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Effects of Gender and Age on Self-reported Odor Imagery Ability

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Abstract

Introduction Odor imagery is known to be more difficult than any other modality of sensory imagery. Consequently, wide between-individuals variability can be found in odor imagery ability. Several studies have shown a positive relationship between olfactory performance and odor imagery ability. In the light of factors known to influence smelling ability, this study therefore investigated the effects of two factors — gender and age — known to influence smelling ability, on self-declared odor imagery ability in normosmic individuals.

Methods Seven hundred and nine French participants were asked to complete the web version of the *French Vividness of Olfactory Imagery Questionnaire* (fVOIQ). General linear models were used to determine the contributions of gender and age to odor imagery vividness scores. Moreover, scores were compared between age intervals ranging from 18–30 years old to 60+ years old.

Results Our findings reveal that at any age, men and women have the same odor imagery ability. Odor imagery ability in self-declared normosmic individuals improves with age until 50–60 years old, and beyond this point the often-reported age-related olfactory decay does not alter it.

Conclusions These findings suggest a high contribution of daily olfactory experience to the development of this cognitive function, and a relationship with olfactory performance that appears less linear than hypothesized.

Implications This study provides food for thought in the field of olfaction: it suggests that distinct mechanisms may underlie two cognitive processes, perception and sensory imagery.

Keywords Odor imagery · Olfaction · Gender · Age · Olfactory experience

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Introduction

Odor imagery, or the ability to “experience the sensation of smell when an appropriate stimulus is absent” (Stevenson and Case, 2005) has long been debated. The main reason is because of its high difficulty in comparison to other modalities of sensory imagery. Indeed, 25% of individuals reported never having formed an odor image (Lawless, 1997). In addition, when an odor image is produced it is usually less vivid than imagery in other modalities (Ashton and White, 1980; Betts, 1910; Sheehan, 1967; White et al. 1978). Several reasons can explain the difficulty in imagining odors and the lack of vividness of the formed images, such as the low importance of olfaction for everyday tasks and the limited occasions to practice odor imagery (Engen, 1982). It is also possible that this difficulty arises from the functioning of olfactory working memory in humans, which is distinct from that of other modalities. Indeed, unlike vision or audition, which relies on modality-specific working memory systems,

olfactory working memory is limited and relies on other information such as language (Arshamian et al. 2020). Yet, despite the difficulty of odor imagery and its lack of vividness, recent studies tend to agree on its existence and on the wide inter-individual variability in self-declared odor imagery ability (Arshamian and Larsson, 2014; Fantin et al. 2020; Stevenson and Case, 2005).

Several studies have assessed self-declared odor imagery ability in different countries (France: Fantin et al. 2020; USA: Gilbert et al. 1998; Germany: Kollndorfer et al. 2015), using translated versions of the *Vividness of Olfactory Imagery Questionnaire* (Gilbert et al. 1998). In these studies, the ability to imagine odors was quantified by the vividness of the formed mental images. The findings of these studies have shown that the likely most important factor contributing to odor imagery ability appears to be smelling ability. Indeed, healthy non-experts (normosmics) have a poorer odor imagery ability than fragrance experts (Gilbert et al. 1998), but are capable of more vivid imagery than individuals with loss of smell (Fantin et al. 2020). Moreover, total loss of smell had a broader impact on odor imagery ability than partial loss of smell (Kollndorfer et al. 2015). These findings are consistent with those of previous studies showing the negative impact of sensory impairment on sensory imagery in the case of sight (Farah et al. 1988, 1992) and hearing (Zatorre and Halpern, 1993). Lastly, Fantin et al. (2020) have shown that congenital anosmics were poorer odor imagers than individuals who had developed loss of smell during their lives, suggesting a potential effect of duration of loss of smell on odor imagery vividness. These findings corroborate the results of numerous other studies showing the close relationship between smelling and odor imagery abilities (Stevenson et al. 2007a, b; Tomiczek and Stevenson, 2009). However, we can still observe wide variability in odor imagery ability in normosmic individuals (Fantin et al. 2020; Gilbert et al. 1998). It has also been shown that factors such as odor awareness (Arshamian et al. 2011), and perhaps the general ability to experience pleasure (Bensafi and Rouby, 2007), can improve the vividness of odor images. Considering the strong relationship between smelling and odor imagery abilities, another lead would be to investigate factors that have been shown as influencing performance in olfaction, as it is notably the case for gender and age.

Regarding gender, many studies have shown the superiority of women in tasks measuring olfactory performance, whether it be in odor identification (Larsson et al. 2009), detection (Hedner et al., 2010) or discrimination (Hummel et al. 2007). Brand and Millot (2001) have suggested two reasons for this effect of gender. First, the authors stated that women's "more developed sensitivity, discrimination, and recognition abilities could compensate for weaker defensive aptitudes by greater capacities in the analysis of the

environment and of its perils. If the assumption of an early division of labour is accepted, it implies a main involvement of women in gathering food supply essentially of plant origin. Thus, a superiority of the chemical senses (taste and olfaction) would be present for women in order to distinguish between the very large diversity of odors and tastes characterizing the different toxic and non-toxic plants and their nutritional values." Second, Brand and Millot (2001) suggested the effect of gender could be explained by the more regular exposure of women to scented products, which could be confirmed by studies demonstrating that mere exposure to odors can improve olfactory ability (see Sorokowska et al. 2017 for a meta-analysis). Moreover, some studies have shown that women are generally more interested in odors (Ferdenzi et al., 2008; Havlicek et al. 2008). Nevertheless, this assumption can be debated, as studies have shown that the superiority of women in olfactory tasks is not systematic (Sorokowska et al. 2015). In fact, it has in some cases been shown that men could perform better in odor detection (Olsson and Laska, 2010). As suggested by Majid et al. (2017), some differences in olfactory performance and notably odor discrimination can be task-dependent or odor-dependent. It is also likely that women's better performance in odor naming and identification can be attributed to better mnemonic integration of odor stimulations over time or superiority in verbal skills (Sorokowski et al. 2019), rather than a better-functioning olfactory system in itself. While the majority of studies have still observed superiority of women in olfactory tasks, the effect of gender on olfactory imagery ability remains unknown.

Age has also been shown to have a strong influence on olfactory performance. Indeed, performance in odor detection (Guarneros et al. 2015; Kern et al. 2014; Kobal et al. 2000), naming (Fornazieri et al. 2015; Wang et al. 2016), and discrimination (Kobal et al. 2000; Zucco et al. 2014) reaches a peak during adulthood, and ultimately decreases with age. According to Mackay-Sim et al. (2006), "significantly reduced sensory sensitivity, even ability, is considered by many to be a normal consequence of aging." This idea has indeed been supported by findings from numerous studies (Hedner et al., 2010; Lehrner, 1999), and the pivotal age after which olfactory performance decreases the most seems to be somewhere between 55 (Doty and Kamath, 2014) and 65 years old (Larsson et al. 2009). However, the nature of this impairment was addressed by Mackay-Sim et al. (2006), who suggested that the decrease in olfactory performance in aging populations may be explained by the onset of pathologies, rather than age-related decline itself. In order to test this assumption, they studied olfactory performance in 485 healthy, non-medicated, non-smokers with no history of nasal problems and in another sample of 457 participants, who were either medicated, smokers, or had a history of nasal problems. Firstly, their results showed that

in the healthy group, olfactory performance declines after 65 years old, but this decline is rather small. Secondly, the between-group comparison has shown broader decline in olfactory performance in the not healthy group. The effect of age on olfactory performance could however be counterbalanced by a larger amount of olfactory experiences. Indeed, numerous studies have shown an increase in odor detection and discrimination, during the course of childhood (Hummel et al. 2011; Stevenson et al. 2007a, b) and sometimes continuing into adult life (Hummel et al. 2011; Zucco et al. 2014). These findings showed that olfactory perception heavily relies on daily olfactory exposure (Stevenson and Boakes, 2003), and underline the need to consider this parameter in odor imagery related studies. This consideration suggests that aging would be accompanied by more olfactory exposure and thus easier access to odor images. In order to test this hypothesis, Arshamian et al. (2020) compared olfactory imagery ability between 4 age groups (9, 10, 11, and 12 years old), and one adult group (aged 18 to 52, mean age = 22 years old). Surprisingly, their findings showed no evolution in odor imagery from 9 years old to adult life. According to the authors, mere exposure would not suffice to continue developing odor imagery ability, and specific and intentional training may be the only way to witness improvement. But the sample sizes were relatively small (ranging from 27 to 72 participants per group). Moreover, clustering all adult participants into one group did not provide the possibility to assess a possible effect of age during later adult life, especially after 55–65 years old, which is a hinge period for olfactory processes. This is why we believe that effect of age should be further investigated, particularly by taking aging into account.

The aim of this study was to determine the effect of gender and age on self-reported odor imagery ability in French normosmic individuals. Considering the relationships between smelling and odor imagery abilities, we expected (1) better self-reported odor imagery ability in women as compared to men and (2) lower olfactory imagery ability after 55–65 years old.

Materials and Methods

Population

Seven hundred and ninety-two individuals participated in the current study over a period of 10 weeks by completing a web form about their odor imagery ability (the *French Vividness of Olfactory Imagery Questionnaire* — fVOIQ). In order to obtain the most heterogeneous sample possible, it was both broadcast on social media and directly distributed to 22 thematically different structures (e.g., hospitals, municipalities, research teams, sports clubs). Participants

were asked their country of birth, country of residence, and since when they lived in their current location. They were also instructed to indicate whether they reported a normal, diminished or absent sense of smell (normosmic, hyposmic, and anosmic, respectively). Participants were asked if their profession involved intense olfactory activity (e.g., perfumers), in which case they were considered olfactory experts. Only French self-declared normosmic participants having always lived in France were included. Pregnant women and participants who had contracted a smell-affecting virus during the past month were not included in the study. Seven exceptions were made for individuals who were born abroad but had lived in France since the age of 2 or younger, and for those who had always lived in France but had recently moved abroad. Therefore, the data of 709 participants (276 men, 433 women, mean age = 36.48 ± 15.3 years old) were analyzed. The inclusion process is detailed in Fig. 1 and the details about their gender and age group are provided in Table 1. Participants were not asked to provide any identifying data at any point of the protocol. Therefore, according to French legislation, no specific ethical approval was needed.

Procedure

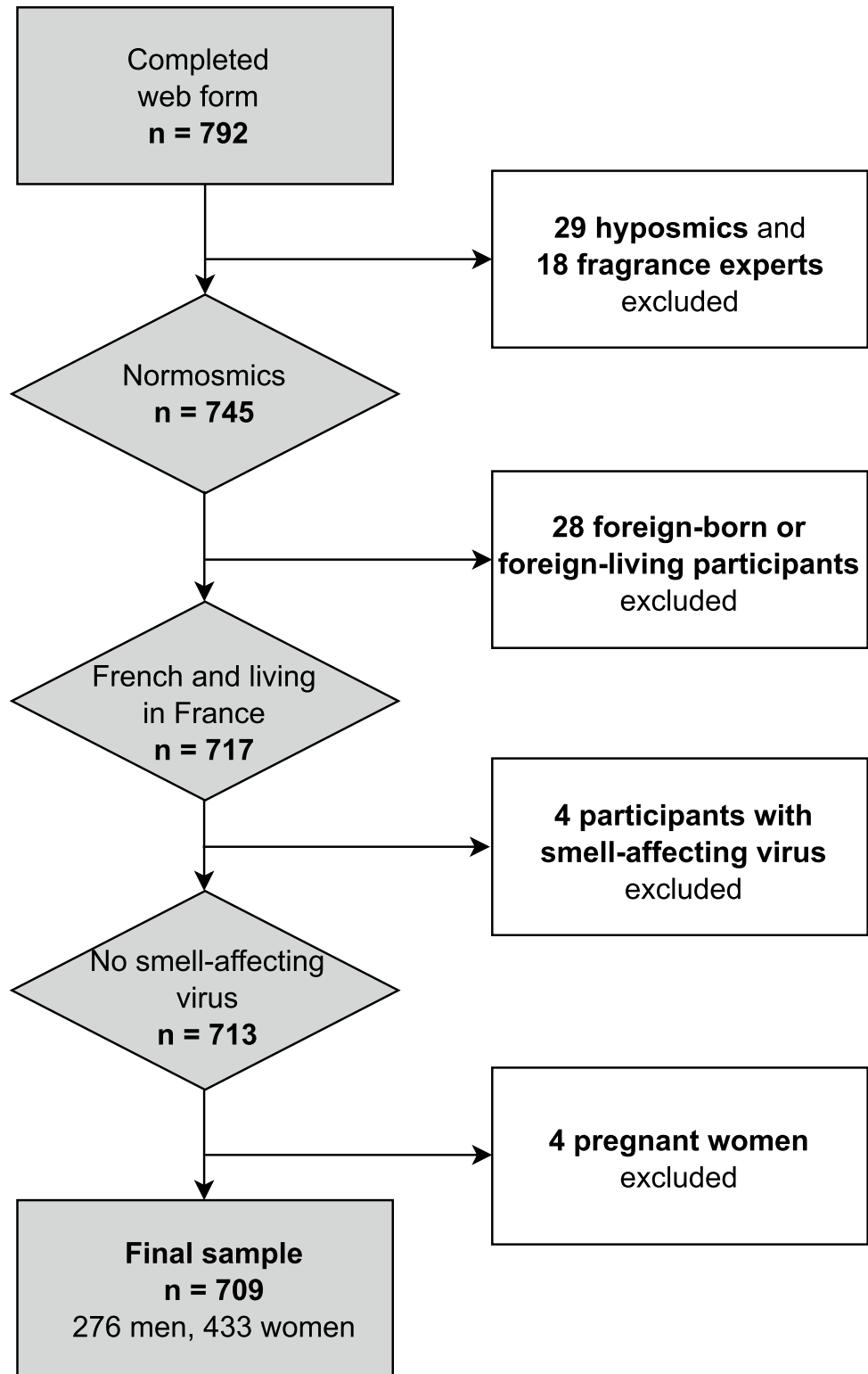
Participants were instructed to complete the fVOIQ in its web version (Fantin et al. 2020). As a reminder, the fVOIQ is presented as 4 daily life situations (e.g., “Think of an outdoor cookout or barbecue. Consider the smells that occur”), for which 4 smells are listed (e.g., “The charcoal or wood has just been lit and is beginning to burn”), making a total of 16 items. The participants were instructed to imagine each smell, and rate the vividness of each imagined smell on a scale ranging from 1 (Perfectly realistic and as vivid as the actual odor) to 5 (No odor at all, you only “know” that you are thinking of the odor).

Data Analysis

For each participant, the $fVOIQ_{\text{mean}}$ score was calculated by using the mean score of vividness ratings on the 16 items of the questionnaire. $fVOIQ_{\text{mean}}$ scores ranged from 1 to 5, with a lower score indicating a higher odor imagery ability.

In order to study the influence of gender and age on fVOIQ score, three General Linear Models (GLMs) were successively used in order to study age, gender, and age*gender interaction on $fVOIQ_{\text{mean}}$. The application conditions of Gaussian models (residuals normality, homoscedasticity, and residual independence) were tested using Shapiro–Wilk, Breush–Pagan, and Durbin–Watson tests, respectively. Since none of these conditions were not met and because of high residual deviance (5.28), negative binomial models were used. Because such models requires positive integers, the $fVOIQ_{\text{mean}}$ score for each participant was

Fig. 1 Flowchart of participant inclusion and exclusion



transformed to a $fVOIQ_{sum}$ score by multiplying it by the number of items in the questionnaire. $fVOIQ_{sum}$ scores were therefore between 16 and 80, and identically to $fVOIQ_{mean}$, a low score indicating high odor imagery ability, and vice versa. The GLMs were then tested on $fVOIQ_{sum}$. The

accuracy of the models was assessed using the Akaike Information Criterion (AIC). A smaller AIC indicates a higher accuracy of the model.

In order to study the effect of age group on odor imagery, all participants were classified in age groups ranging from

Table 1 Distribution of participants per gender and age group

Age	Males	Females	Total
[18;30]	129	191	320 (45%)
]30;40]	49	59	108 (15%)
]40;50]	37	76	113 (16%)
]50;60]	37	81	118 (17%)
]60;+]	24	26	50 (7%)
Total	276	433	709 (100%)

18–30 years old, to 60 years and over. Intermediate groups were set at 10-year intervals. The Shapiro–Wilk test revealed that $fVOIQ_{\text{mean}}$ did not follow normal distribution for any age group ([18;30]: $W=0.94$; [30;40]: $W=0.93$; [40;50]: $W=0.89$; [50;60]: $W=0.84$; [60;+]: $W=0.90$; $p < 0.001$). A Kruskal–Wallis ANOVA was therefore used to assess the effect of age group on $fVOIQ_{\text{mean}}$ score. Post hoc Dunn tests were used to compare $fVOIQ_{\text{mean}}$ scores between age groups. The significance threshold was set to $\alpha=0.05$ and test probabilities were adjusted by Bonferroni corrections for multiple comparisons.

R software (version 4.0.5) was used for all statistical analyses and figure creation. The dataset is available by following this link: <https://doi.org/10.6084/m9.figshare.19731931.v1>

Results

Effects of Gender and Age on Odor Imagery

The comparison of GLMs revealed that age alone provides the best fitting model to explain $fVOIQ_{\text{sum}}$. Indeed, the results showed that the effect of age on $fVOIQ_{\text{sum}}$ was significant ($AIC=5707.5$; $Z=-6.91$, $p < 0.001$), while gender ($AIC=5752.8$; $Z=-0.07$) and age*gender interaction ($AIC=5710.4$; $Z=-1.01$) were not ($p > 0.05$).

Effect of Age Group on Odor Imagery

The Kruskal–Wallis ANOVA revealed a significant effect of age group on $fVOIQ_{\text{mean}}$ [$H(4, 708)=65.6$; $p < 0.001$; $\eta^2=0.09$]. Dunn post hoc tests revealed multiple differences in $fVOIQ_{\text{mean}}$ between age groups (see Fig. 2). The score in the [18;30] group (Med = 2.38, IQR = 1.06) was significantly higher than in the [40;50] (Med = 2.06, IQR = 1.06, $p < 0.01$), [50;60] (Med = 1.75, IQR = 0.86, $p < 0.001$) and [60;+] groups (Med = 1.88, IQR = 0.92, $p < 0.001$). Likewise, $fVOIQ_{\text{mean}}$ score in the [30;40] group (Med = 2.28, IQR = 1.22) was significantly higher than in the [50;60] ($p < 0.001$) and [60;+] groups ($p < 0.05$). Finally, $fVOIQ_{\text{mean}}$

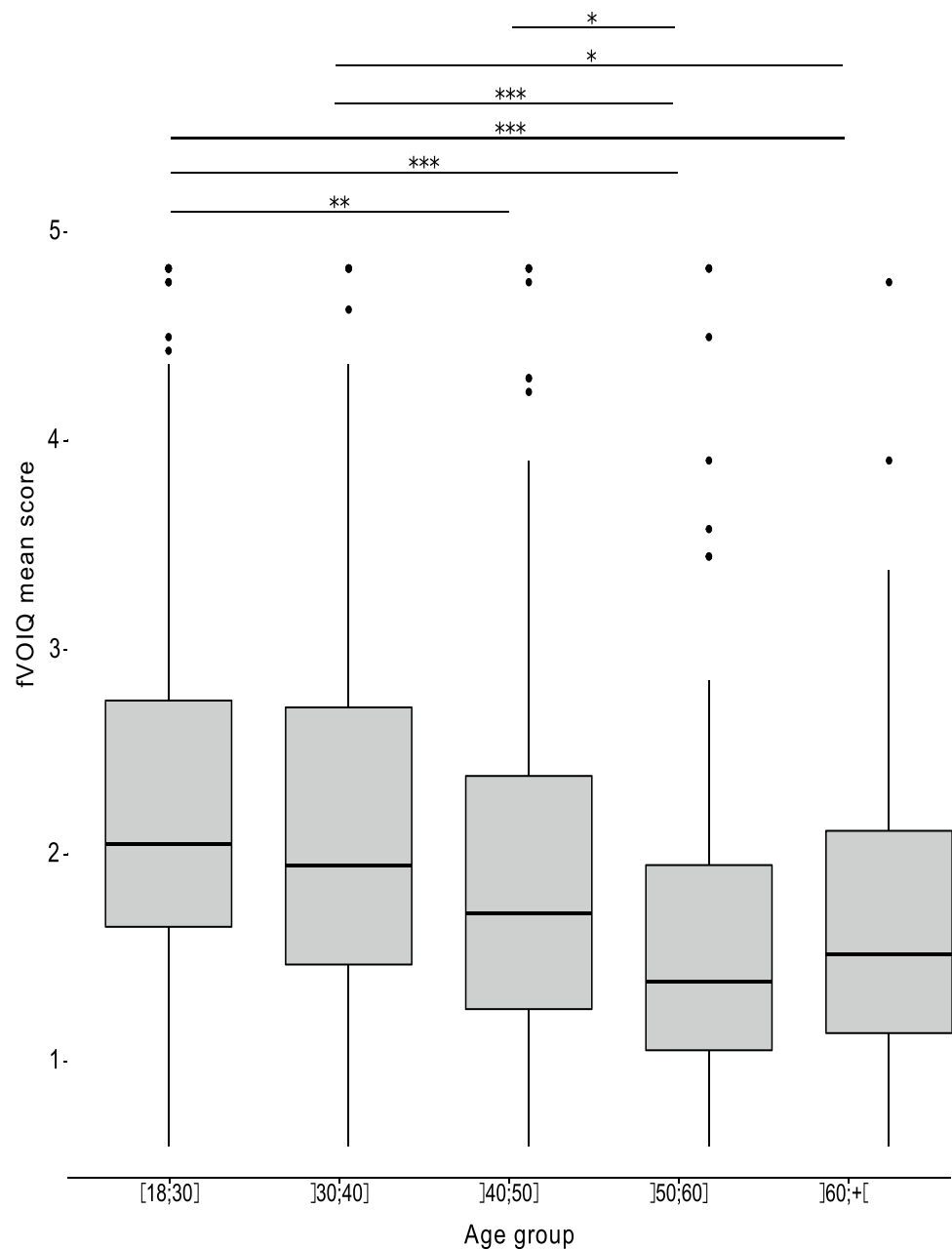
score in the [40;50] group was significantly higher than in the [50;60] group ($p < 0.05$).

Discussion

The aim of this study was to determine the effect of gender and age on self-reported odor imagery ability in French normosmic individuals. First, based upon previous reports of superior olfactory performance in women, we expected women to be capable of more vivid odor imagery than men. However, our results indicate there was no effect of gender on $fVOIQ$ scores, suggesting that men and women presented similar odor imagery ability. This absence of effect can be interpreted in two ways. On the one hand, it is possible that there is no difference in olfactory performance between men and women, corroborating the numerous recent studies revealing no difference in olfactory tasks between genders (Hedner et al. 2010; Sorokowska et al. 2015). On the other hand, the relationship between smelling and olfactory imagery abilities could be more complex than hypothesized, suggesting that other factors should be taken into account to explain the absence of difference between genders.

Second, we hypothesized poorer odor imagery ability in older individuals, associated with age-related olfactory decay. As expected, our findings on a large sample did reveal an effect of age on the participants' self-reported odor imagery ability, thus contradicting the results of Arshamian et al. (2020). Our consideration of age during the entirety of adult life allowed for a more precise assessment of odor imagery over time. However, surprisingly, the effect showed a decrease in $fVOIQ$ scores with age, representing an improvement in odor imagery ability, thus disproving our hypothesis. More precisely, our multiple comparisons of $fVOIQ_{\text{mean}}$ between age groups showed that, regardless of gender, odor imagery ability improves until the 50–60-year-old range, after which it remains stable. These findings suggest that up to 50–60 years old, a higher quantity of olfactory experiences would be related to the improvement of one's odor imagery ability, as opposed to performance in olfactory tasks. Our findings also lead us to believe that self-reported odor imagery ability is not significantly altered by age-related olfactory decay. It is nevertheless possible that the effect of age in our study was underestimated. Indeed, unlike Mackay-Sim et al. (2006), we did not exclude from our study any smokers, individuals under medication, or having had nasal problems. However, it is known that some pathologies appearing at an advanced age such as Parkinson's disease or Alzheimer's disease, can impair olfaction (Albers et al. 2006; Haehner et al. 2011), and therefore possibly affect odor imagery ability. Thus, being more selective

Fig. 2 Median fVOIQ_{mean} scores and Inter-Quartile Ranges for each age group (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$)



during the inclusion process could have led to an even stronger effect of age. One limitation of this study could be the small sample sizes of over-70-year-old participants. This may for instance be due to their lower affinity to web forms. In order to increase our statistical power, we added these data to those of 60–70-year-olds, the new group ranging from 61 to 77 years old. In this context, we have been able to show that odor imagery ability in our oldest age group was not lower than that of our 50–60-year-old interval. In fact, the oldest participant had a fVOIQ_{mean} score of 1.06. Further studies should verify this assumption on wider samples by focusing more precisely on the potential effects of age-related olfactory decay on odor

imagery ability. However, the present study did not perform any direct measure of smelling ability such as the widely used sniffin' sticks test. Therefore, the apparent independence between smelling and odor imagery abilities needs to be verified in additional studies. In order to confirm the assertion that perception and imagery of smells are not linearly related, coupling measurements of smelling ability to tools such as the VOIQ is necessary.

Overall, the improvement of olfactory imagery ability with age could reflect a general effect of aging on sensory imagery. Indeed, it is possible that due to a larger amount of sensory experiences, older individuals have a higher propensity to evoke sensory images of any

modality. Although similarities between olfactory and visual imagery abilities have already been demonstrated in normosmic and fragrance expert populations (Gilbert et al. 1998), the specific question of aging across different sensory modalities has, to our knowledge, never been addressed. Investigating sensory imagery from a general approach at advanced ages could provide insight on a potential systematic effect of age on these cognitive processes.

This study focused on factors known to influence smelling ability, in order to see if their effect was transposable to odor imagery ability. In the light of our findings, we can assert that both these processes do not seem unequivocally related. Odor imagery ability would thus result from the interaction between environmental factors (rurality, professional activity, local pollution...) and human factors such as ability to experience pleasure, odor familiarity and hedonic valence, and mnemonic processes (Arshamian and Larsson, 2014). This corroborates the results of brain imaging studies, which have shown that odor perception and odor imagery only partially share neural networks (Djordjevic et al. 2005). Indeed, although odor imagery has been shown to activate secondary and associative olfactory cortices, the implication of the primary olfactory areas is still questioned (Royet et al., 2013). The authors notably suggest that activations in the piriform cortex could be, for instance, caused by the anticipation of the presence of a smell (González et al. 2006; Zelano et al. 2011), or the action of sniffing (Bensafi et al. 2003; Kleemann et al. 2008), rather than odor imagery itself. The absence of direct relationship between odor perception and imagery highlights the need to assess individuals' odor imagery ability, particularly prior to brain imaging paradigms. Indeed, to this day, few studies have screened participants, in order to focus on good imagers. In these paradigms, the presence on poor odor imagers may induce two types of biases, which are the absence of activations in brain regions involved in odor imagery, and falsely positive activations in less connected areas. This is why, screening good odor imagers in future brain imaging studies may lead to clearer answers regarding the mechanisms of odor imagery, and to the better understanding of the involved neural networks. The VOIQ or its translations could be a way to assess odor imagery ability during the recruitment process. This way, specific populations could be selected to have more accurate answers regarding the complex mechanisms of odor imagery.

Author contribution Conceptualization: GH and HC; Methodology: GH and HC; Formal analysis and investigation: LF, CP, GH and HC; Writing – original draft: LF, GH and HC; Writing – review and editing: CP and CR; Project administration: GH and HC; Visualization: LF, GH and HC.

Data availability The dataset is accessible by following this <https://doi.org/10.6084/m9.figshare.14974602>

Declarations

Conflict of Interest The authors have no relevant financial or non-financial interests to disclose.

Ethical Approval Participants in this study were not asked to provide any identifying data. Therefore, in accordance with local legislation, no ethical approval was needed to conduct this study.

Informed Consent Participants provided their consent to participate in this study by voluntarily completing the online form.

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