Vegetables" (respectively, m = 33.8 ± 6.6 %; m = 38.9 ± 5.1 % and m = 35.4 ± 6.2 % Vs. m = 16.2 ± 6.2 % and m = 10 ± 9.3 %, all $p \leq .05$).

Table 1
Intercorrelations of our variables of interest. Statistical significance was set at $p \leq .005$ for multiple comparisons.

	Generic identification	Specific identification	EVOC	MEM	Emotion	Vividness	Feeling of 'being brought back in time"	Specific	Childhood	Adulthood
Generic identification	1.00	**- 0.40****	0.32	**0.39****	0.29	0.16	0.20	−0.13	0.00	−0.17
Specific identification		1.00	0.20	0.27	0.15	**0.41****	0.10	0.23	−0.03	0.23
EVOC			1.00	**0.63****	**0.35***	0.02	0.17	−0.09	0.12	−0.23
MEM				1.00	**0.41****	0.28	0.27	−0.12	−0.02	0.03
Emotion					1.00	**0.57****	**0.64****	−0.07	0.34	−0.19
Vividness						1.00	**0.56****	0.15	0.26	0.13
Feeling of "being brought back in time"							1.00	0.06	**0.48****	**- 0.35***
Specific								1.00	−0.16	0.02
Childhood									1.00	**- 0.64****
Adulthood										1.00

* $p \leq .005$.
** $p \leq .001$.

2.1. Principal component analysis

Following Kaiser law (eigenvalue >1) the first four PC explaining 77 % of total variance were kept for the analysis (Figs. 1 and 2). To facilitate the interpretation of the PC, only variables with contributions greater than the average contribution were considered in the analysis.

The first PC (26.4 %) was positively correlated with memory variables (vividness, childhood and "feeling of being brought back in time") and generic identification and negatively correlated with two other identification variables (specific and spontaneous) and adulthood memories. It opposed odors evoking emotional memories from childhood (banana, shaving cream, burned rubber, lilac, madeleine, toasted bread) to odors associated to adulthood and easily identifiable (lemon, vinegar, peach, coffee).

The second PC (22.9 %) was positively correlated with all memory dimensions (emotional intensity, vividness and "feeling of being brought back in time") and specific and spontaneous identification and negatively correlated with generic identification. It opposed odors which are easily identified and evocative of vivid memories (Anis/pastis, Mint/toothpaste, lavender, chocolate, excrement/fawn, strawberry) to odors leading to generic identifications and less vivid memories (jasmin, cumin/curry, tomato juice, shampoo).

The last two PCs were correlated with memory variables. The third PC (18.1 %) opposed odors evoking more personal memories (coffee, anis/pastis, peach and violet) to odors evoking more specific memories (rose, vanilla, excrement/fawn, amaretto, banana). The Fourth PC (10,3 %) opposed odors evoking more adulthood memories (vinegar, chocolate, hot milk, madeleine) to odors evoking more childhood memories (detergent, apple, jasmine, cologne, mint/toothpaste). The first ones evoked a lower proportion of souvenirs than the last ones.

The HCA carried out on the coordinates of the first fourth principal components yielded five main clusters (Fig. 3).

The 1st cluster (amaretto, banana, excrement/fawn, shaving cream, and rose) was characterized only by memory variables. Odors from this cluster gave rise to less personal memories than the average (%MEM), especially from Adulthood. However, the evoked memories had higher

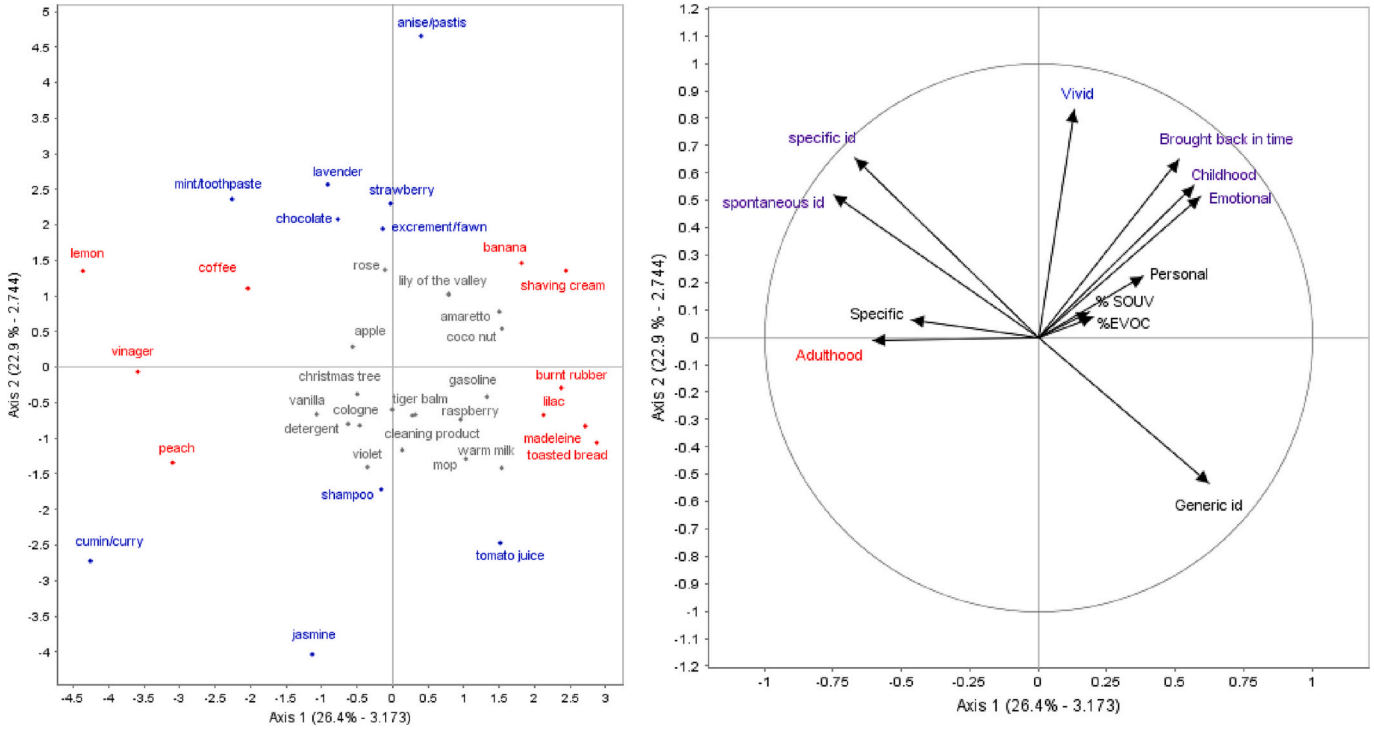

Fig. 1. First two dimensions of the principal component analysis. The red and blue colours represent variables and odors with a contribution to the first and second component, respectively, greater than the average contribution. "Id" = Identification. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

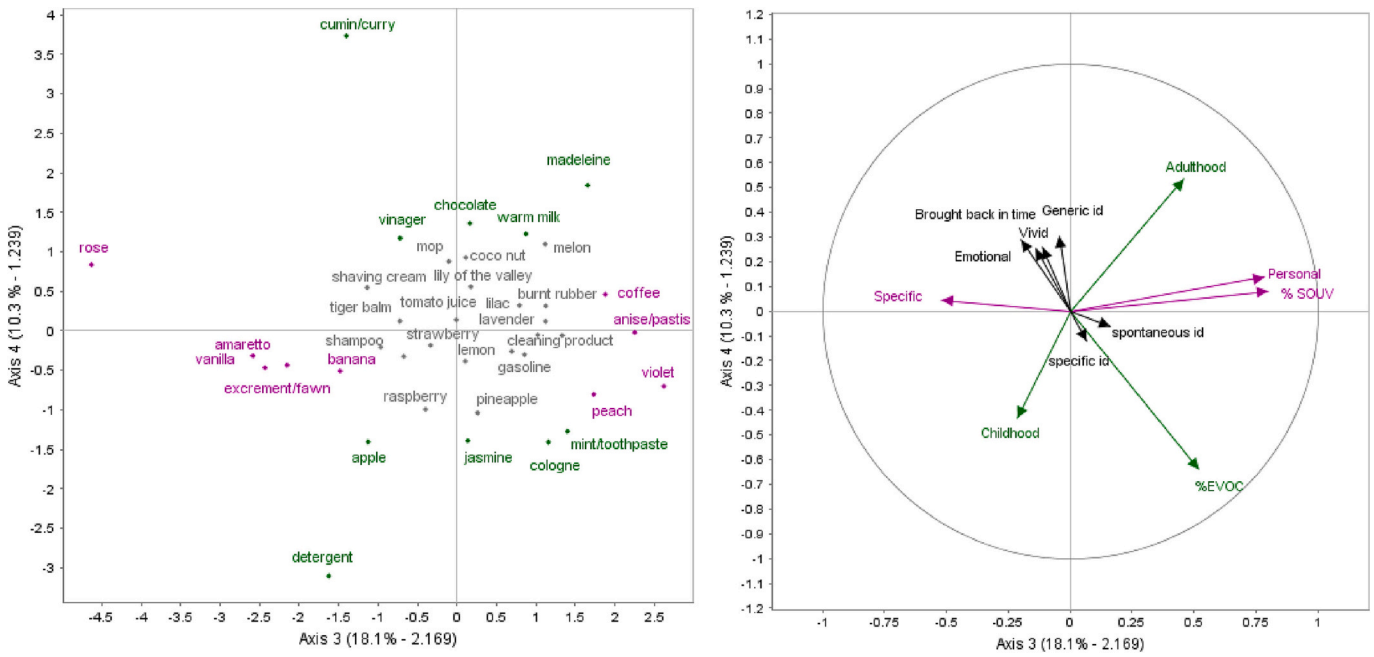

Fig. 2. Dimension 3 and 4 of the principal component analysis. The green and pink colours represent variables and odors with a contribution to the third and fourth component, respectively, greater than the average contribution. "Id" = Identification. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

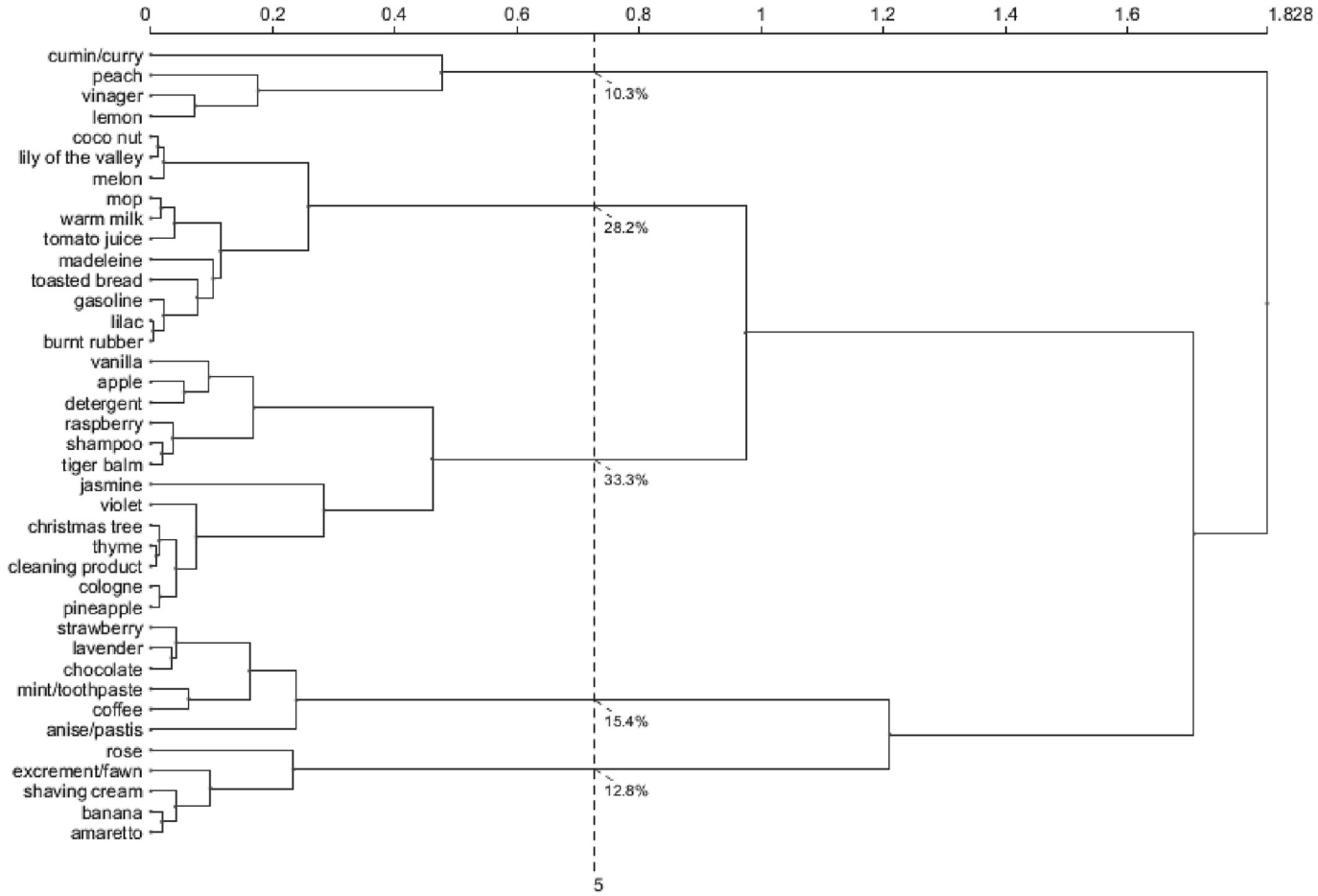

Fig. 3. Hierarchical cluster analysis carried out on the Coordinates of the odors on the first four dimensions of the PC.

scores in emotionality, vividness and "feeling of being brought back in time" than the average. They were also more linked to Childhood than the average. Amaretto was the best exemplar (ie. closer to the center of the cluster) of this cluster.

The 2nd cluster (anis, coffee, chocolate, strawberry, lavender, and mint/toothpaste) was characterized by both identification and memory variables. The odors grouped in this cluster had higher scores in specific and spontaneous identification and lower scores in generic identification than the average. They also evoked more memories than the average which were more vivid, originating from adulthood and more characterized by a feeling of "being brought back in time" than the average. Lavender was the best exemplar of this cluster.

The 3rd and larger cluster was mainly characterized by the evocative power of its odors (pineapple, tiger balm, cologne, raspberry, jasmine, detergent, apple, cleaning product, Christmas tree, shampoo, and thyme). These odors indeed produced a higher proportion of evocations (%EVOC) than the average but all the memory-contents were less emotional, vivid and bringing less feelings of "being brought back in time" than the average. The best exemplar of this cluster was pineapple.

The 4th cluster (burnt rubber, gasoline, tomato juice, warm milk, lilac, madeleine, and coconut) was characterized both by memory and identification variables. Odors from this cluster gave rise to less specific, spontaneous, and more general identifications than the average. Memory-contents originating from these odors were more frequent and personal than the average but less specific. The best exemplar from this cluster was lilac.

Finally, the 5th cluster (lemon, cumin/curry, peach, and vinegar) gave rise to more specific memories and identifications associated with adulthood but less personal, emotional, and with less feeling of "being brought back in time" than the average. The best exemplar of this group was vinegar.

2.2. Stimuli selection

In order to pursue our long-term research aim (i.e. providing dementia care professionals with a selection of empirically tested odors) we proceeded to select a narrower pool of odors out of our 39 stimuli. This was done according to two main criteria: (1) identifying the best-characterized clusters in order to maximize the variability of odors' properties, and (2) selecting the most representative odors for each cluster (i.e. by considering their distance value from the center of the cluster) with the only constraint to obtain a balanced number of odors between clusters. This proceeding led us to exclude the 3rd cluster since odors from this cluster were mainly characterized by an overall lack of properties of interest (i.e., identifications variables, evocation of personal memories and phenomenological dimensions) when comparing with the average. The final pool consisted of 20 odors, which are shown in Table 2. Odors are presented along with their cluster's code, their distance from the center of the cluster and their properties in terms of identification and memory variables.

2.3. Textual analysis

Fig. 4 displays the words clouds obtained for the odors in each cluster.

The first cluster included various odors like amaretto, banana, excrement/fawn, shaving cream and rose. Amaretto and banana were mainly described as *candies* and evoked words like *chewing-gum*, *fruit syrup*, *almond*, *banana, to eat*, etc. Excrement/fawn was associated to *countryside*, *farm* and *pig*. Shaving cream was linked to *perfume*, *man*, *shaving*, *father*, etc. Rose evoked words like *paper*, *grand-mother*, *garden*, *rose*, *to burn*, *mother*. Childhood was a word mentioned for almost all odor of the cluster. There were also frequent evocations to family (*mother*, *grand-mother*, *father*…). The evocations and memories mentioned are consistent with the specificity of this cluster: higher scores on childhood, emotionality, vividness and "feeling of being

Table 2
Final selection of 20 odors presented along with their cluster's code, their distance from the center of the cluster and their properties in terms of identification and memory variables.

Group	Labels	ACP clusters	Distance	Memory variables						Identification variables			
				Specific memories	Lot of memories	Emotionality	Vividness/ Reviviscence	From Childhood	From Adulthood	Specific and spontaneous identification	Mainly general identification	Almost no identification attempts
1	Amaretto	1	0,860			x	x	x				x
1	Banana	1	1240			x	x	x				x
1	Excrement/ Fawn	1	1440			x	x	x				x
1	Shaving cream	1	1890			x	x	x				x
1	Rose	1	2700			x	x	x				x
2	Anis	2	2786		x		x		x	x		
2	Coffee	2	1994		x		x		x	x		
2	Chocolate	2	1643		x		x		x	x		
2	Strawberry	2	1714		x		x		x	x		
2	Lavender	2	0,084		x		x		x	x		
2	Mint/ Toothpaste	2	1925		x		x		x	x		
3	Burnt rubber	4	0,977		x						x	
3	Gasoline	4	1034		x						x	
3	Warm milk	4	1142		x						x	
3	Lilac	4	0,593		x						x	
3	Coconut	4	1208		x						x	
4	Lemon	5	2497	x					x	x		
4	Cumin/curry	5	3734	x					x	x		
4	Peach	5	2685	x					x	x		
4	Vinegar	5	0,967	x					x	x		

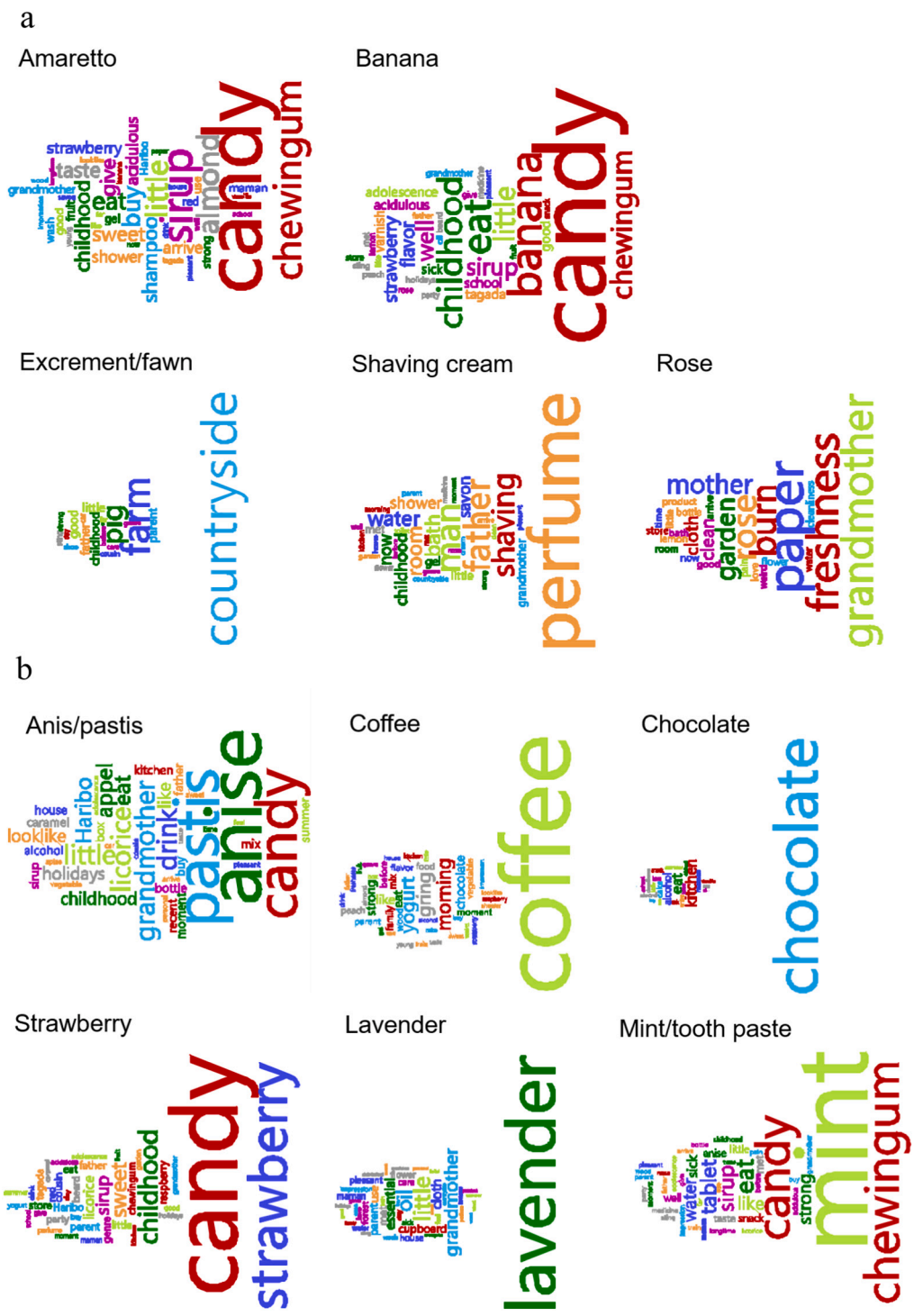

Fig. 4. Words clouds obtained for the odors in each cluster. a) Cluster 1. b) Cluster 2. c) Cluster 4 and d) Cluster 5.

brought back in time".

The second cluster regrouped anis/pastis, coffee, chocolate, strawberry, lavender, mint/tooth paste odors. These odors had a higher score in specific and spontaneous identification. Consistently, the exact label was mentioned for all the odors of the group: *candy/anise*, *coffee*, *chocolate*, *candy/strawberry*, *lavender,* and *mint/chewing-gum*. Moreover, odors from this cluster also evoked more memories linked to adulthood, that were more vivid and more linked to "the feeling of being brought back in time" than the average. Indeed, except for strawberry and anise which are directly associated to *childhood*, the other odors of the cluster referred to everyday situations. For example, the words *morning*, *to eat*, *like*, *grind* were mentioned for coffee. Chocolate evoked *cakes*, *kitchen, alcohol, to eat*. Anise evoked *candies* and *beverage.* Lavender reminded *essential oils*, *care*, *clothes*, and *wardrobe*.

The third cluster was represented by burnt rubber, gasoline, warm milk, lilac, and coconut odors. They were more associated to general identification and more personal memories. This cluster included the two "Alert" odors evoking "*burning items*" and specifically, *smoke* and *wood* for burnt rubber and *white spirit, paint, car* for gasoline. Warm milk was described as *cake*, *caramel*, *candies, sugar, to eat* and coconut was

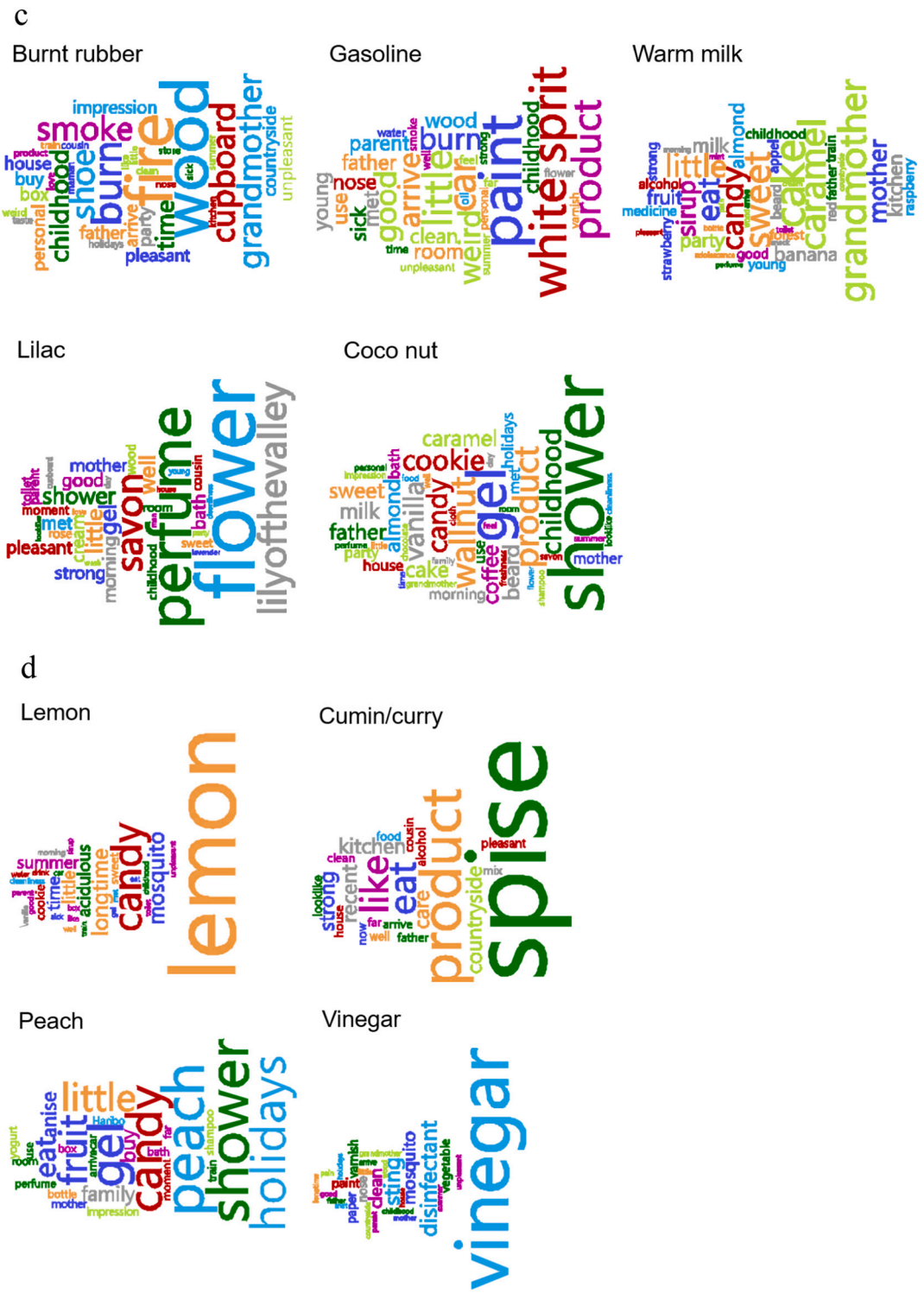

Fig. 4. (*continued*).

associated to *shower*, *vanilla*, *candies*, *almond*, *childhood*. Lastly, lilac evoked *perfume*, *flowers*, *lily of the valley*, *soap*.

The fourth cluster included lemon, cumin/curry, peach, and vinegar. These odors were significantly represented by specific memories linked to adulthood and specific identification. Indeed, all odors, except cumin/curry were frequently associated to their exact label. For cumin/curry the general label was mentioned: spice. Regarding the memories associated with these odors, they refered to a variety of individual situations. For example, lemon was associated to *cake*, *candies* but also to *mosquitos*, *clean*, *toilet*, *sick*. Peach was linked to *shower*, *candies*, *holidays*, *family*, etc. Cumin/curry was linked to *food*, *product*, *countryside,* and *care*. Lastly, vinegar was associated to *disinfectant*, *clean*, *mosquitos* and *paint* or *paper*.

In conclusion, our statistical approaches allowed to characterize a set of odorous stimuli and form four different clusters of odors. The aim of this analysis was to maximize the variability of odors' properties between clusters while minimizing it within them. Our supplementary textual analysis allowed to bring some additional information about the

semantic network tapped by each odor. The final selection of odors is presented in Table 2.

3. Discussion

The aim of the present study was to test the evocative power of a large set of odorants through an exploratory, empirical approach. More specifically, we aimed at characterizing the evoked memory-content associated to these odorants to better understand the psychological processes tapped by each odor. Overall, our data confirmed that odors have different evocative properties. The following discussion will tackle some theoretical considerations before addressing the practical implications of our work.

3.1. Psychological processes following odor perception: theoretical considerations

Following odor presentation, the evocation of a verbal content occurred in >90 % of the trials in average. However, as expected, all the stimuli were not equally evocative as some odors triggered a verbal response in only half of the cases. About half of the verbal responses included personal memories but less than one-third of them was deemed to be "Specific". In short, these data suggest that while some odors ensured good chances to trigger episodic (specific) AMs at each presentation, some others managed to do so in less than one twelfth of cases.

As expected, odor naming was a difficult task. Correct labelling (either generic or specific) occurred in <1/3 of cases which is in line with previous data (Cain, 1979; Engen, 1987; Huisman & Majid, 2018 for a review). Spontaneous attempts concerned almost the whole set of stimuli, but their occurrence was not systematic (less than ¼ of cases). Noteworthy, specific labelling was more frequently spontaneous than generic one, suggesting that when a specific odor's name is available (i.e., when the subject has a specific knowledge about the odor), the access to the label is fast and automatic (i.e., demanding little or no retrieval efforts). These considerations are in line with previous work suggesting that the ineffability of odors is best explained by a lack of knowledge about the odors' identity and not by difficulties in retrieving labels (see Jönsson & Olsson, 2012 for a review).

Our data also allow to characterize language contribution to memories' retrieval processes. We observed a positive correlation between the percentage of correct generic identification and the percentage of evoked memories. Notably, Conway and Pleydell-Pearce (2000) distinguished between two different memories' retrieval processes: strategic and automatic. In strategic retrieval, cues entail an intentional cyclic and elaborative search process of information in memory until a specific memory is formed, a process that has been associated with verbal cues (Haque & Conway, 2001). In automatic retrieval, recollection is direct and effortless and immediately activates a representation of an event in memory. In line with this model, it is possible that the less participants were able to specifically identify the odor, the deeper the semantic exploration and the larger the production of verbal cues and subsequent memories. On the other hand, however, the percentage of correct specific identification is positively correlated with the magnitude of the vividness of memories. This suggests that when a specific label is available, the access to memories' visual properties is facilitated.

These considerations only partially support the existing literature. In the last decades, several groups of authors have showed that the explicit knowledge of an odor name during a memory retrieval task negatively affects the phenomenological qualities of the evoked memories (Willander & Larsson, 2007). In our task, however, odors' labels were retrieved by participants themselves, whilst in previous studies investigating the phenomenon, they were provided in association with the odorous stimuli (see Larsson & Willander, 2009 for a review). It is possible that, when self-retrieved, odor's label is nothing but an additional element that is available during an automatic retrieval process triggered by an odor. In these cases, memories' phenomenological qualities are not affected by odors' label knowledge. By contrast, when the label is provided in association with the odor, semantic knowledge prevails over the sensory stimulation as a starting point of the retrieval process. An important topic for future research, therefore, will be to further elucidate the role played by verbal information in the phenomenological experience of olfactory-evoked autobiographical information.

3.2. Olfactory stimulation: practical implications for professionals

Our long-term, applied goal was to provide dementia care professionals with a limited selection of empirically tested olfactory stimuli addressing different memory processes.

The stimuli selection presented in Table 2 should help professionals performing sensory-based cognitive stimulation in tailoring the choice of stimuli to target specific psychological/memory processes. To further explicit our stimuli applied potential, we propose an overview of each cluster properties along with some examples of activities in Table 3. Please note that, from now on, the feeling of "being brought back in time" will be conveyed by the word "reviviscent".

For example, we strongly recommend using odors from Group 1 (i.e., Amaretto, Banana, Excrement/Fawn, shaving cream and Rose) to lead activities based on autobiographical memories' evocation as they're more likely to address rare memories from childhood related to family members. These memories will also likely be emotional, vivid, and reviviscent. On the other hand, as stimulating semantic networks allows to reinforce the links between concepts related to the same semantic field (see Nickels, 2002 for a review), professionals can encourage patients to deeply explore all the evoked semantic fields during the odor naming task. For example, odors from Group 3 (i.e. Burnt rubber, Gasoline, Warm milk, Lilac, Coconut) allow to explore two extremely different semantic fields (i.e. alert Vs. sweetness, perfumes and flowers) while maintaining an acceptable level of struggling. Moreover, since Group 3 also integrates odors from the "Alert" category, dangers-preventing workshops related to olfactory dysfunction can also be proposed.

3.3. Limitations

Our study has several limitations.

The first – and probably the most important one – is that our findings are essentially culture-centered. Human olfactory experience is shaped by environment and cultural factors. The panel of odors to which we are likely to be exposed from birth ultimately depends on where we are born on earth. For some cultures, talking about odors is more frequent and odor naming easier (see for example Majid & Burenhult, 2014). Importantly, different ways of talking about odors likely shape aspects of olfactory cognition too (see Majid, 2021 for a review). Readers need to bear in mind that our findings stem from a sample of young, well-educated, European subjects so great caution is needed when considering them outside the framework of the western-European culture.

We also did not ask participants to assess some important stimuli's properties, like their accuracy in representing the real (i.e. ecological) odor source or their intensity (Lopis, Le Pape, Manetta, & Conty, 2021). Participants' affective reactions (e.g., pleasantness and familiarity) were not monitored either, although they could have allowed additional insights about the psychological processes engaged after odors' presentation. This was done in order to limit the duration of the experimental task and, consequently, the risk of causing cognitive fatigability in our participants.

Finally, even though our analysis already allowed to make some recommendations for professionals performing sensory-based cognitive stimulation, additional work is needed to tailor the olfactory experience to dementia patients. The next steps include an extensive testing of the proposed selection in a sample of healthy older adults and people with

Table 3
Overview of each cluster properties along with some examples of proposed activities.

Group	Number of odors	Evoked memories will likely be…	Odors' identification will likely be…	Addressed semantic network	Recommended examples of activities
1	5	Rare, from childhood, emotional, vivid, and reviviscent.	Difficult and/or unspontaneous	Childhood, sweetness, family members (mother, grand-mother, father, etc.),	• Autobiographical memories evocation
2	6	Numerous, from adulthood, vivid, and reviviscent.	Specific and spontaneous	All the semantics directly related to odors' exact labels and everyday situations (i.e. eating, morning, clothes, wardrobe, etc.)	• Autobiographical memories evocation • Odor free identification • Semantic networking • Matching tasks with everyday objects
3	5	Numerous but unspecific.	Mildly difficult but more general labels related to each odor will be easily retrieved.	Two different semantic fields: • Semantics related to "alert" situations implying "burning items". • Semantics related to sweetness, perfumes, and flowers	• Semantic networking • Odor-cued identification • Danger prevention
4	4	Specific, from adulthood. No emotional charge, vividness or reviviscence are expected.	Specific and spontaneous	All the semantics directly related to odors' exact labels and food, house, and hygiene products.	• Odor free identification • Semantic networking • Matching tasks with everyday objects

dementia.

4. Conclusion

Through a deep testing of odors' evocativeness performed with advanced statistical analysis in a large variety of stimuli, our study is the first to provide a deeper understanding of the psychological processes underpinning olfactory-based memory stimulation. Even though odor-evoked verbal contents are frequent (but not systematic), the chances to trigger episodic AMs are extremely low. In most cases, people engage in an odor naming task or evoke unspecific memory contents. This contributes to explain the discrepancies we observe in results from studies investigating odor-evoked memories. We also provided a limited selection of the most well-characterized odorous stimuli: we sorted them in 4 groups as a function of the memory contents (and their phenomenological experience) they're more likely to trigger. This allowed us to formulate recommendations for professionals (either researchers or practitioners) performing olfactory-based cognitive stimulation.

CRediT authorship contribution statement

DV and CM collected the data. DL, DV and CM conceived and performed the analysis. DL and DV wrote the paper.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2023.103932.

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