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Evidence for Different Patterns of Chemosensory Alterations in the Elderly Population: Impact of Age Versus Dependency

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Abstract

The present experiment aimed to explore the interindividual variability in chemosensory abilities among the elderly population. The chemosensory abilities of 559 subjects, aged from 65 to 99 years, were evaluated. Various categories of the elderly, including people who were living at home either without or with assistance, and people who were living in a nursing home, were interviewed. The results revealed that 43% of the sample presented well-preserved chemosensory abilities, whereas 21% of the participants presented a moderate impairment. Of the sample, 33% presented well-preserved olfactory abilities but strong impairment in gustatory abilities and 3% were nearly anosmic but remained able to perceive the salty taste, demonstrating that gustation and olfaction were not systematically damaged simultaneously. The results showed a link between the level of dependence (free living vs. living at home with help vs. nursing home) and chemosensory abilities, independently of the age effect. These results strengthen the hypothesis that the impairment of chemosensory abilities is not only an effect of age *per se*; rather, it is related to events that are associated with aging. Factors that lead to increased dependence (such as poor health) also lead to an impairment in chemosensory performance.

Key words: aging, nursing home, odor, perception, segmentation, taste

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Introduction

Aging is accompanied by an impairment of chemosensory abilities, that is, the ability to perceive an odor or a taste (Doty et al. 1984a; Murphy 1986; Schiffman 1993; Mojet et al. 2001). However, beyond this overall effect of age on chemosensory abilities, aging is accompanied by interindividual variability in olfactory performance scores and, to a lesser degree, in taste performance scores (Stevens and Cain 1987; Stevens and Dadarwala 1993; Thomas-Danguin et al. 2003; Laureati et al. 2008). For instance, Laureati et al. (2008) evaluated the ability of elderly subjects (mean age: 81 years) and younger subjects (mean age: 23 years) to identify odors and tastes using a forced choice procedure. The results showed that for a composite score with a maximum value of 20, the scores of the elderly subjects varied from 4 to 17.5, whereas those of the younger subjects varied from 12 to 20.

Several mechanisms have been proposed to explain the effect of age on olfactory and gustatory sensitivity (Boyce and Shone 2006). From a physiological standpoint, aging is accompanied by the drying of the olfactory mucosa; modifications in the flow and composition of saliva, which disrupts the release and transport of aromatic and sapid molecules; changes in cell membranes, leading to the impaired functioning of ion channels and taste receptors; and slower turnover of sensory cells, leading to a reduction in the number of olfactory receptors (Larsson 1996; Mioche et al. 2004). However, beyond these physiological mechanisms that are inherent in the aging process *per se*, factors that are related

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to the lifetime experiences of each individual are likely to affect chemosensory perception. Mackay-Sim et al. (2006) reported a relatively small impairment in the olfactory abilities of elderly subjects who were in good health, that is, those who did not require medication, did not smoke, and did not have a history of nasal problems (age range: 60–79 years old). By contrast, there was a marked impairment in the olfactory abilities of elderly persons who did not meet these criteria. Similarly, Griep et al. (1997) reported that independently of the effect of age, poor general health correlated with a decrease in the detection threshold for isoamyl acetate (age range: 53–86 years old). Finally, de Jong et al. (1999) showed that institutionalized persons had lower scores on a smell identification task and a taste perception task than did persons who lived independently (see also Pelchat and Burkhardt-Kulpa 1996; Gopinath et al. 2012).

The first objective of the present experiment was to explore this interindividual variability among the elderly population. This goal was achieved using a multicenter survey that was conducted in France (Aupalesens survey). The chemosensory abilities of a large sample of subjects who were aged from 65 to 99 years (n = 559) were evaluated using both gustatory and olfactory tests. In line with authors who recommend using different measurements rather than a single measurement to evaluate olfaction (Cain and Rabin 1989; Weiffentbach 1991; Hummel et al. 1997), we selected olfactory tests that measured the participants' ability to detect, discriminate, and categorize different odors. In fact, Weiffentbach (1991) pointed out that "the individual members of the composite family of sensory capabilities that comprise the chemical senses do not all age in the same way." The gustatory test measured the subjects' ability to detect and identify the salty taste. Indeed, according to the literature review of Mojet et al. (2001), salt perception seems to be more affected by age than are the other tastes. As we hypothesized that some respondents could present lower abilities for only one sensory system (gustation or olfaction) and/or that some respondents could present lower ability for some olfactory abilities but not all (detection, discrimination, or categorization), we sought for clusters of respondents who presented similar patterns of performance rather than considering a continuum of performance combining the different scores.

The second objective of the present experiment was to explore the impact of age versus the impact of dependency on the elderly's chemosensory abilities. Dependency was defined as an individual's propensity to rely on others for support in everyday activities. The factor dependency was chosen as a proxy of the physical and mental shape of the elderly respondents. Indeed, elderly people who experience difficulty with everyday activities are more likely to require medical services (Mor et al. 1994), suffer from depression (Girling et al. 1995; Alexopoulos et al. 2002; Covinsky et al. 2010), and suffer from cognitive deficiency (Alaphilippe and Bailly 2013). In the Aupalesens survey, interviews were conducted with various categories of elderly people, including people who were living at home, either without or with assistance, and people who were living in a nursing home. Older people who presented a severe cognitive impairment were not included in the present experiment, as the chemosensory tests required verbal answers and were no validated for such a population.

Materials and methods

Elderly sample

The data were collected as part of a program that aimed to study eating behavior and dependency (Aupalesens project: Improving the pleasure of elderly people for better aging and to fight against malnutrition). In 2011, 559 participants who were older than 65 years old (65–99 years old, 387 women, 172 men) were recruited in 4 French cities and their suburbs (Angers, Brest, Dijon, Nantes). These participants were categorized into 4 categories that ranged from a high level of autonomy to a high level of dependency. These 4 categories were defined prior to the survey, as follows: category 1, elderly people living independently at home; category 2, elderly people living at home with help unrelated to food activity (e.g., housekeeping; gardening; personal care); category 3, elderly people living at home with help including that related to food activity (e.g., food purchasing; cooking; home meal delivery); category 4, elderly people living in a nursing home.

The recruitment criteria were as follows: older than 65 years old; no acute pathological episode at the time of the survey; no food allergies; not on a doctor-prescribed diet; scoring at least 20 on the Mini–Mental State Examination (MMSE) (Folstein et al. 1975). The MMSE screens for cognitive impairment; scores that are greater than or equal to 25 points (out of 30) indicate normal cognition. Below this, scores can indicate mild (21–24 points), moderate (10–20 points), or severe (≤9 points) cognitive impairment. Participants who self-reported a congenital anosmia or an anosmia due to head injury, and participants who suffered from a sinusitis or a severe respiratory infection at the moment of the survey were also excluded. An interview was carried out with each candidate to ensure that they met the inclusion criteria. The experimental protocol of the survey was approved by the French Ethics Committee for Research (CPP Est I, Dijon, #2010/42, AFSSAPS# 2010-A01079-30). In accordance with the rules of ethics, all of the participants received written and oral information on the survey before signing a consent form.

Chemosensory tests

The olfactory and gustatory tests were selected based on a preliminary experiment that was conducted with 60 elderly participants (24 men and 36 women; mean age: 73 years; age range: 61–85 years). These participants were not included in the current survey. The preliminary experiment allowed us to select a battery of tests to explore the variability of chemosensory abilities within a population of elderly people, particularly frail, dependent individuals. We sought a compromise between

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having a sufficient number of tests and stimuli and the risk of tiring/exasperating the participants. In addition, as elderly dependent subjects (notably those living in nursing homes) often tend to be depressive (Girling et al. 1995; Alexopoulos et al. 2002; Covinsky et al. 2010), we selected tests that did not give the impression that the participants consistently failed.

Short European Test of Olfactory Capabilities

Based on the results of the preliminary experiment, 6 trials (i.e., vanilla, apple, petroleum, orange, rose, and thyme) were selected from the 16 that were proposed in the European Test of Olfactory Capabilities (ETOC) test. Each trial consists of 4 vials, and only one of these vials contains an odorant (Thomas-Danguin et al. 2003). For each trial, the participants were asked to note the odorous vial through a forced choice detection task. A detection score (/6), corresponding to the number of odors that were correctly noted, was calculated for each respondent. The odorants of the ETOC test were provided by the creators of this test (EZUS LYON).

Monadic olfactory test

Twelve vials were presented one by one to the participants. These included 6 vials that contained an odorant with a food smell and 6 vials that contained an odorant with a non-food smell (Table 1). For each vial, the participants were asked to indicate whether they could smell something in the vial. When they perceived an odor, they were asked to indicate whether it was a food or a non-food smell. The following 2 scores were calculated: a detection score (/12), corresponding to the number of odors that were perceived, and a categorization score (/12), corresponding to the number of odors that were correctly categorized according to their edibility value. When the odor was not perceived, the answers to the edibility task were classified as inaccurate.

Odor discrimination test

Three blocks of 3 odorous vials were presented one by one to the participants. Within each block, one vial was identified as the control. Of the other 2 vials, one contained the same odorant as the control and the other contained a different odorant. The 2 stimuli were chosen to present different qualities of odor (Table 2). For each block, the participants were asked to indicate which of the 2 vials held a smell that differed from the smell in the control vial (duo-trio task). A discrimination score (/3), corresponding to the number of successful trials, was calculated from the results.

For the monadic and discrimination tests, the odorants consisted of food flavorings, odorous preparations, food and non-food products. The experimenters adjusted the concentrations

Table 2 Stimuli of the odor discrimination test

Control	Sample 1	Sample 2
Chicken aroma	80% chicken aroma + 20% onion aroma	Chicken aroma
Chicken aroma	Chicken aroma	80% chicken aroma + 20% garlic aroma
Beef aroma	Fish aroma	Beef aroma

All of the aromas were provided by Frutarom. For the first 2 trials, the odd stimulus was prepared by mixing 20% of an aroma (onion or garlic) with 80% of the control aroma.

Table 1 Stimuli of the monadic olfactory test

Odor	Origin	Concentration	Diluent
Food smells			
Caramel	Meilleur du Chef	5 mL/L	Propylene glycol
Lemon	Meilleur du Chef	200 mL/L	Mineral oil
Milk	Sentosphère	—	Encapsulated
Pear	Meilleur du Chef	200 mL/L	Propylene glycol
Strawberry	Meilleur du Chef	200 mL/L	Propylene glycol
Thyme	Meilleur du Chef	10 mL/L	Mineral oil
Non-food smells			
Chanel n°5	Perfume	—	—
Eau of Cologne	Mont-Saint-Michel	500 mL/L	Propylene glycol
Lilac	Sentosphère	—	Encapsulated
Lily of the valley	Cinquième Sens	—	—
Rolland Garros	Perfume	—	—
Rose	Firmenich	10 mL/L	Mineral oil

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of the odorants during successive trials to equalize the subjective intensity of all olfactory stimuli within each test. The monadic test and the discrimination test were designed to present rather high odor intensities to ensure that above-threshold levels were reached. Ten members of the laboratory staff rated the intensity of each odor on a 7-point scale that ranged from "very weak" (0) to "very strong" (6); the 5 intermediate points of the scale were anchored by increasing concentrations of butan-1-ol, as follows: 0.05–0.10–0.20–0.40–0.80 mL/L. According to this preliminary experiment, the odors of the discrimination test tended to be rated as more intense than the odors of the categorization test; however, for both tests, the intensity scores were higher than the medium of the scale (categorization: $M = 6.50$; standard error [SE] = 0.20; discrimination: $M = 7.80$; SE = 0.22; $F_{1,16} = 3.40$; $P = 0.08$). Regarding the monadic test, the same 10 subjects rated the edibility of each odor on a scale that ranged from "does not evoke a food at all" (0) to "strongly evokes a food" (10). The results showed that the food odors were rated as more edible than the non-food odors (food odor: $M = 8.43$; SE = 0.26; non-food odors: $M = 0.67$; SE = 0.13; $F_{1,10} = 297.37$; $P < 0.001$).

Gustatory test

Eight solutions were presented one by one to the participants. These solutions included 2 blanks (Evian water) and 4 concentrations of NaCl (S1: 0.21 g/L, S2: 0.59 g/L; S3: 1.90 g/L; S4: 5.90 g/L); the 2 middle concentrations (S2, S3) were replicated. The concentrations were chosen from the results of Mojet et al. (2001) and the preliminary experiments that were conducted with laboratory staff. S1 was lower than the thresholds that were indicated in Mojet et al. (very difficult level); S2 was near the mean threshold (difficult level); S3 was higher than the highest thresholds (easy level); S4 was far above the thresholds (very easy level) to avoid, as far as possible, some participants' failure on all of the tests. The solutions were presented in the following sequence: S1, S2, blank, S2, S3, S3, blank, S4. The participants were asked to taste a glass of water (Evian) and, then, to taste 20 mL of each sample and to indicate whether they perceived water or a taste. They were asked to rinse with water between each sample. The following 2 scores were calculated from the gustatory task: a taste detection score (/8), corresponding to the number of salt samples that were perceived as having a taste and the number of blank samples that were perceived as water, and a salt detection score (/6), corresponding to the number of salt samples that were perceived as having a taste.

Background information

Dental status: the respondents were asked to indicate whether their dentition was complete (either natural or including bridges and dental implants—good dentition status) or incomplete with or without a denture (poor dentition status). Depression: depression was measured using the short form of the Geriatric Depression Scale (GDS) (Sheikh 1986). Diseases and drug use: a geriatrician counted the number of diseases, the number of drugs, and the number of drugs that were liable to affect olfaction and/or taste from the medical prescription. Instrumental Activities of Daily Living Scale (IADL): this questionnaire assesses one's ability to perform the tasks that are necessary to live independently, such as food preparation, housekeeping, and laundering (Lawton and Brody 1969). Smoking status: the respondents were asked to indicate whether they had never smoked, they were a former smoker, or they currently smoked. Short Physical Performance Battery (SPPB): this test detects mobility limitations by measuring physical strength, endurance, and balance (Guralnik et al. 1994).

Procedure

The respondents participated in 2 sessions of approximately 90 min each. During these sessions, extensive medical, nutritional, psychological, sociological, and sensory data were collected on the basis of tests and questionnaires. The sessions were organized as face-to-face interviews that were conducted by 6 experimenters (all women) who had previously followed a 1-day training session. The monadic olfactory test, the gustatory test, and the odor discrimination test were performed during the first session, and the short ETOC test was performed during the second session. The order of the tests and the order of the odorants within each test were the same for all of the participants, as we intended to compare the participants' performance.

In parallel of this survey, one group of 63 young adults performed the olfactory tests (30 men and 33 women; mean age: 28 years; age range: 18–40 years) and a second group performed the gustatory test (21 men and 42 women; mean age: 26 years; age range: 20–40 years).

Data analysis

The sensory scores were converted into frequency scores that varied between 0 (poor performance) and 1 (good performance). A matrix that contained the elderly subjects in rows and the sensory scores in columns was submitted to a non-normed principal component analysis (PCA). The principal components were then submitted to a hierarchical cluster analysis (HCA; Euclidean distance, Ward criteria, *k*-Means consolidation), and the number of clusters was chosen based on the dendrogram. The HCA was run on the principal components rather than on the raw data in order to run the HCA on independent variables and thus to improve the stability of the results. To characterize the chemosensory capacities of the different clusters, each sensory score was submitted to an ANOVA with cluster as a between-subject factor.

The PCA and HCA were conducted using SPAD software (7.4; COHERIS). ANOVA and analysis of covariance (ANCOVA) were performed using the General Linear Model procedure of STATGRAPHICS plus (5.1) (type III sum of squares). Least-squares means were computed for each significant factor and submitted to multiple

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comparison analysis using the Fisher's least significant difference method. χ^2 tests were performed using Question data 6.7. All of the results that are reported here were significant at a level of 0.05 unless otherwise stated.

Results

Description of the elderly sample

Table 3 displays the variables that are related to the physical, mental, and health status of each category of dependency. As stated in the introduction, an increase in dependency is associated with a decrease in physical and mental status.

Correlation between the scores

Significant Pearson's correlations were observed both within the olfactory scores and within the gustatory scores (Table 4). None of the olfactory scores correlated with the gustatory scores ($R < 0.10$, $P > 0.05$), suggesting that effect of aging on the olfactory system was independent of that on the gustatory system.

Evidence for different patterns of chemosensory impairment

The clustering analysis highlighted four patterns of chemosensory capacities among the elderly sample. According to

Table 3 Description of the elderly sample according to the level of dependence

Level of dependence	At home: without help	At home: help unrelated to food activity	At home: help related to food activity	Nursing home	
n	289	74	101	95	
Age mean	74 (6)[a]	81 (6)[b]	85 (6)[c]	87 (6)[d]	$F = 161.4$*
Age range	65–90	68–92	67–97	69–99	
Male	31%	27%	34%	28%	$\chi^2 = 1.2$
IADL[1]	7.6 (0.8)[a]	7.5 (1.0)[a]	5.8 (1.7)[b]	3.7 (1.4)[c]	$F = 296.4$*
SPPB[2]	10.9 (1.6)[a]	9.1 (2.6)[b]	6.1 (3.5)[c]	5.3 (3.6)[d]	$F = 157.6$*
MMSE[3]	27.7 (2.1)[a]	26.9 (2.4)[b]	26.4 (2.5)[b]	25.6 (2.8)[c]	$F = 22.6$*
Short GDS[4]	2.5 (2.4)[a]	3.7 (2.8)[b]	5.0 (2.7)[c]	4.8 (3.0)[c]	$F = 33.7$*
Pathologies[5]	2.2 (1.7)[a]	3.6 (1.7)[b]	4.0 (1.9)[b]	4.0 (2.0)[b]	$F = 40.2$*
Drugs[5]	4.2 (3.1)[a]	5.9 (3.8)[b]	8.2 (4.8)[c]	9.4 (5.6)[c]	$F = 45.4$*

Continuous variables: the means for each level of dependence (in brackets: standard deviation). The means associated with the same letter were not significantly different ($P > 0.05$). Categorical variable: the percentages for each level of dependence. The percentages for each level of dependence were compared using a χ^2 test. *F* ratios and χ^2 values: $*P < 0.001$.
[1]IADL: Instrumental Activities of Daily Living Scale (Lawton and Brody 1969). This questionnaire assesses one's ability to perform the tasks that are necessary to live independently (maximum score: 8).
[2]SPPB: Short Physical Performance Battery (Guralnik et al. 1994). This test detects mobility limitations by measuring physical strength, endurance, and balance (maximum score: 12).
[3]MMSE (Folstein et al. 1975). Scores >25 points (out of 30): normal cognition. Scores ranging from 20 to 24: mild cognitive impairment (people with a score <20 were not included in the study).
[4]GDS: short form of the Geriatric Depression Scale (Sheikh 1986) (maximum score: 15).
[5]For each respondent, the number of diseases and the number of drugs were collected through medical prescription.

Table 4 Pearson's correlations between the sensory scores

	Short ETOC	Odor detection	Odor discrimination	Odor categorization	Taste detection	Salt detection
Short ETOC	**1**					
Odor detection	**0.48**	**1**				
Odor discrimination	**0.28**	**0.37**	**1**			
Odor categorization	**0.52**	**0.71**	**0.35**	**1**		
Taste detection	0.05	0.03	0.04	0.05	**1**	
Salt detection	0.05	0.06	0.03	0.05	**0.84**	**1**

Significant correlations are indicated in bold; $P < 0.05$.

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the ANOVA, each sensory score was associated with a significant cluster effect ($P < 0.001$) (Table 5).

Cluster 1, which accounted for 43% of the elderly sample ($n = 238$), included the elderly participants who displayed well-preserved olfactory and gustatory abilities. For all of the tests, this cluster obtained the highest scores among those observed in the sample of elderly people (Table 5, *post-hoc* analyses). This cluster was labeled "chemosensory preserved." The performances of this cluster were compared with those of young participants by computing the *t*-statistic when the variances were equal or the Cochran and Cox (1950) approximation when the variances were unequal (Table 5, last column). According to the results, the elderly respondents of the first cluster performed less well than the young participants on the short ETOC detection score ($t_{258} = 16.77$; $P < 0.001$), the odor detection score of the monadic test ($t_{143} = 3.82$; $P < 0.001$), the odor categorization score ($t_{143} = 10.81$; $P < 0.001$) and, to a lesser extent, the taste detection score ($t_{82} = 2.00$; $P < 0.05$) and the odor discrimination score ($t_{299} = 1.89$; $P = 0.06$). No significant difference was observed for the salt detection score ($t_{82} = 0.07$; $P > 0.05$). Notwithstanding their preserved abilities compared with their counterparts, the elderly participants of cluster 1 performed somewhat less well than the young participants on the olfactory tests, specifically the tests that included low intensity odors, such as the ETOC test, and the tests that required semantic processes, such as the categorization task.

Cluster 2 ($n = 186$; 33% of the elderly sample) included the elderly participants who experienced difficulties in perceiving the salty taste but not odors. In fact, this cluster obtained the lowest gustatory scores among those that were observed in the sample of elderly people, whereas this group's olfactory scores were not significantly different from those of cluster 1. This cluster was labeled "strong gustatory impairment."

The elderly participants of cluster 3 ($n = 120$; 21% of the elderly sample) displayed impaired olfactory and gustatory abilities. Regarding olfaction, this impairment was particularly evident for the detection task of the short ETOC and, to a slightly lesser extent, the discrimination test and the categorization task. However, although their monadic detection test scores were lower than those of clusters 1 and 2, the participants of cluster 3 remained able to perceive odors of moderate intensity. Regarding taste, the scores of this cluster were lower than those of cluster 1 but higher than those of cluster 2. This cluster was labeled "chemosensory impaired."

Finally, a fourth and small cluster ($n = 15$; 3% of the elderly sample) presented severely impaired olfaction, with very low detection scores, on both the short ETOC and the monadic olfactory test. As can be expected, this impairment in the ability to perceive odors was combined with low scores on the discrimination test and the categorization test. Not surprisingly, it is difficult to categorize or even distinguish between different odor qualities if the odors are barely perceived. All of the olfactory scores of this cluster were significantly lower than those of cluster 3. However, the gustatory scores of cluster 4 were significantly lower than those of cluster 1 but higher than those of cluster 2. Cluster 4 was labeled "severe olfactory impairment."

Based on the background information that was collected during the survey, each cluster was portrayed according to the following variables: age, gender, cognitive status (MMSE score), dental status, drug use, smoking status, and dependence (Table 6). Regarding the continuous variables (age, MMSE), the means for each cluster were compared using a one-way ANOVA followed by a *post-hoc* comparison of means. Regarding the categorical variables, the percentages for each cluster were compared using χ^2 tests. As shown in Table 6, the cluster 1 (chemosensory-preserved cluster) participants were younger and less likely to report poor dentition and the use of drugs with side effects on chemosensory perception than were the other clusters. By contrast, the clusters 3 and 4 (moderate and severe olfactory impairment) participants were older and more likely to report poor dentition and the use of drugs with side effects on chemosensory

Table 5 Segmentation of the sample of elderly people according to chemosensory performances

Scores	Elderly sample				Young panel
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	
n	238	186	120	15	63
Short ETOC	0.77 (0.20)[a]	0.77 (0.21)[a]	0.41 (0.28)[b]	0.08 (0.22)[c]	0.99 (0.02)
Odor detection[1]	0.93 (0.09)[a]	0.93 (0.08)[a]	0.76 (0.17)[b]	0.18 (0.25)[c]	0.97 (0.06)
Odor discrimination	0.78 (0.26)[a]	0.79 (0.27)[a]	0.52 (0.28)[b]	0.04 (0.12)[c]	0.85 (0.30)
Odor categorization[1]	0.73 (0.14)[a]	0.74 (0.14)[a]	0.44 (0.15)[b]	0.08 (0.15)[c]	0.90 (0.09)
Taste detection	0.81 (0.10)[a]	0.54 (0.12)[c]	0.66 (0.14)[b]	0.67 (0.20)[b]	0.84 (0.13)
Salt detection	0.85 (0.12)[a]	0.49 (0.15)[c]	0.67 (0.19)[b]	0.66 (0.26)[b]	0.85 (0.16)

The means for each cluster and for each sensory score (in brackets: standard deviation). The means associated with the same letter were not significantly different ($P > 0.05$). The last column presents the scores that were obtained with a young panel.
[1]Scores computed from the results of the monadic olfactory test.

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Table 6 Descriptive characteristics of the clusters

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	
Age	76.8 (7.8)[a]	79.2 (8.3)[b]	82.5 (7.0)[c]	85.1 (6.2)[c]	$F = 17.52$**
Male	27% (64)	30% (56)	38% (46)	40% (6)	$X^2 = 5.54$
MMSE[1]	27.6 (2.1)[a]	27.2 (2.4)[a]	25.9 (2.7)[b]	25.7 (3.0)[b]	$F = 13.76$**
Percentage of people with 20 < MMSE < 24	*8% (15)*	13% (20)	**25% (28)**	21% (3)	$X^2 = 19.58$**
Poor dentition[2]	*19% (45)*	25% (46)	**33% (40)**	**60% (9)**	$X^2 = 18.95$**
Drugs liable to affect olfaction/taste[3]	*45% (107)*	49% (91)	**59% (71)**	**80% (12)**	$X^2 = 11.92$*
Nonsmoker	66% (158)	66% (122)	63% (76)	60% (9)	$X^2 = 9.05$
Former smoker	27% (65)	33% (61)	32% (38)	40% (6)	
Smoker	6% (15)	2% (3)	6% (6)	0% (0)	
At home without help	*66% (157)*	50% (93)	*30% (36)*	*20% (3)*	$X^2 = 66.84$**
At home with help unrelated to food	12% (29)	12% (23)	**18% (22)**	0% (0)	
At home with help related to food activity	15% (35)	18% (34)	21% (25)	**47% (7)**	
Nursing home	*7% (17)*	19% (36)	**31% (37)**	33% (5)	

Continuous variables: the means for each cluster (in brackets: standard deviation). The means associated with the same letter were not significantly different ($P > 0.05$). Categorical variables: the percentages for each cluster (in brackets: size). The percentages for each cluster were compared using a X^2 test. Bold values were significantly higher than expected percentage, whereas italicized values were significantly lower ($P < 0.05$). F ratios and X^2 values: *$P < 0.01$; **$P < 0.001$.

[1]MMSE (Folstein et al. 1975). Scores >25 points (out of 30): normal cognition. Scores ranging from 20 to 24: mild cognitive impairment (people with a score <20 were not included in the study).

[2]Percentage of respondents with incomplete dentition, with or without a denture.

[3]Percentage of respondents who reported taking at least one drug that is liable to affect odor or taste perception per day.

perception. No differences in gender and smoking status were found between the clusters. Cluster 2 did not stand out from the other clusters in terms of the measured variables. Finally, the respondents in cluster 1 were more likely to be autonomous, that is, living at home without help. By contrast, the respondents in clusters 3 and 4 were more likely to be dependent, that is, living at home with help or living in a nursing home.

Impact of age versus dependency on chemosensory performances

The sensory scores were submitted to an ANCOVA with gender and dependency category as categorical independent variables and age as a numerical independent variable (Table 7). Because the interactions were not significant, they were removed from the model. The results showed that the odor detection and categorization scores of the monadic olfactory test were associated with a significant age effect and a significant gender effect. As shown in Figure 1, the females outperformed the males, and the performances decreased with age for both genders. Interestingly, the short ETOC score, the odor discrimination score and the taste detection score were associated with a significant dependency category effect. The short ETOC score was also associated with an age effect, and this effect just failed to be significant for the taste detection score ($P = 0.06$). No age effect was observed for the odor discrimination score. According to the *post-hoc* analysis,

Table 7 Impact of age, gender, and dependency category on chemosensory performances

	Age	Gender	Dependency category
Short ETOC	10.55**	2.31	4.08**
Odor detection[1]	7.88**	9.07**	1.96
Odor discrimination	0.01	0.39	2.62*
Odor categorization[1]	26.32***	15.03***	1.31
Taste detection	3.36	0.20	3.45*
Salt detection	1.28	0.44	1.61

Presentation of the F ratios and significance levels (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$) that were obtained from the ANCOVA performed on each sensory score.

[1]Scores computed from the results of the monadic olfactory test.

the autonomous elderly people (category 1) obtained higher ETOC and taste detection scores than did the dependent elderly people (Figure 2a,b), whereas the performances decreased (ETOC) or tended to decrease (taste) with age for all categories. With regard to the odor discrimination score, the elderly people who lived at home without help or with help that was unrelated to food activities (categories 1 and 2) outperformed the elderly people who lived at home with help that was related to food activities (category 3). The discrimination score of the elderly people who lived in a nursing home (category 4) was intermediate and not significantly

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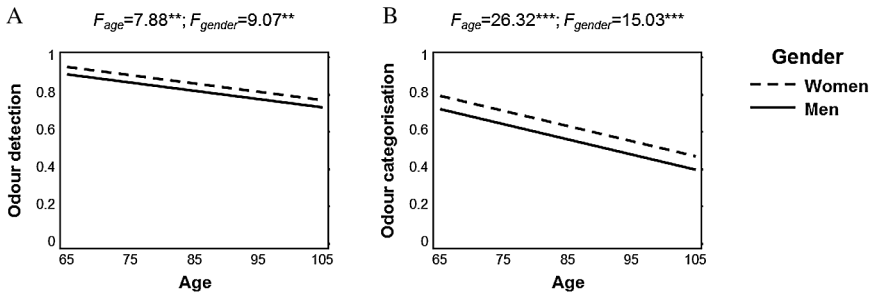


Figure 1 Relationship between age and the odor detection score (**A**) and the odor categorization score (**B**) for each gender (monadic olfactory test). *F* ratios: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

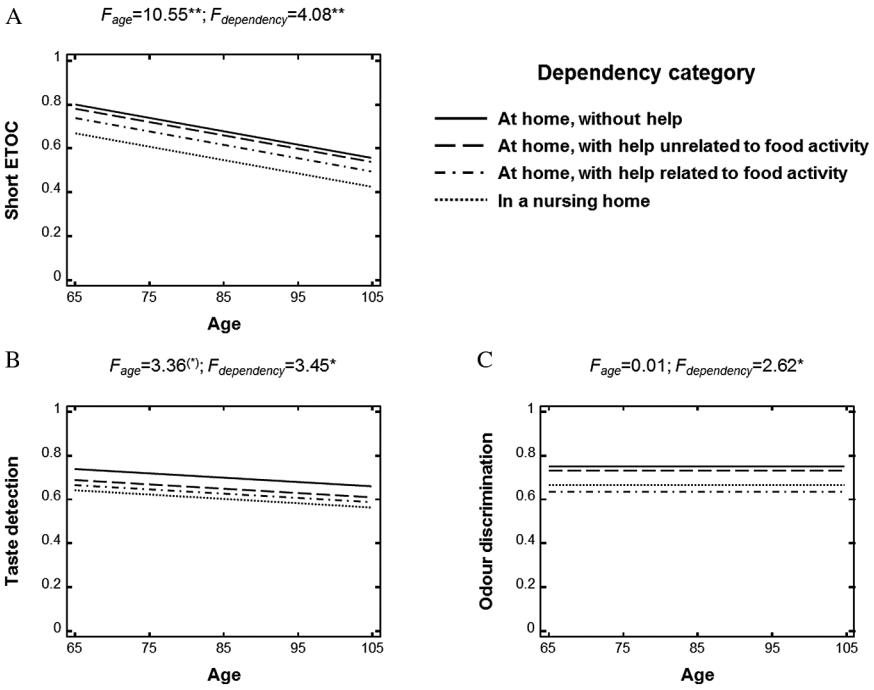


Figure 2 Relationship between age and the short ETOC score (**A**), the taste detection score (**B**), and the odor discrimination score (**C**) for each dependency category. *F* ratios: $(*)P < 0.10$; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

different from the scores of the other categories (Figure 2c). No significant effect was observed for the salt detection score.

Discussion

Evidence for different patterns of chemosensory impairment

Beyond the mean effect of age on chemosensory abilities that has been frequently reported in the scientific literature (Doty et al. 1984b; Mojet et al. 2001; Murphy et al. 2002; Mojet et al. 2003; Mackay-Sim et al. 2004; Schubert et al. 2012), the present work showed substantial variations in the olfactory and gustatory performances of elderly people. The current results showed that 21% of the sample presented impaired olfactory and gustatory abilities (cluster 3). A small number of subjects (3% of the sample) were nearly unable to perceive odors (close to anosmia) but remained able to perceive the salty taste (cluster 4). By contrast, 33% of the sample presented salt detection impairment without olfactory impairment (cluster 3). Finally, 43% of the sample presented relatively good olfactory and gustatory abilities (cluster 1).

The current results showed that gustation and olfaction are not systematically damaged simultaneously. This was shown through the segmentation of the results and correlations between the scores. For example, although the seniors of cluster 2 presented severely impaired gustatory abilities, they displayed quite good olfactory abilities. The absence of a significant correlation between gustatory and olfactory scores reinforces the results that were obtained in previous studies with different age groups that ranged from 19 to 87 years (Cowart 1989; Stinton et al. 2010; Sulmont-Rossé et al. 2010; Lundström et al. 2012). No such discrepancy was observed for the different olfactory abilities (detection,

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discrimination, categorization). The hypothesis that some respondents could present lower abilities for some olfactory abilities but not all (e.g., some respondents could have presented impaired categorization but preserved detection and discrimination, whereas others could have presented impairment for these 3 tasks) was not confirmed.

Beyond the physiological mechanisms that are inherent in the aging process *per se*, several factors that are associated with aging are likely to affect chemosensory perception. These factors are most likely responsible for a large part of the variability that was observed in the current sample. Exposure to environmental pollutants (exposure to metals, dust, organic compounds, etc.), notably in a professional context (Amoore 1986; Corwin et al. 1995), poor dental health (Griep et al. 1997; Lamy et al. 1999), certain deficiencies and a wide range of pathological conditions (Doty 1991; Murphy et al. 2002; Imoscopi et al. 2012; Schubert et al. 2012; Henkin et al. 2013), and the use of a large number of drugs (Schiffman 1991; Doty and Bromley 2004; Henkin et al. 2013) may amplify the age-related impairment in chemosensory performance. Furthermore, the senses of taste and smell are not necessarily affected by the same factors or to the same degree (Mor et al. 1994). In fact, both gustatory and olfactory dysfunctions may be associated with oral and systemic diseases, or drugs. However, as the olfactory neurons are in direct contact with the external environment, they are more likely to be exposed to environmental aggressive factors than gustatory cells (Weiffentbach 1991).

Although the current study did not measure exposure to environmental pollutants, it found that seniors who presented impaired olfactory abilities (clusters 3 and 4) were more likely to have poor dental health and to take drugs that had side effects on chemosensory performance than were seniors with preserved olfactory abilities (cluster 1). We also found a negative relationship between olfactory performance and the MMSE score, with lower MMSE scores in cluster 3 than in cluster 1. However, 75% of the participants of cluster 3 obtained an MMSE score that was above 24 and, thus, presented no cognitive impairment (Table 6). In other words, cognitive impairment alone cannot explain the low chemosensory scores in this cluster. Finally, we found no link between smoking status and impaired chemosensory abilities. This finding remains controversial in the literature, as several authors reported a link between smoking status and olfactory performance (de Jong et al. 1999; Murphy et al. 2002; Doty et al. 2011; Schubert et al. 2012), whereas others found no link (Mackay-Sim et al. 2004). Of note, the current sample included only 5% of current smokers compared with 30% of former smokers and 65% of nonsmokers.

Impact of age versus dependency on chemosensory performances

The results of the current survey showed a link between the level of dependence (free living vs. living at home with help vs. in a nursing home) and chemosensory abilities, independently of the effect of age. A high level of dependence was significantly associated with a lower ability to detect low concentration odors (ETOC test), distinguish between different qualities of odors and detect the salty taste. These findings reinforce the results of the studies that were mentioned in the introduction (Pelchat and Burkhardt-Kulpa 1996; de Jong et al. 1999; Gopinath et al. 2012). In a study of 89 independently living elderly people and 67 institutionalized elderly people, de Jong et al. (1999) found that independently of age and sex, dependence significantly contributed to variance in the identification of odors and the discrimination between tastes. Together, these results strengthen the hypothesis that age leads to an impairment of chemosensory abilities (cf., clusters 3 and 4) but that this impairment is not only an effect of age *per se* (« idiopathic age-related impairment »); rather, it is related to events that are associated with aging (failing health, drugs, deterioration in dental health, etc.) (Mackay-Sim et al. 2006). In other words, the factors that lead to increased dependence (such as a poor health status) may also lead to an impairment of chemosensory performance (Nordin et al. 2012).

Nonetheless, the impact of age versus that of dependence varies depending on the chemosensory ability tested. The performances on the ETOC and gustatory test were associated with both an age and a dependence effect (the effect of age just failed to be significant for the taste score; $P = 0.06$), whereas the performances on the olfactory discrimination test were only associated with a dependence effect. As a reminder, this last test involved odors with intensities that were considerably greater than threshold levels, whereas the former tests included stimuli that were around or slightly above the threshold level. It can be hypothesized that age *per se* impacts the perception of stimuli at a low intensity level, whereas the factors that are associated with dependence, such as pathological status or drugs, may impact the perception of stimuli at a high intensity level. Finally, the 2 scores that were determined from the monadic olfaction test were not related to the level of dependency but were associated with sex and age, notably with women displaying better performances than men. This effect of sex confirmed earlier studies (Murphy et al. 2002; Schubert et al. 2012). This effect may be explained by the choice of odors (foods, flowers, perfumes) and the nature of the task—determine whether the odor is of something « edible ». This task has a close relationship with the preparation of meals, which is traditionally the role of women particularly for the generations that were tested.

Limitations and strengths of the present experiment

A first limitation of the present study was that older people suffering from cognitive impairment were not included, despite the increase of cognitive disorders with dependency (Millán-Calentia et al. 2010). It is acknowledged that chemosensory function could be affected by cognitive impairment (Doty 1991; Hedner et al. 2010; Wong et al. 2010). A decrease in odor identification was even pinpointed to be an early sign of the onset of cognitive disabilities (Wilson et al. 2007) or

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neurodegenerative diseases (Ross et al. 2008). However, the tests used in the present experiment (and in almost all if not all surveys exploring the impact of aging on chemosensory abilities) require a verbal response: for people suffering from cognitive impairment, a wrong answer could either indicate a true inability to detect the stimulus, and/or an inability to understand the instructions/to provide a coherent answer. Further methodological development is definitively needed to design nonverbal test validated for people suffering from cognitive impairment, in order to decipher the impact of age versus cognitive impairment on chemosensory abilities.

A second limitation of the present experiment was the assessment of only one taste—salt perception—to evaluate gustatory ability. It would have been definitively very interesting to include other tastes or at least a taste including a different transduction mechanism (e.g., sweet or bitter taste). However, Mojet et al. (2003) showed strong correlations for the elderly between sensitivities to different tastants. Notably, sensitivity to NaCl was significantly correlated with sweet, sour, and umami tastants (Mojet et al. 2001). Moreover, when selecting the tests, we sought a compromise between having a sufficient number of tests and stimuli, and the risk of tiring/exasperating the participants. We prioritized olfaction tests over gustation tests, as previous studies showed that olfaction is modified to a greater degree with aging than is taste (Stevens et al. 1984; Sulmont-Rossé et al. 2010).

Concerning methodology, a strength of the current work was to propose a battery of tests to explore the variability of chemosensory abilities within a population of elderly dependent subjects. In line with the authors who recommended the use of a composite score rather than a single measurement to evaluate olfaction (Cain and Rabin 1989; Hummel et al. 1997), we selected a battery of olfaction tests to evaluate the participants' ability to detect, discriminate, and categorize different odors. The odors were selected to be representative of a daily olfactory environment. In particular, we included many food smells, which made this battery of tests particularly pertinent to study the relationship between olfactory perception and eating behavior in elderly people. Finally, depending on the test, different concentrations were used, ranging from a concentration that was close to the threshold (ETOC test) to a concentration that was far above this threshold (discrimination test). This method allowed us to explore a wide range of olfactory intensities. We included olfactory tests with different levels of difficulty. Interestingly, we found that the largest difference between cluster 1 (preserved chemosensory ability) and the young participants occurred in the most difficult tests, that is to say, those with the weakest olfactory intensity (short ETOC test) and the test that required the strongest cognitive resources (categorization task).

Conclusion

In conclusion, this work revealed different degrees of olfactory and gustatory impairment in an elderly population. Nearly half of the tested population presented well-preserved chemosensory abilities that were relatively close to those of younger subjects. This was particularly true when the chemosensory abilities were tested using « easy » tests (high olfactory intensity; tasks with little demand on cognitive resources). Nearly one-fourth of the participants presented a moderate impairment in olfactory and gustatory abilities. Beyond the effect of age *per se*, it seemed that this impairment was related to factors that were specific to each person's lifetime experiences (poor health, consumption of medication, deterioration in cognitive status, deterioration in dental health...). Finally, showing that gustation and olfaction were not consistently impaired to the same extent, one-third of the sample presented relatively well-preserved olfactory abilities but a clear impairment in salt perception.

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References

Alaphilippe D, Bailly N. 2013. Psychologie de l'Adulte Âgé. Bruxelles: De Boeck Supérieur.

Alexopoulos GS, Borson S, Cuthbert BN, Devanand DP, Mulsant BH, Olin JT, Oslin DW. 2002. Assessment of late life depression. Biol Psychiatry. 52(3):164–174.

Amoore J. 1986. Effects of chemical exposure on olfaction in humans. In: Barrow CS, editor. Toxicology of the nasal passages. Washington: Hemisphere Publishing Corporation. p. 155–190.

Boyce JM, Shone GR. 2006. Effects of ageing on smell and taste. Postgrad Med J. 82(966):239–241.

Cain WS, Rabin MD. 1989. Comparability of two tests of olfactory functioning. Chem Senses. 14(4):479–485.

Cochran WG, Cox GM. 1950. Experimental designs. New York: John Wiley & Sons.

Corwin J, Loury M, Gilbert AN. 1995. Workplace, age, and sex as mediators of olfactory function: data from the National Geographic Smell Survey. J Gerontol B Psychol Sci Soc Sci. 50(4):P179–P186.

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Covinsky KE, Yaffe K, Lindquist K, Cherkasova E, Yelin E, Blazer DG. 2010. Depressive symptoms in middle age and the development of later-life functional limitations: the long-term effect of depressive symptoms. J Am Geriatr Soc. 58(3):551–556.

Cowart BJ. 1989. Relationships between taste and smell across the adult life span. Ann N Y Acad Sci. 561:39–55.

de Jong N, Mulder I, de Graaf C, van Staveren WA. 1999. Impaired sensory functioning in elders: the relation with its potential determinants and nutritional intake. J Gerontol A Biol Sci Med Sci. 54(8):B324–B331.

Doty RL, Shaman P, Applebaum SL, Giberson R, Siksorski L, Rosenberg L. 1984a. Smell identification ability: changes with age. Science. 226(4681):1441–1443.

Doty RL, Shaman P, Dann M. 1984b. Development of the University of Pennsylvania Smell Identification Test: a standardized microencapsulated test of olfactory function. Physiol Behav. 32(3):489–502.

Doty RL. 1991. Olfactory dysfunction in neurodegenerative disorders. In: Getchell TV, editor. Smell and taste in health and disease. New York: Raven Press. p. 735–751.

Doty RL, Bromley SM. 2004. Effects of drugs on olfaction and taste. Otolaryngol Clin North Am. 37(6):1229–1254.

Doty RL, Petersen I, Mensah N, Christensen K. 2011. Genetic and environmental influences on odor identification ability in the very old. Psychol Aging. 26(4):864–871.

Folstein MF, Folstein SE, McHugh PR. 1975. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 12(3):189–198.

Gopinath B, Anstey KJ, Kifley A, Mitchell P. 2012. Olfactory impairment is associated with functional disability and reduced independence among older adults. Maturitas. 72(1):50–55.

Girling DM, Barkley C, Paykel ES, Gehlhaar E, Brayne C, Gill C, Mathewson D, Huppert FA. 1995. The prevalence of depression in a cohort of the very elderly. J Affect Disord. 34(4):319–329.

Griep MI, Mets TF, Collys K, Vogelaere P, Laska M, Massart DL. 1997. Odour perception in relation to age, general health, anthropometry and dental state. Arch Gerontol Geriatr. 25(3):263–275.

Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, Scherr PA, Wallace RB. 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol. 49(2):M85–M94.

Hedner M, Larsson M, Arnold N, Zucco GM, Hummel T. 2010. Cognitive factors in odor detection, odor discrimination, and odor identification tasks. J Clin Exp Neuropsychol. 32(10):1062–1067.

Henkin RI, Levy LM, Fordyce A. 2013. Taste and smell function in chronic disease: a review of clinical and biochemical evaluations of taste and smell dysfunction in over 5000 patients at The Taste and Smell Clinic in Washington, DC. Am J Otolaryngol. 34(5):477–489.

Hummel T, Sekinger B, Wolf SR, Pauli E, Kobal G. 1997. 'Sniffin' sticks': olfactory performance assessed by the combined testing of odor identification, odor discrimination and olfactory threshold. Chem Senses. 22(1):39–52.

Imoscopi A, Inelmen EM, Sergi G, Miotto F, Manzato E. 2012. Taste loss in the elderly: epidemiology, causes and consequences. Aging Clin Exp Res. 24(6):570–579.

Lamy M, Mojon P, Kalykakis G, Legrand R, Butz-Jorgensen E. 1999. Oral status and nutrition in the institutionalized elderly. J Dent. 27(6):443–448.

Larsson M. 1996. Odor and source remembering in adulthood and aging: influences of semantic activation and item richness. Thesis report. Stockholm: Karolinska Institute.

Laureati M, Pagliarini E, Calcinoni O. 2008. Does the enhancement of chemosensory stimuli improve the enjoyment of food in institutionalized elderly people? J Sens Stud. 23:234–250.

Lawton MP, Brody EM. 1969. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist. 9(3):179–186.

Lundström JN, Gordon AR, Wise P, Frasnelli J. 2012. Individual differences in the chemical senses: is there a common sensitivity? Chem Senses. 37(4):371–378.

Mackay-Sim A, Grant L, Owen C, Chant D, Silburn P. 2004. Australian norms for a quantitative olfactory function test. J Clin Neurosci. 11(8):874–879.

Mackay-Sim A, Johnston AN, Owen C, Burne TH. 2006. Olfactory ability in the healthy population: reassessing presbyosmia. Chem Senses. 31(8):763–771.

Millán-Calentia JC, Tubíoa J, Pita-Fernándezb S, González-Abraldesa I, Lorenzoa T, Fernández-Arrutya T, Masedaa A. 2010. Prevalence of functional disability in activities of daily living (ADL), instrumental activities of daily living (IADL) and associated factors, as predictors of morbidity and mortality. Arch Gerontol Geriat. 50:306–310.

Mioche L, Bourdiol P, Peyron MA. 2004. Influence of age on mastication: effects on eating behaviour. Nutr Res Rev. 17(1):43–54.

Mojet J, Christ-Hazelhof E, Heidema J. 2001. Taste perception with age: generic or specific losses in threshold sensitivity to the five basic tastes? Chem Senses. 26(7):845–860.

Mojet J, Heidema J, Christ-Hazelhof E. 2003. Taste perception with age: generic or specific losses in supra-threshold intensities of five taste qualities? Chem Senses. 28(5):397–413.

Mor V, Wilcox V, Rakowski W, Hiris J. 1994. Functional transitions among the elderly: patterns, predictors, and related hospital use. Am J Public Health. 84(8):1274–1280.

Murphy C. 1986. Taste and smell in the elderly. In Meiselman MI, Rivlin Rs, editors: Clinical measurement of taste and smell. New York: Macmillan. p. 343–369.

Murphy C, Schubert CR, Cruickshanks KJ, Klein BE, Klein R, Nondahl DM. 2002. Prevalence of olfactory impairment in older adults. JAMA. 288(18):2307–2312.

Nordin S, Almkvist O, Berglund B. 2012. Is loss in odor sensitivity inevitable to the aging individual? A Study of "Successfully Aged" Elderly. Chemosens Percept. 5:188–196.

Pelchat MC, Burkhardt-Kulpa D. 1996. Taste sensitivity and preference in the frail, institutionalized elderly. Chem Senses. 21:654.

Ross GW, Petrovitch H, Abbott RD, Tanner CM, Popper J, Masaki K, Launer L, White LR. 2008. Association of olfactory dysfunction with risk for future Parkinson's disease. Ann Neurol. 63(2):167–173.

Sheikh JI. 1986. Geriatric depression scale (GDS) recent evidence and development of a shorter version. Clin Gerontol. 5:165–173.

Schiffman SS. 1991. Drugs influencing taste and smell perception. In: Getchell TV, Doty RL, Bartoshuk LM, Snow JB, editors. Smell and taste in health and disease. New York: Raven Press. p. 845–850.

Schiffman SS. 1993. Perception of taste and smell in elderly persons. Crit Rev Food Sci Nutr. 33(1):17–26.

Schubert CR, Cruickshanks KJ, Fischer ME, Huang GH, Klein BE, Klein R, Pankow JS, Nondahl DM. 2012. Olfactory impairment in an

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adult population: the Beaver Dam Offspring Study. Chem Senses. 37(4):325–334.

Stevens JC, Dadarwala AD. 1993. Variability of olfactory threshold and its role in assessment of aging. Percept Psychophys. 54(3):296–302.

Stevens JC, Bartoshuk LM, Cain WS. 1984. Chemical senses and aging: taste versus smell. Chem Senses. 9:167–179.

Stevens JC, Cain WS. 1987. Old-age deficits in the sense of smell as gauged by thresholds, magnitude matching, and odor identification. Psychol Aging. 2(1):36–42.

Stinton N, Atif MA, Barkat N, Doty RL. 2010. Influence of smell loss on taste function. Behav Neurosci. 124(2):256–264.

Sulmont-Rossé C, Maître I, Issanchou S. 2010. Âge, perception chimiosensorielle et préférences alimentaires. Gérontologie et Société: Cahiers de la Fondation Nationale de Gérontologie. 134:87–106.

Thomas-Danguin T, Rouby C, Sicard G, Vigouroux M, Farget V, Johanson A, Bengtzon A, Hall G, Ormel W, De Graaf C, *et al.* 2003. Development of the ETOC: a European test of olfactory capabilities. Rhinology. 41(3):142–151.

Weiffentbach JM. 1991. Chemical senses in aging. In Getchell TV, Doty RL, Bartoshuk LM, Snow JB, editors. Smell and taste in health and disease. New York: Raven Press. p. 369–378.

Wilson RS, Schneider JA, Arnold SE, Tang Y, Boyle PA, Bennett DA. 2007. Olfactory identification and incidence of mild cognitive impairment in older age. Arch Gen Psychiatry. 64(7):802–808.

Wong KK, Muller ML, Kuwabara H, Studenski SA, Bohnen NI. 2010. Olfactory loss and nigrostriatal dopaminergic denervation in the elderly. Neurosci Lett. 484(3):163–167.

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