Research Article

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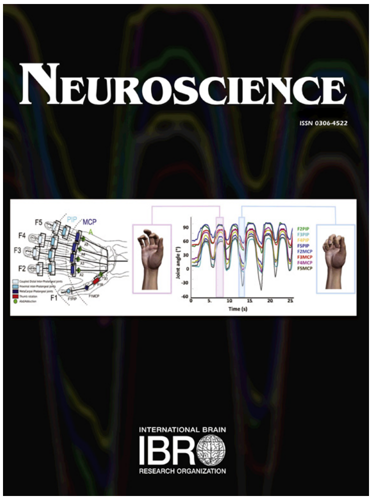

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Early-blind individuals show impaired performance in wine odor categorization

Research Report

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Abstract

Blind individuals display superior sensory abilities in other modalities, yet results remain contradictory regarding their performance on olfactory tasks. Using complex ecological olfactory tasks, we evaluated the impact of blindness on olfactory performance. We tested 12 early-blind individuals (*M* = 49, *SD* = 13.09) and 12 sighted controls (*M* = 49, *SD* = 14.31) who were all blindfolded. Based solely on the wine odors, participants evaluated 24 pairs of wine and determined if both samples belonged to the same category (red wine, white wine, or rosé wine) or not (*odor categorization*), and if so, whether they were identical or not (*odor differentiation)*. Then, they had to classify 15 different wines (5 red, 5 white and 5 rosé) into red, white, and rosé wines (*odor classification*). Blind individuals (*d'*: *M* = 1.3, *SD* = 1.2) presented lower scores compared to sighted controls (*M* = 2.2 *SD* = 0. 8; *p* < .05) in the *odor categorization* task, but no group difference was observed for the other tasks. For all participants, red wine odors were the easiest to *classify* (1.8 ± 1.0), followed by white wine odors (0.5 ± 0.6) and finally rosé wine odors (blind and sighted; *F*[2; 44] = 11.9, *p* < .001). In summary, early-blind individuals had a harder time to *categorize* wine odors. This could be explained by a different construction of internal reference categories for wine in early-blind individuals. Finally, this research is in line with the notion of the absence of higher olfactory sensitivity in blind individuals.

Keywords

Blindness, early-blind, wine odours, olfaction, odour perception, odour categorisation,

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Conflict of interest

None declared.

Introduction

It has been generally demonstrated that blind individuals compensate for their lack of visual input by displaying supra-normal abilities in their intact modalities (Burton, 2003; Norman and Bartholomew, 2011). These capacities seem to be in part modulated by age of blindness onset because earlier onsets are associated with a better performance (e.g., individuals who lost their sight early in life were better at determining the change in pitch directionality compared to those who lost their vision later in life and sighted controls (Gougoux et al., 2004)). It should be noted that in the literature, the age for defining early-blindness can vary from 1 to 14 years (Lewald, 2002; Wakefield et al., 2004; Cuevas et al., 2010) or not defined at all (Murphy and Cain, 1986), which complicates the understanding of the results within this population. Consequently, it is important to differentiate and consider the age at which sight was lost (i.e., at birth—congenitally blind; within the first few years of their life—early-blind; or during adulthood—late-blind). For the scope of the present paper, we defined early-blind as individuals who lost their sight before the age of 5 (Lewald, 2002). Congenitally and early-blind individuals showed supra-normal abilities in the auditory (Lessard et al., 1998; Simon et al., 2002; Gougoux et al., 2004) and tactile modalities (Alary et al., 2008; Goldreich & Kanics, 2003), whereas results are less systematic within the late-blind population (Voss et al., 2004; Wan et al., 2010). This body of research supports the notion that congenitally and early-blind individuals show supra-normal performance, and more so than late-blind, especially for tasks that are more complex and difficult, where more subtle cues are needed to complete the task (Frasnelli et al., 2011).

Unlike the auditory and tactile modalities, there is less of a consensus regarding the olfactory capacities within the blind population (Majid et al., 2017). Olfactory function is typically investigated by assessing the capacity to detect (threshold), to discriminate and/ or to identify odors. Most studies on odor detection thresholds did not find any difference between the blind and sighted individuals (Rosenbluth et al., 2000; Schwenn et al., 2002; Wakefield et al., 2004; Luers et al., 2014; Kärnekull et al., 2016; Sorokowska, 2016) although a few studies reported that blind people had a lower detection threshold (i.e., had a better sensitivity to odors and needed a lower concentration to be able to detect them; (Cuevas et al., 2010; Beaulieu-Lefebvre et al., 2011; Comoglu et al., 2015)). When it comes to olfactory discrimination, some studies reported no difference between the groups (Schwenn et al., 2002; Beaulieu-Lefebvre et al., 2011; Luers et al., 2014; Sorokowska, 2016), while others suggested that blind individuals outperform the sighted (Cuevas et al., 2010; Rombaux et al., 2010; Renier et al., 2013; Comoglu et al., 2015). With regards to odor identification it appears that group differences depend on the paradigm that is used. Indeed, in the case of a forced-choice paradigm, the consensus is that blindness does not affect the performance (Smith et al., 1993; Rosenbluth et al., 2000; Schwenn et al., 2002; Cuevas et al., 2010; Beaulieu-Lefebvre et al., 2011; Luers et al., 2014; Comoglu et al., 2015; Gagnon et al., 2015; Sorokowska, 2016). However, in the case of a free naming identification task, several studies suggest that blind individuals outperform the sighted (Murphy and Cain, 1986; Rosenbluth et al., 2000; Wakefield et al., 2004; Cuevas et al., 2010; Rombaux et al., 2010; Renier et al., 2013; Gagnon et al., 2015), while only one team did not find significant results (Sorokowska, 2016; Sorokowska and Karwowski, 2017). Some authors have suggested that the heightened performance of blind individuals in free odor identification may be explainable by a greater ability for blind individuals to generate words (Burton et al., 2002), rather than from genuine increased olfactory ability. Further, shorter response times has been observed in blind individuals, suggesting a faster olfactory processing (Cuevas et al., 2010; Gagnon et al., 2015). Among the studies which reported significant differences between sighted and blind participants, most included only cases with an early blindness onset, but a few compared early-blind and late-blind individuals. While a team reported that blindness onset did not affect performance in olfactory detection, discrimination, or forced-choice identification (Comoglu et al., 2015), another team found that early-blind were better at identifying odors in a free naming paradigm than late-blind (Kärnekull et al., 2016). Altogether, these results seem to suggest that that a supra-normal performance in early-blind individuals is more readily observable if the undergoing tasks present higher levels of difficulty (e.g., free naming identification task); a phenomenon that was previously shown in blind individuals within other modalities (Simon et al., 2002; Alary et al., 2008).

A recent metanalysis (Sorokowska et al., 2018) investigated this body of literature and observed, based on the data of more than thousand observations, an important publication bias, i.e., selective publishing of positive results. In fact, studies that reported significant group differences, typically had small sample sizes. By correcting for the publication bias, the authors provided convincing evidence that blindness does not affect odor identification, odor discrimination and odor thresholds.

While this may lead one to conclude the olfactory function is unchanged in blind individuals, the picture may be more complex. In fact, most studies used tests to evaluate olfactory function that are designed to differentiate between normal or reduced olfactory function (i.e., Sniffin' Sticks or UPSIT; Doty, Shaman, & Dann, 1984; Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997) and they are fairly easy to complete when no olfactory abnormality is present. Consequently, any differences between two groups would be dampened by a ceiling effect, since these tools are not meant to detect supra-normal performance. Such a ceiling effect, however, could be avoided by using more complex olfactory tasks to discern any potential performance differences between blind and sighted subjects.

An example of a more demanding olfactory task is wine odor assessment, which is challenging even for wine experts (Ballester et al., 2009). In this study, Ballester et al., examined the ability of wine experts, novices, and trained subjects, to classify wine odors—based solely on the wine's olfactory information—as red, white, or rosé wines. All groups could correctly classify red and white wines, but none were able to do so for rosé wines. Similar results were replicated with beer odor categorization (Lelièvre et al., 2009). It is thus possible that, in this kind of task, congenitally and early-blind individuals would outperform sighted controls.

However, in another study, white wines that were colored with an odorless red dye were described as red wines, suggesting that the visual aspects of the wine influenced more its perception than its olfactory aspects (Morrot et al., 2001). Put differently, it seems that the pre-established visual mental categorization of a red wine (i.e., it looks like a red wine, therefore, it should be a red wine) dictates more readily its odor perception than an olfactory mental categorization (i.e., it smells like a red wine, therefore, it should be a red wine). Altogether, these results suggest that wine and beer drinkers rely heavily on visual mental categories rather than olfactory ones to accurately assess these odors. This is further supported by a perceptual olfactory facilitation when odors and visual stimuli are presented congruently (i.e., the smell and the image of orange) versus when they are presented incongruently (i.e., smell of fish and the image of cheese; Gottfried & Dolan, 2003). Additionally, our group has shown that odor perception can be modulated by the labels we give them (i.e., the same odor can be perceived as pleasant and unpleasant if we attribute it a negative or a positive label, respectively). This result suggests that a label activates mental representations which modulate the perception of the odor, and thus provides further support for the influence of internal categories on odor perception (Manescu et al., 2014). Together, these studies highlight the importance of visual mental categorization in olfactory processing. In contrast with what was previously stated with respect to the blind, the implication of visual mental categorization would support an alternative hypothesis, namely, that congenitally and early-blind individuals would perform worse than controls in a categorization task, because early-blind individuals did not have the opportunity to create visual mental categories. In summary, the literature raises the question of whether blind individuals (i.) present superior performance due to supra-normal olfactory capacities or (ii.) show reduced performance because they do not benefit from visual mental categorization.

To answer this question, we set out to examine olfactory performance in an early-blind population on more difficult and ecological tasks, which include a strong visual mental categorization such as classification of wine odors into red, white, and rosé wines and different control tasks. More specifically, we evaluated performance of blindfolded participants (blind and sighted) on (a.) a wine odor *categorization* task ("do these two wines belong to the same category?"), (b.) a wine *differentiation* task ("are these two wines the same wine or different wines?"), (c.) a wine odor *classification* task ("is this a red, white or rosé wine?"), (d.) a general odor *identification* task; always exclusively based on the odors with no visual input. For all assessments, we put a particular emphasis on meticulously matching groups in terms of age and gender.

Experimental procedures

Participants

We tested 12 early-blind (age M = 49, SD = 13, range 24 to 65 years, 3 women) and 12 controls (age M = 49, SD=14, range 25 to 71 years, 3 women). All participants were congenitally blind, apart from one who was completely blind since the age of 3 years and a half. Since all blind participants lost their vision within the first few years of life, we will refer to them as the early-blind group. Causes of blindness include retinopathy of prematurity (5/12), congenital cataracts (2/12), microphthalmia (1/12), retinoblastoma (1/12), retinal detachment (1/12), congenital eye defect (1/12) and unknown (1/12). A bit less than half of the early-blind participants had some residual vision in at least one eye (5/12). Early-blind and sighted participants were matched in terms of age, gender, and smoking habits (1/12 in both groups). Participants were also asked about their consumption of red, white and rosé wine, and were matched in terms of how many glasses of wine they drank on average per week (Early-blind: M = 1.6, SD =1 .2; Sighted: M = 1.4, SD = 1.2). All participants declared that they did not suffer from any medical condition that could affect their sense of smell at the time of the testing and did not have any history of alcohol abuse. Participants were instructed not to eat or drink anything besides water one hour prior to the experiment. Before taking part in the study, subjects gave their written informed consent. After completion, they received a $60 monetary compensation for their participation as well as reimbursement of their travel expenses. The Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR) approved this study.

Stimuli

Fifteen different wines, five red, five white, and five rosé, were bought locally at the Société des Alcools du Québec (SAQ). For the differentiation task (see below), 2 additional bottles per category were purchased from these initial 15 wines selection. Wine information can be found in Table 1. To preserve the wine for a longer period, each 750mL bottle was transferred into ten 60mL amber glass bottles. Once the wine was transferred, it was refrigerated for a maximum of 12 days after which it was discarded if it was not used in the experiment. When testing occurred, the wine was transferred into wine glasses (Palma; INAO Tasting glass 200mL) which enabled participants to smell the wine within a relatively ecological setting. Each of the 15 wines had their own coded bottles and glasses to avoid any cross-contamination between the wines.

Insert Table 1 here

Tasks and Procedures

Two hours prior to each testing, all the wines used for testing were taken out of the refrigerator to reach room temperature (23ºC). Before the participant's arrival, the wines were transferred in their corresponding glasses. All participants, including the early-blind participants, were blindfolded for the rest of the two hours of the experiment to maintain uniformity amongst the participants and to avoid any biased effect associated with wearing a blindfold (e.g., pressure on the nose, blindfold odors, etc.). Additionally, tissue paper was inserted between the blindfold and the participant's eyes to avoid any sighting of the wine. Then, we administered the different olfactory tasks, which are further detailed in the following sections. Each of these tasks required the participants to respond based solely on the odors of each wine; there was no wine tasting. For all the tasks, wines were served in wine glasses which were placed in front of the blindfolded participants and guided towards their hands, allowing the participants to know the location of the glass. Once they grasped the glass, they could either bring it to their nose and smell it, or, bring their nose to the glass while the glass remained on the table. All wines in all tasks were presented randomly. After the experiment, the used wine was discarded, and all the glassware was washed and air dried. After every wash and before every experiment, the experimenter verified that there was no lingering odor in the glasses.

Wine odor categorization and differentiation

From the total of 15 wines, two red, two white, and two rosé wines were used for the wine odor *categorization* and *differentiation* tasks. Recall that participants were blindfolded and had to respond based solely on the odor of the wine. The participants were presented simultaneously with two wine glasses and they had to answer by "yes" or "no" the two following questions: (1) "do these wines belong to the same category?" knowing that categories referred to red, white, or rosé wine (*categorization*; task a) and (2) "do these two glasses contain the same wine or two different wines?" (*differentiation*; task b). Categorization and differentiation tasks were embedded, the second task depending on the outcome of the first one: after smelling one after the other the two glasses of wine placed in front of them, participants first had to determine whether the wines belonged to the same category (by answering "yes" or "no") without attempting to name the category (task a). Then, if they said that the wines were from the same category, they were asked to determine whether both wine glasses contained the same exact wine, or two different wines (task b). If the participant said that both glasses were not from the same category, it automatically meant that the participant determined that both wine glasses contained different wines. 24 pairs of wines were presented only once in a random order. More specifically, we presented 6 pairs of identical wines (same wine and same category), 6 pairs of wines from the same category (different wines from the same category) and 12 pairs of wines from different categories (different wines from different categories). Participants could take as much time as needed to give their response, but a 40-second wait period was taken between each presentation to avoid olfactory fatigue, which is in line with the literature in the domain (Hummel and Kobal, 1999)

Wine odor classification

Participants had to correctly classify each of the 15 different wines (5 red, 5 white, and 5 rosé) by labelling each of them as “red wine,” “white wine,” or “rosé wine” (task c). Wine order presentation was randomized for every participant before the experiment. Participants were presented with one glass of wine at a time. They could either smell the wine by taking the glass and bringing it to their nose or by bringing their nose to the glass while it remained on the table. Similarly, to the previous task, participants could smell the wines for as long as needed. Response times were measured with a stopwatch, from the moment when they put their nose over the glass, about to take their first sniff, to the moment when their response was given.

After they classified the wine, we additionally asked participants to provide three different descriptors for each of the 15 wines. They were free to give any descriptor they wanted, without restriction as to the type of descriptors they could use (e.g., citrus, grass, leather), but were told that they should refrain from comparing the wines between them (e.g., “this wine smells more like grapes compared to the one before”). If they gave less than three descriptors, they were encouraged to generate more descriptors to sum up to three. When they gave more than three descriptors, we asked them to choose which of the given descriptors described the wine best. Thus, they provided a total number of 45 descriptors (three for each of the 15 wines). Similarly, to the last task, a 40-second delay was incorporated between each wine presentation to avoid olfactory fatigue.

Odor identification

In order to assess the participants' ability for odor *identification* (task d), we administered the identification subtest of the "Sniffin' Sticks" (Hummel et al., 1997). This subtest consists of the presentation of 16 common odors (e.g., apple, rose, leather) in felt-markers which the participants had to correctly identify. The test was administered under two conditions. First, we presented each of the 16 odors to the participants and they had to identify the odors without any cue (free condition). Answers were scored as correct when the participants gave the exact correct label of the odor. If they gave a category (e.g., "fruity" for the banana odor), they were asked to be more specific. Then, we presented the same odors a second time, but this time they had to choose between four alternative choices (forced-choice condition) which were presented verbally to them. For both conditions, we calculated the total number of right responses out of a possible score of 16. Therefore, every participant had a score for the free and the forced-choice conditions. The same researcher scored all responses to assure reliability within the scoring.

Statistical analyses

For the analysis of wine odor *categorization, differentiation* and *classification,* we computed sensitivity index *d'* and bias criterion *C* (Signal Detection Theory: Snodgrass & Corwin, 1988). Here, *d'* indicates the sensitivity to accurately detect a stimulus by comparing the correct hits (e.g., correctly categorizing a wine as a red wine) to the false alarms (e.g., incorrectly categorizing a wine as a red wine). *C*, in turn, represents the participant's criterion when responding; a positive value represents a conservative approach (e.g., a bias towards not responding that the wine is red) and a negative value represents a liberal approach (e.g., a bias towards responding that the wine is red). Both variables (*d*', and *C*) were taken as dependent variables and analyzed in separate ANOVAs.

All analyses were conducted with SPSS Statistics 24 (IBM, Corp, Armonk, NY). For each measure, we examined whether there were any outliers beyond three standard deviations; none were found. Specifically, for all our dependent variables, we carried out the following analyses: first, z-transformed data; the first on the whole sample of 24 participants and the second on the 12 participants of the early-blind group. We then verified whether any of the blind subjects had a z-score larger than 3. We did not find any outlier, indicating that the sample of blind participants was indeed homogenous.

Secondly, we then analysed homogeneity of variances for both groups by using the Levene's test. This yielded a significant difference for one variable, namely d' for the wine odor differentiation (p=0.002). Therefore, for only this measure we additionally conducted a non-parametric Mann-Whitney Test to compare both groups. For all analyses, age, gender, wine consumption, and educational level were used as covariates but were removed if they did not impact the results. For all analyses, Bonferroni corrections were applied to correct for multiple comparisons. The alpha level was set at *p* = .05.

For both the wine odor *categorization* task (task a) and the wine odor *differentiation* task (task b) we used *blindness* (2 levels: early-blind and sighted controls) as a between-subject factor on the dependent variables *d*' and *C*.

For the wine odor *classification* task (task c) we used *category* (3 levels*:* 1. Red 2. White 3. Rosé) as a within-subject factor and *blindness* as a between-subject factor. Furthermore, we computed a third repeated measures ANOVA for the dependent variable *response times* with the same within-subject and between-subject factors.

For the general *odor identification* task (task d), we conducted a repeated measure analysis of variance (ANOVA) by using *odor identification* (2 levels: free and forced-choice) as a within-subject factor and *blindness* as a between-subject factor.

For the exploratory analysis of the use of wine descriptors, we counted how many different descriptors the participants gave: they provided a total number of 45 descriptors but, because they could use the same words to describe different wines, the number of different descriptors was less than 45 and varied across participants. We calculated this number of different descriptors separately for each of the three categories (red, white, and rosé). Then, we performed a repeated-measures analysis of variance (ANOVA) for the dependent variable *number of descriptors,* with *category* and *blindness* as within-subject and between-subject factors, respectively. We analysed the descriptors in two ways: first, we performed the analysis based on the number of descriptors given to the actually presented wine (e.g., descriptors provided for a white wine were considered as white wine descriptors). Because three descriptors were provided for each wine and there were five wines from each category, there can be up to 15 different descriptors for each category. Second, because participants classified each wine before giving descriptors, we knew whether they perceived it as a red, white, or rosé wine, which allowed us to perform another analysis, this time depending on the perceived wine (e.g., descriptors provided for a red wine classified as a white wine were considered as white wine descriptors).

Results

No significant group difference in terms of age, gender and wine consumption frequency was found. However, the sighted controls had a higher level of education (M = 17.8 years; SD = 3.0) compared to the early-blind individuals (M = 12.9; SD = 3.1; $t[22] = 3.2$; $p < .005$). We also verified if the performance of the one non-congenitally blind participant modulated our results. Since this was not the case, this participant was included in all analyses.

Wine odor categorization

For the (a) *categorization* task, ANOVA with the sensitivity index d' as dependent variable revealed a main effect of *group* ($F[1,22] = 4.7$; $p < 0.05$; $\eta_p^2 = 0.18$) with sighted controls (2.2±0.8) being able to categorize wine odors better than early-blind individuals (1.3±1.2). See Figure 1. With the criterion C analysis as dependent variable, we do not observe an effect of *group* ($F[1,22] = 1.4$; $p > .05$; $\eta_p^2 = .06$).

Insert Figure 1 here

Wine odor differentiation

For the (b) *differentiation* task, the ANOVA yielded no significant *group* effects, neither for d' ($F[1,22] = 2.1$ $p > .05$; $\eta_p^2 = .09$) nor criterion C ($F[1,22] = 2.8$; $p > .05$; $\eta_p^2 = .12$) as dependent variables. See Figure 2. Sighted controls (2.4 ± 0.5) and early-blind individuals (1.9±1.2) had comparable results for *d*'. Mann-Whitney Test for *d'* which was also non-significant ($z = -.96$; $p > .05$).

Insert Figure 2 here

Wine odor classification

For the (c) *classification* task, the ANOVA with *d*' as dependent variable revealed a main effect of *category* ($F[2,44] = 31.6$; $p < .001$; $\eta_p^2 = .60$). Post-hoc t-tests (see Figure 3) revealed that for all participants, red wine odors were the easiest to classify (1.8 ± 1.0), followed by white wine odors (0.5 ± 0.6), and finally by rosé wine odors (–0.2 ± 0 .8; $p < .001$ and $p < .01$ respectively; corrected comparisons). Importantly, there was no main effect of *blindness* ($F[1,22] = .15$; $p > .05$; $\eta_p^2 = .01$) nor an interaction between the two factors ($F[2,44] = .16$; $p > .05$; $\eta_p^2 = .01$). The ANOVA with *C* as dependent variable revealed a main effect of *category* ($F[2,44] = 11.9$; $p < .001$; $\eta_p^2 = .35$), yet there was no main effect of *blindness* ($F[1,22] = .04$; $p > .05$; $\eta_p^2 = .00$) nor an interaction between the two factors ($F[2,44] = .89$; $p > .05$; $\eta_p^2 = .04$). Post-hoc t-tests revealed that participants were more conservative when classifying a rosé wine compared to when classifying a white and red wine [for all participants, rosé (0.5 ± 0.2) > white (0.3 ± 0.3; $p < .05$, corrected) and rosé > red (0.2 ± 0.1; $p < .001$, corrected), See Figure 3].

Although response times were slightly longer in blind individuals than in sighted participants, the ANOVA with *response times* as dependent variable yielded no significant main effect of *category* ($F[2,44] = 1.24$; $p > .05$; $\eta_p^2 = .06$), *blindness* ($F[1,22] = 2.80$; $p > .05$; $\eta_p^2 = .12$) nor an interaction between the two factors ($F[2,44] = .02$; $p > .05$; $\eta_p^2 = .00$).

Insert Figure 3 here

Odor identification

For the (d) general odor identification task, the ANOVA revealed a main effect of *odor identification* ($F[1,21] = 147.40$; $p < .001$; $\eta_p^2 = .88$) with higher scores in the forced-choice condition (13.0 ± 1.6; blind: 13.1± 1.6; sighted 12.9 ± 1.6) compared to the free condition (6.0 ± 2.9; blind 6.7 ± 2.7; sighted: 5.4 ± 2.8), a result suggesting that it was easier to identify odors when a multiple choice was presented to the participants (See Figure 4). There was no main effect of *blindness* ($F[1,21] = .7$; $p > .05$; $\eta_p^2 = .04$) nor an interaction between *blindness* and *identification task* ($F[1,21] = 1.1$; $p > .05$; $\eta_p^2 = .05$).

Insert Figure 4 here

Wine odor description

Our exploratory analysis of wine odor description yielded no significant differences between sighted and early-blind for neither of the variables (all analyses: $F<2.0$; $p > .05$; $\eta_p^2<.08$).

Discussion

The goal of the present study was to evaluate whether early-blind individuals present different olfactory abilities while undergoing a more complex and ecological task such as a wine odor assessment. We observed that early-blind individuals had a harder time to determine whether two simultaneously presented wine odors belonged to the same category or not (red, white, or rosé; odor categorization). However, early-blind participants were as good as sighted individuals to (1.) differentiate between wine odors, (2.) to classify wine as red, white, or rosé, and (3.) to identify odors. Therefore, we did not find any olfactory superiority in early-blind subjects, but rather lower performance in one specific task, for which participants have an important comparison of pure sensory input to make.

The main finding of the present study is that, compared to controls, early-blind individuals were less able to determine if two wines odors belonged to the same category or not (both red, white, or rosé wines), but other olfactory measures appear to be unaffected. This finding provides some support for the hypothesis that the lack of visual input in blind individuals penalised them in learning and constructing internal categories such as red, white, and rosé wines and their respective odors. One could have expected that early-blind participants would perform better either due to potentially heightened olfactory abilities (e.g., (Renier et al., 2013)) and/or due to increased verbal memory (e.g., (Amedi et al., 2003)). However, our current results seem to provide support for a stronger association between visual-olfactory processing compared to verbal-olfactory processing, at least for wine odors assessment. Additionally, increased mental imagery abilities could be positively linked with olfactory task performance (i.e., increased accuracy in odor detection when visualizing the tested odor; Djordjevic et al., 2004). Similarly, we can expect that the capacity to imagine the odor of a glass of red wine will aid its accurate odor categorization. Although few studies have supported the notion that early-blind individuals also exhibit mental imagery in other modalities (e.g., mental imagery of shapes, De Volder et al., 2001) and visual-spatial imagery (Vanlierde et al., 2003), it remains unknown whether early-blind individuals can exhibit olfactory-related mental imagery, i.e., creating a visual mental representation when smelling an odor. Consequently, it is possible that a lack of olfactory mental imagery in early-blind individuals explains our current results. A similar mechanism should be at play in the classification task; however, we did not observe a corresponding effect of blindness on the performance in this particular task. One may argue that the classification task was more challenging than the categorization task and this would diminish any differences. Nevertheless, blind individuals took more time to classify wine odors in red, white, and rosé, a pattern which could indicate that they struggled more with the task than did the sighted group. This result was not significant, but it is possible that with a larger sample size, blind individuals would have shown worse performance in the classification task as well. Therefore, to further our understanding of the mechanisms at play, it will be interesting to compare early-blind and late-blind individuals on similar tasks in future studies and evaluate whether the previous experience with mental imagery will increase the performance in the latter group.

Although early-blind individuals had a harder time to determine if two wine odors belonged to the same category, their ability to discriminate wine odors (i.e., to evaluate whether two wine odors stem from the same or from different wines) was no different from sighted controls. These results are in line with previous research in which blind individuals did not outperform sighted controls on odor discrimination tasks (Cuevas et al., 2010; Beaulieu-Lefebvre et al., 2011; Sorokowska et al., 2018), even when the tasks are more complex, as in the present study.

We also did not find any significant group differences with regards to free odor identification, despite a small advantage for the early-blind individuals, in line with Sorokowska (2018). We also examined whether early-blind individuals were better at generating odor descriptors (Burton et al., 2002), which may explain better free odor identification performance reported in some studies. However, we did not observe any group difference in terms of number of descriptors, whether the analyses concerned the actually presented wine category (i.e., presentation of a red wine) or the perceived wine odor category (i.e., perceived a white wine when in fact it was red). Therefore, we can speculate that the heightened free odor identification found in the literature in the early-blind population could be due to heightened attention (Collignon et al., 2006) or verbal memory (Roder et al., 2001; Amedi et al., 2003).

Finally, our results also show that all participants (blind and sighted) were more sensitive to correctly classifying the odors of red wines, followed by the odors of white wine and finally those of rosé wine. This is in line with previous work (Ballester et al., 2009), and that white wine odors were easier to categorize compared to rosé wine odors. The use of different wines could explain this difference (i.e., our rosé and white wine categories could have been more distinguishable odors compared to the white and rosé wines used in Ballester et al. (2009).

As previously mentioned, one of the possible limitations of the present study is its small sample size. Although this could have dampened our results, we prioritized highly controlled inclusion criteria. Namely, not only we recruited solely early-blind individuals who are very rare, but they also had to drink wine frequently enough without having a history of alcohol abuse or any olfactory abnormalities. Additionally, we took great precaution to closely match our groups regarding age, gender, and wine consumption. Another limitation may be that two of the tasks were not completely independent: the *differentiation* task depended on the outcome of the *categorization* task, since a participant saying two wines are not from the same category will not need to say whether these wines are the same or not, because not being from the same category automatically implies they are different. This might have influenced the results of the second task as, for example, a false negative in the first task (i.e., saying the wines are not from the same categories when they are) will lead to a false negative in the second task if the wines are actually the same. A closer look at the data shows that there is indeed a correlation between the numbers of false negatives in the first and second tasks (Spearman's, p=0.006). However, there is no correlation between the global sensitivity scores in both tasks, suggesting that the bias is slim and did not affect the overall results.

To sum, the goal of the present study was to evaluate whether early-blind individuals present different olfactory abilities compared to sighted matched controls while undergoing various complex and ecological tasks by means of wine odor discrimination. We found that early-blind individuals had a harder time to determine whether two simultaneously presented wine odors belonged to the same category or not (wine odor categorization in red, white, or rosé). The reason for this, however, does not appear to be due to differences in olfactory abilities between sighted and blind, but rather in different construction of internal reference categories. The present study is one of its first to explore olfactory discrimination in early-blind individuals using complex and ecological tasks.

Figure Legends

Figure 1. (Single column fitting image). Signal detection theory scores (*d*' and criterion *C*) for wine odor categorization task. Each dot represents one participant. Black line: median, Box: upper and lower quartiles; Whiskers: extreme values; Outliers: more than 1.5 times the interquartile range from the box. $*p < 0.05$.

Figure 2. (Single column fitting image). Signal detection theory scores (*d*' and criterion *C*) for wine odor differentiation. Each dot represents one participant. Black line: median, Box: upper and lower quartiles; Whiskers: extreme values.

Figure 3. (1.5 column fitting image) Signal detection theory scores for wine odor classification. *d*' and criterion *C* scores for each type of wine are shown. Each dot represents one participant. Black line: median, Box: upper and lower quartiles; Whiskers: extreme values; Outliers: more than 1.5 times the interquartile range from the box.

Figure 4. (Single column fitting image). Scores for odor identification under the free and cued conditions. Each dot represents one participant. Black line: median, Box: upper and lower quartiles; Whiskers: extreme values; Outliers: more than 1.5 times the interquartile range from the box.

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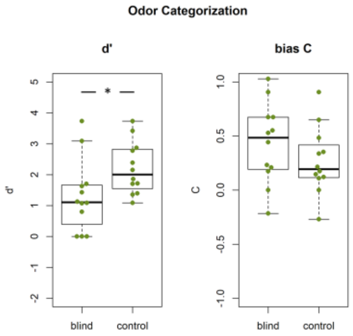
Type	Name	Year	Odor categorization and differentiation	Odor classification
Red	Beaujolais Albert Bichot	2010,2011		X
Red	Beaujolais Collin-Bourisset	2010,2011		X
Red	Belleruche Côtes du Rhône	2010,2012	X	X
Red	Château Cap de Merle Lussac-Saint-Emilion	2010	X	X
Red	Château de Fesles vieilles vignes Anjou	2011,2012		X
White	Calvet Edition Limitée Sauvignon blanc Bordeaux	2011,2012		X
White	Guigal Côtes du Rhône	2011	X	X
White	Pinot gris Pfaffenheim Alsace	2011,2012		X
White	Château Bonnet Sauvignonblanc/Sémillon /Muscadelle Entre-Deux-Mers	2011,2012	X	X
White	Chardonnay/Sauvignon C'est la Vie vin de pays d'Oc	2011		X
Rosé	Domaine de Gournier vin de pays de Cévennes	2011,2012		X
Rosé	Mouton Cadet Bordeaux	2011,2012		X
Rosé	Château Bellevue La Forêt Fronton	2011,2012		X
Rosé	Vieux Château d'Astros Côtes de Provence	2011,2012	X	X
Rosé	Nages Costières de Nîmes	2011,2012	X	X

Table 1. (Double column fitting table) Wine used for the categorization, differentiation, and classification tasks.


Odor Categorization
d'
bias C
*
d'
C
5
4
3
2
1
0
-1
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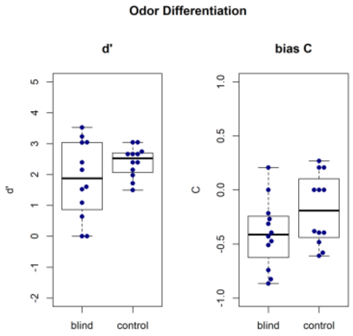
1.0
0.5
0.0
-0.5
-1.0
blind
control
blind
control


Odor Differentiation
d'
bias C
d'
C
5
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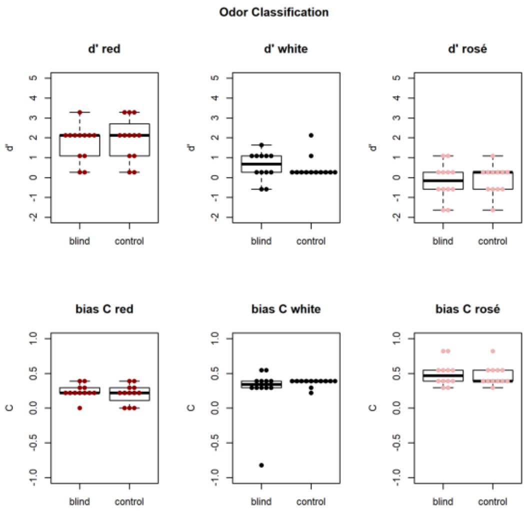
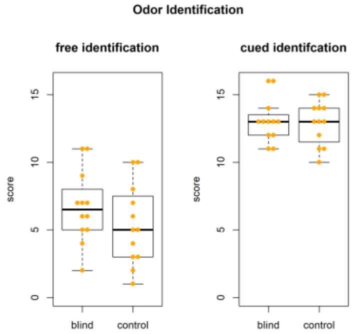
-2
1.0
0.5
0.0
-0.5
-1.0
blind
control
blind
control


Odor Classification
d' red
d' white
d' rosé
d'
-2
-1
0
1
2
3
4
5
bias C red
bias C white
bias C rosé
C
-1.0
-0.5
0.0
0.5
1.0
blind
control


Odor Identification
free identification
cued identifcation
score
0
5
10
15
blind
control

Highlights

- Early-blind individuals had more difficulty to categorize wine odors
- Early-blind individuals do not seem to have higher olfactory sensitivity
- Red wines were easier to classify followed by white and then rosé wines.