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Short Communication

The smell of *terroir*! Olfactory discrimination between wines of different grape variety and different *terroir*

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ABSTRACT

The French term '*terroir*' refers to the relationship between a particular wine and the specific place where it is produced. To date, no investigation has directly tested in an experimentally-controlled setting whether participants can detect different *terroir*s in wines, and if their level of expertise can modulate such performance. We investigated wine olfactory discrimination ability by using a computer-controlled olfactometer. Participants' ability to discriminate two wines only based on the olfactory features of their *terroir* (zone and vineyard), their variety (e.g., cabernet vs. merlot) or both was tested. Olfactory discrimination performance of both novices and wine-professionals reflected whether two wines differed by *terroir*, variety or both. Performance peaked when wines differed in both *terroir* and variety, with *terroir* being more easily discriminated than variety. These results, obtained by controlling for the first time the precision of the olfactory stimulation, provide insightful clues in understanding the wine appreciation process, specifically with respect to the perceptual aspects of *terroir*.

1. Introduction

Soil, an element of paramount importance in agriculture, is derived by a close relationship between abiotic and biotic factors represented by a large and diverse multitude of living organisms (Paoletti, 2012; Paoletti, Thomson, & Hoffmann, 2007). With respect to wine cultivation, the presence of organic matter and soil nutrients in a vineyard ensures plant growth and its yield at harvest, and soil characteristics are thought to affect the organoleptic properties of grapes produced in a specific location and, hence, of the resulting wine. In recent years, increasing attention has been given to the relationship between a wine and its specific production location, named with the French term '*terroir*' (from the word *terre*, meaning, *soil*). According to the most strict definition of *terroir*, similar grape varieties from different *terroir*s express significantly different characteristics (Frost et al., 2015). For example, many would say that the characteristic mineral flavour of wines from the French Chablis area results from the limestone beds beneath the vineyards. However, the direct link between geological materials in a vineyard and the correlated wine perceptual features has been recently undermined (Maltman, 2013). Although, the proposition that the natural conditions (i.e., physical and chemical properties of the soil) give unique characteristics to the wine of a clearly-defined geographical area is still under scrutiny. If true, the phenotypic plasticity present in environmentally-determined features should be manifest irrespective of the grapevine genotype.

Based on this contention, one should be able to perceive the 'signature' of the terroir in a wine upon sampling it. Yet, to date, a few reports suggest that the type of soil, its chemical composition, and the geographical exposure of the vineyards has no effect on the perceived quality of wines (Cross, Plantinga, & Stavins, 2011; Gergaud & Ginsburgh, 2001). These investigations on *terroir* have focused on global quality judgments of the wine, namely, whether consumers like the products of a given *terroir* based on multisensory information (e.g., visual, olfactory, taste). As yet no investigation has directly tested whether pairs of wines can be distinguished based only on their unimodal, olfactory terroir features. This is important since volatile components of wine are typically perceived prior to tasting and substantially contribute to the recognition of the taste qualities of wine (Parr, Heatherbell, & White, 2002).

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Whether such differences are detectable may be greatly modulated by the expertise of the sampler. Indeed, long-term experience and practice with wine-related stimuli produce significant perceptual learning in experts (Bende & Nordin, 1997). In general, wine-tasting expertise involves advanced discriminative and descriptive abilities for wine stimuli (Hughson & Boakes, 2002), as demonstrated by differences in performance between novice and expert tasters. With respect to olfactory skills, experts appear to generalize perceptual learning to the discrimination but not to the identification of odors (Bende & Nordin, 1997). Moreover, experts outperform novices in selecting the odd sample among three wines (triangle tests: Solomon, 1990) and they are reported to have better recognition memory for wine-related odors (Parr et al., 2002, 2004). Interestingly, this research suggested that experts show better odor recognition ability even though bias measures (i.e., tendency to respond following a certain criterion) and olfactory sensitivity (i.e., olfactory detection threshold of the same odor presented in different concentrations, namely wine-relevant compounds like 1-butanol) are in line with the performance of novices (Parr, White, & Heatherbell, 2004). As evident from this brief review of the available literature, no study has focused yet on the ability to distinguish two wines by their odor. Altogether, these results suggest that wine expertise may be more grounded on cognitive, higher level skills rather than better perceptual, low level abilities (e.g., Parr et al., 2004). However, this conclusion is drawn from evaluating the performance of participants who were allowed to freely sample the stimuli (e.g., Ballester, Patris, Symoneaux, & Valentin, 2008), and thus there was no control for several factors (e.g., air-flow rate reaching the nose, sampling time).

In the present study, these concerns were addressed by investigating experts' and novices' ability to discriminate two wines, their terroirs and/or their variety via use of olfactory cues only. The design allowed us to extend the investigation of the perceptual aspects of wine experience in several innovative ways. First, this test provides a unimodal evaluation of wine percepts based solely on olfactory cues, the first cues used in the creation of a wine representation. Second, the stimulus is presented by means of a computer-controlled olfactometer, an apparatus that delivers a stream of medical air to a jar containing a wine stimulus, as to fill the nasal cavity with the volatile molecules of that wine, which will be then carried bi-rhinally, via two Teflon tubes to the nose of each participant (Lundström, Gordon, Alden, Boesveldt, and Albrecht, 2010). The benefits of using an olfactometer, among others, are the maintenance of constant odor concentration and consistent exposure-time across participants. These features allow for the evaluation of subtle olfactory differences across stimuli, such as those related to wine terroir and variety. Indeed, wines can differ in terroir, which we define as a precise geographical area with a unique combination of physical and chemical properties of the soil as well as human factors characterizing wine production (i.e., a given vineyard), wines can also differ in grape variety (such as cabernet or merlot), or both a vineyard or a grape variety. No investigation so far has addressed the distinct role of variety and *terroir* in discriminating two wines. It is possible that the olfactometer presentation of the wines limits the possible strategies available to sample each stimulus, which in turn may result in a lack of differentiation of experts and novices (see Parr et al., 2004).

1.1. Overview and hypotheses

In the present study, participants were orthonasally exposed to pairs of wine odors, delivered in sequence. Participants were asked to select whether the two smelled samples featured 'two different wines' or the 'same wine'. Participants were exposed to four different wine-pairs: (i) different grape variety from different *terroir* (d-V/d-T; e.g., one cabernet and one merlot from two different *terroir*s); (ii) different grape variety from the same *terroir* (d-V/s-T; e.g., one cabernet and one merlot from the same *terroir*); (iii) same grape variety from different *terroir*s (s-V/d-T; e.g., two cabernet from two different *terroir*s); (iv) same grape variety from the same *terroir* (s-V/s-T; i.e., twice the same wine). We consider the condition d-V/d-T as the standard and possibly simplest comparative condition, as it provides the most extreme difference between the two stimuli. We expected that, irrespectively of the level of expertise, discrimination performance on d-V/d-T pairs should be better than performance on d-V/s-T and s-V/d-T pairs. The comparison between d-V/d-T with the conditions d-V/s-T and s-V/d-T was expected to inform us on the conditional contribution of grape variety and *terroir* to accurate wine odor discrimination. If, for instance, *terroir* substantially contributes to the discrimination of two odors, then performance should not be at chance level in the condition where grape variety is the same but *terroir* is different (i.e., s-V/d-T). Parallel reasoning applies to grape variety.

Finally, reaction time (RT) was expected to negatively correlate with confidence, with a shorter RT expected when participants were the most confident. Moreover, differences in response speed were predicted based on whether the two wines differed in grape variety, in *terroir*, or in both features, with the latter condition supposedly being the easiest task. Thus, we tested whether RT performance on the three conditions differed systematically.

2. Methods

2.1. Participants

Thirty-two healthy volunteers participated in the experiment (17 females; $M_{age} = 35.63 \pm 7.3$ yrs.; $M_{education} = 15.5 \pm 2.7$ yrs.). The number of participants is in line with the extant literature in this field (e.g., Livermore & Laing, 1998; Plailly, d'Amato, Saoud, & Royet, 2006). Based on previously proposed criteria (e.g., Ballester et al., 2008; Bende & Nordin, 1997; Parr et al., 2004) such as being an 'established winemaker' or a 'person with extensive (>10 years) history of wine involvement', a 'sommelier', our sample was composed of twelve (7 females) wine-professionals and twenty (10 females) were novices (as defined in Parr et al., 2004). Wine-professionals ($M_{age} = 37.25 \pm 8$ yrs.; $M_{education} = 15.4 \pm 1.56$ yrs.) and novices ($M_{age} = 34.65 \pm 6.82$ yrs.; $M_{education} = 14.8 \pm 2.55$ yrs.) did not differ by age ($t(30) = 0.98$, $p = 0.34$) or education ($t(30) = 1.1$, $p = 0.27$). Novices reported to consume on any given occasion, on average, a similar number of glasses of wine ($M = 2.14 \pm 1.12$) compared to wine-professionals ($M = 2.00 \pm 0.90$), $t(30) = 0.38$, $p = 0.70$. However, over the course of a month, novices reported to drink less frequently ($M = 5.55 \pm 6.27$) than wine-professionals ($M = 15.00 \pm 11.13$; $t(15) = 2.69$, $p = 0.016$).

2.2. Stimulus material

The wines selected as experimental stimuli for the experiment were from the DOC areas of the Berici and Euganei hills (ITALY; vintage 2012–2013). Production of wine in these vineyards goes back to ancient times. The mosaic environment and the great value of these two 'islands' in the Veneto region, prompted the selection of 5 different vineyards, all within the DOC area (i.e., Denominazione di Origine Controllata meaning 'controlled designation of origin') and some using organic or biodynamic management (see Table 1).

Wines were preserved in the original, sealed bottles that were opened immeadiately before each experimental session. Consistent with the literature, a sample of 10 ml of each wine was pipetted in hermetically-closed containers (i.e., glass jars),

Table 1
The commercial wines used as stimuli in the olfactory discrimination task. Wines were selected from the wineries that took part in the VeneTerroir project.

Winery	Wine Region	Style of management of the winery	Grape Variety
Cristoferi	DOC Berici	Conventional	Merlot
Cristoferi	DOC Berici	Conventional	Cabernet
Del Maso	DOC Berici	Conventional	Tai Rosso
Il Pianzo	DOC Euganei	Conventional	Cabernet
Piovene	DOC Berici	Conventional	Tai Rosso
Soranzo	DOC Euganei	Bio-dynamic	Carmenere
Soranzo	DOC Euganei	Bio-dynamic	Merlot

connected to the olfactometer (Lundström et al., 2010). Throughout the task, the same wine was delivered through the same olfactory channel. After each experimental session, all wine samples used were discarded and the jars were washed with odor-free soap and air-dried before the subsequent session.

2.3. Procedure

Participants were tested individually in a single, 45 min-long session, in a well-ventilated room (ambient temperature: 20 ± 2 °C). The experiment was organized in three phases: a training phase, followed by the olfactory discrimination task and the completion of questionnaires including participants' demographic information.

2.4. Experimental tasks

2.4.1. Training phase

Participants underwent a short training phase. The experimenter presented each participant with 10 pairs (i.e., trials) of wines. Each wine in a pair was presented one after the other, to allow for the perceptual storage of the odor of the first wine to be compared with the second wine (Plailly, d'Amato, Saoud, & Royet, 2006). For each wine-pair, participants had to decide if the two odors corresponded to two different wines or to the same wine repeated twice.

2.4.2. Olfactory discrimination task

The task consisted in a series of 96 trials in which participants had to decide whether the two odors belonged to two different wines or by the same wine, presented twice. The odors were delivered by a computer-controlled olfactometer (Lundström et al., 2010), at a concentration of 3 L per minute (L/min; a constant flow of clean air was delivered at 1.5 L/m). The release of the odors was regulated by a computer and the whole experiment (including trial randomization) was managed and controlled by E-Prime software (Psychology Software Tools, Pittsburgh, PA). The sequence of events in each trial was as follows: first, a white screen appeared (4000 ms), then on the center of the screen a black-ink cross was shown (400 ms). Participants were instructed to start inhaling when the cross appeared. The first odor (delivered for 2000 ms) was followed by a blank screen (5000 ms). After this, a second cross appeared (400 ms) to warn the participants of the release of the second odor, which lasted 2000 ms. Clean air interleaved the presentation of the wine odors, to reduce the effect of somatosensory stimulation. After the delivery of the second odor the following question appeared on the screen: "Are the two odors the same or are they different?". Participants responded using a response box.

After the response, participants were asked to estimate their level of confidence in the response by answering to the question "How certain are you of your answer?". Subjective confidence was reported using a 5-point scale from 1 ('not at all confident') to 5 ('extremely confident'). At the end of each trial, an inter-trial interval of 4000 ms was included. The order of the two wines in each pair was decided randomly, such that each wine occurred as the first and as the second odor a comparable number of times.

Due to constraints on the wine varieties and *terroirs* available as well as the number of channels included in the olfactometer, the present within-subject design included 96 trials divided in the following wine-pair types: 30 s-V/s-T, 44 d-V/d-T, 8 d-V/s-T and 14 s-V/d-T trials. The disparity in trial number across conditions was statistically accounted for following the guidelines outlined by Stanislaw and Todorov (1999; see Section 2.5 – Data analyses).

2.4.3. Questionnaires

In order to determine their level of expertise, participants were requested to report their demographic information (e.g., age, gender, profession) as well as their drinking habits (e.g., frequency of drinking and average amount of alcohol consumed at any drinking occasion) and their life- and work-experience in wine production and appreciation.

2.5. Data analyses

Discriminability of wine-pairs was assessed via Signal Detection Theory (SDT; Green & Swets, 1966; Macmillan & Creelman, 1996). The present 'same/different' task is a two-alternative forced-choice task. Here, we calculated the sensitivity index and the response bias based on the combination of one of three wine-pair types (d-V/d-T, d-V/s-T, and s-V/d-T) and a subset of 10 s-V/s-T trials (i.e., trials where the odor of the same wine was presented twice). The three subsets of 10 s-V/s-T trials were created randomly with the only restriction that in each subset a comparable proportion of each given trial (e.g., twice the odor of the Merlot from Winery Cristoferi) was present in each subset. In this paradigm, 'hits' were the trials in which participants correctly identified that the two odors were different wines; 'false alarms' included the erroneous 'different' response to a same pair; 'omissions' were the response 'same' to different pairs; and 'correct rejections' were the correct discrimination of same wine pairs as 'same'. To accommodate hit and false alarm proportion values of 0 and 1, was selected as measure of discriminative ability the index A' (Pollack & Norman, 1964; Stanislaw & Todorov, 1999), whose values range from 0 to 1. Typically, meaningful values are included between 0.5 (i.e., sensitivity at chance level) and 1 (perfect discrimination between signal and noise). Values below 0.5 may represent sampling error. The computation of A' was based on the formula proposed by Stanislaw and Todorov (1999, p. 142, formula [2]).

As response bias measure, we adopted Grier's B'' (Grier, 1971), calculated following the formula reported in Stanislaw and Todorov (1999, p. 142, formula [8]). The B'' measure ranges from -1 (liberal bias, here extreme bias in favor of the response 'different') to 1 (conservative bias, here extreme bias in favor of the response 'same'). A value of 0 represents no response bias (Grier, 1971).

The RT and accuracy for each discrimination were collected as well as participants' level of confidence in their response by answering the question "How certain are you of your answer?". Confidence rating was reported using a 5-point scale from 1 ('not at all confident') to 5 ('extremely confident').

Data from A' and B'' as well as RTs and confidence ratings were analyzed via Linear Mixed Models (LMM), with the variable *subject* as a random factor, and group (novices, wine-professionals) and wine variety and terroir as fixed factors. Variables were normalized to avoid scaling issues. One-sample t-tests were used to determine whether A' and B'' were different from chance (0.5 and 0, respectively). For post hoc analyses, we used Tukey HSD. The significance level was set for all tests at alpha <0.05 and all tests were conducted as two-tailed.

3. Results

The training session was used to familiarize participants with the discrimination task and, thus, is not further discussed. We hereby report the results of the olfactory discrimination task testing for the effect of the different wine-pair types and group as well as the effect of the accuracy of the response and the confidence expressed by each participant in her discrimination performance on the response speed.

3.1. Discrimination sensitivity (A')

We first compared the discrimination sensitivity expressed by A' against chance level (i.e., 0.5) separately for wine-pair types and groups by means of t-tests. As shown in Fig. 1, both Novices and Wine-professionals showed a significant ability to discriminate d-V/d-T wine pairs (respectively, $M = 0.70$, $t(19) = 16.00$, $p < 0.001$; $M = 0.70$, $t(11) = 12.45$, $p < 0.001$) and s-V/d-T wine pairs (respectively, $M = 0.55$, $t(19) = 2.52$, $p = 0.02$; $M = 0.58$, $t(11) = 2.46$, $p = 0.03$). On the other hand, while wine-professionals showed no significant ability in discriminating d-V/s-T pairs ($M = 0.51$, $t(11) = 0.17$, $p = 0.87$), novices showed a discriminant ability significantly below chance levels ($M = 0.46$, $t(19) = -2.17$, $p = 0.04$). Notably, values below chance levels in this specific task may reflect sampling errors (Stanislaw & Todorov, 1999).

As evident from the LMM using A' as dependent variable, the wine-pair d-V/s-T and s-V/d-T showed a significant decrease in A' as compared to d-V/d-T (d-V/s-T: $\beta = -0.47$, $p < 0.001$, 95% CI [−0.54, −0.39]; s-V/d-T: $\beta = -0.30$, $p < 0.001$, 95% CI [−0.38, −0.22]). Moreover, there was a significant increase of the A' of s-V/d-T when compared to the A' of d-V/s-T ($\beta = 0.17$, $p < 0.001$, 95% CI [0.10, 0.32]). No *group* effects were retrieved alone ($\beta = 0.01$, $p = 0.85$, 95% CI [−0.10, 0.12]) and in interaction with *wine-pair types* (d-V/s-T*group: $\beta = 0.08$, $p = 0.23$, 95% CI [−0.04, 0.20]; s-V/d-T*group: $\beta = 0.05$, $p = 0.45$, 95% CI [−0.08, 0.17]).

3.2. Response bias (B'')

We first compared response bias B'' against zero (indicating no bias) separately by group using t-tests. Both novices and wine-professionals showed a significant bias toward the response 'different' (respectively, $M = -0.65$, $t(19) = -24.63$, $p < 0.001$; $M = -0.64$, $t(11) = -18.19$, $p < 0.001$). The LMM approach also revealed that B'' was comparable across groups ($\beta = 0.02$, $p = 0.80$, 95% *CI* [−0.16, 0.21]).

3.3. Reaction times

A LMM using RTs as dependent variable and wine variety, *terroirs*, group, response accuracy, and confidence rating as factors revealed that response accuracy and confidence were the sole significant predictors of the RTs. Indeed, accurate responses were given faster ($\beta = -0.01$, $p = 0.003$, 95% CI [−0.02, 0]). Similarly, confidence rating linearly decreased RTs at every increment in confidence ($\beta = -0.04$, $p < 0.001$, 95% *CI* [−0.05, −0.04]).

4. Discussion

The aim of the present study was threefold: *first*, we aimed to investigate the ability to discriminate two wines presented uni-modally, via olfactory cues. To reach this goal, we introduced a novel approach to wine research implementing an olfactometer to fully control odor delivery (Lundström et al., 2010). *Second*, we aimed to test whether odor discrimination ability differed between novices and wine-professionals (Parr et al., 2004; Solomon, 1990). *Finally*, we aimed at exploring whether odor discrimination accuracy and speed of response differed in conditions in which the two wine differed in grape variety, in *terroir*, or in both features.

First, in this controlled experiment participants showed significantly above-chance ability to discriminate two wines solely based on olfactory cues. These results clearly support the notion that we can detect subtle olfactory differences between two wines, even when uni-modally presented. The present experiment used wines as stimuli and did not require participants to detect wine-relevant compounds or to discriminate wines based on specific odor features, like sweetness as done by others (e.g., Parr et al., 2004). Furthermore, the present test limited the use of differential sampling strategies, controlling, for instance, the concentration consistency and the duration of the olfactory stimulation (Lundström et al., 2010).

The *second* important result was that, irrespective of expertise, novices and wine-professionals did not show any significant difference in their odor discrimination ability, neither in accuracy nor in response speed. Thus, novices and wine-professionals seem to have similar basic sensory ability to discriminate the presence of olfactory differences, as previously suggested (Bende & Nordin,

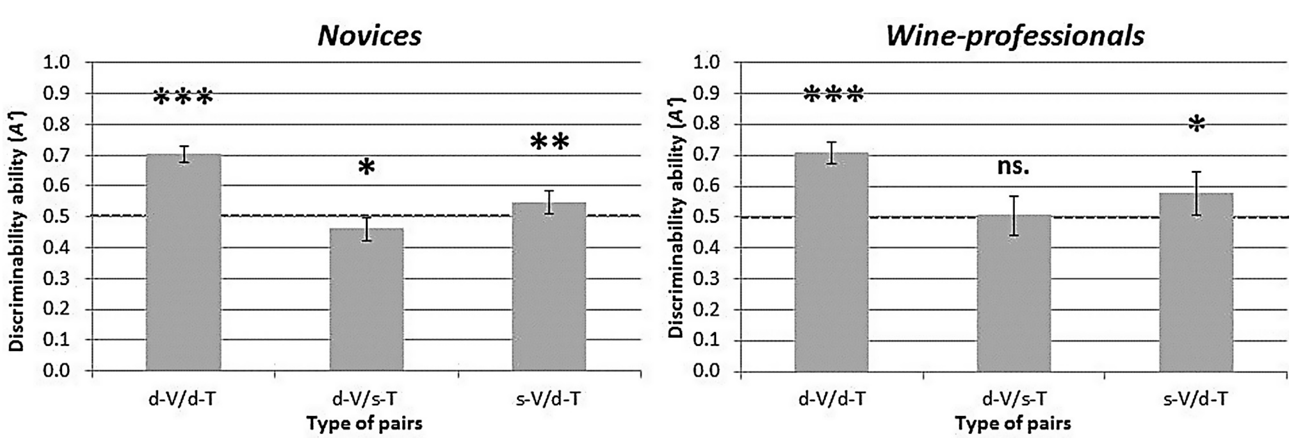

Fig. 1. Left panel shows results for novices, right panel shows results for wine-professionals. Discriminant ability (expressed in A′) by different types of wine-pairs (error bars express 95% confidence intervals of means). Means significantly different from chance level 0.5 (indicated by the dashed line) are marked: ***p < 0.001, **p < 0.02, *p < 0.05. Trial type: d-V/d-T (different grape variety from different terroir), d-V/s-T (different grape variety from same terroir), s-V/d-T (same grape variety from different terroir).

1997; Parr et al., 2004; Tempere et al., 2011). The present results are, however, in contrast with previous research reporting expertise advantage, in triangle testing (Solomon, 1990), odor discrimination (Bende & Nordin, 1997) and recognition memory for wine-related odors (Parr et al., 2002, 2004).

One may wonder whether the 12 wine professionals and 20 novices in our sample constitute a sufficient sample to allow differences emerge. We believe that this is the case. The exisiting literature uses comparable samples (e.g., Parr et al., 2002, 2004) and Solomon (1990) reported expertise advantages with only 8 participants (4 experts and 4 novices). Of course, olfactory discrimination ability shows high inter-individual variability (Bushdid, Magnasco, Vosshall, & Keller, 2014) that may have decreased the possibility to find a difference between groups reported using other dependent variables (e.g., Ballester et al., 2008; Urdapilleta, Parr, Dacremont, & Green, 2011).

Differing results between the current study and previous work may be accounted for by procedural differences. For instance, Parr and colleagues (2004), took threshold detection of increasing wine-relevant compounds and odorants concentration (e.g., 1-butanol) as an index of odor-identification abilities (Parr et al., 2004). We used instead the ability to distinguish two wines exclusively from their odor as an index of basic perceptual abilities. A similar approach to ours was used by Solomon (1990), who implemented a triangle task in which participants were presented with three glasses of wine, two of which contained the same wine from the same bottle. Participants had to pick the odd wine but were free to smell the wines as long and repeatedly to their satisfaction. This latter feature may explain the results reported by Solomon (1990). Indeed, allowing free odor sampling makes the task closer to standard wine appreciation settings rather than to basic ability testing settings. Wine experts are reported to implement sophisticated sampling strategies (e.g., sniffing longer/more intensively and repeatedly compare odors on separate aspects; cf. Hughson & Boakes, 2002). Unlike previous research (e.g., Ballester et al., 2008), the procedure here may have prevented wine-professionals and novices from implementing different wine-sampling strategies allowing for a more stringent test on basic discriminant abilities. When it comes to long-term experience and practice with wine-related stimuli, the lack of significant difference between our groups under standardized stimulus presentation does not support the perceptual learning in experts' hypothesis proposed by Bende and Nordin (1997) at least with respect to uni-modal sensory ability. This set of results in odor discrimination accuracy is also mirrored when considering the speed of response. Despite participants of both groups responding faster when the discrimination was accurate and when they felt the most confident about their judgement, no significant differences between groups emerged.

One aspect that could consistently differentiate experts from novices may be in regard to top-down processing, involving knowledge about wine that allows focusing on individual features which best differentiate wines (Ballester et al., 2008). In other domains expertise is also defined by the use of underlying principles to face domain-specific problems, rather than surface features as for novices (cfr. Hughson & Boakes, 2002). The possible source of expertise-advantage was limited in this experiment.

Additionally, wine-professionals may have not been able to capitalize on their greater skills in integrating information from multiple senses (see also Parr et al., 2002), emerging when the ability to perceive, judge, and appreciate wine is put in a complex multisensory integrative ability. These hypotheses are beyond the scope of the present experiment but they may suggest fruitful directions for future research.

The *third* and probably most interesting result relates to the difference in discriminant ability between wine-pair types. Participants overall showed that they can discriminate between two wines that differ in variety and *terroir* (d-V/d-T) and their performance in this condition is better than the condition in which the two wines differ only on variety (d-V/s-T) or only on *terroir* (s-V/d-T). Both novices and wine-professionals can, however, discriminate significantly above chance level also when two wines are of the same variety but from different *terroir*s. Results showed that panelists can '*smell the terroir*'. While previous experiments on *terroir* have focused on global quality judgments of the wine based on multisensory information (e.g., Cross et al., 2011; Gergaud & Ginsburgh, 2001), to our knowledge, this is the first investigation that directly tested whether differences between two *terroirs* (e.g., two Cabernet wines from different *terroirs*) can be detected solely on the base of uni-sensory information.

Furthermore, panelists better discriminated *terroir* than wine variety. The fact that performance is not significantly better than chance when two wines are different in variety is particularly striking and it was unexpected. At least for wine-professionals, wines of the same variety are described as more similar than wines from different varieties suggesting that variety is an important dimension (Solomon, 1997). In this condition (d-V/s-T) wine-professionals' performance was at chance level and novices showed performance reflecting possibly sampling error (Stanislaw & Todorov, 1999). For this reason, one possible explanation for this lack of discriminant ability for d-V/s-T pairs could be related to the limited number of available trials in this condition (i.e., 8 trials). This limited number was due to the difficulty in obtaining wines of different variety from the same *terroir* as operationalized in the present paper (geographic location and vineyard). Future research should investigate this possibility including a larger set of pairs to allow a more powerful comparison across conditions.

The results on the bias measure (B'') are interesting in their own right, as bias measures are independent from sensitivity measures (e.g., Macmillan & Creelman, 1990, 1996). Both novices and wine-professionals show a liberal bias that is a bias in responding that the pairs are constituted by different samples. Again no significant differences are reported between groups. It seems as if the participants, knowing that discriminating a set of complex olfactory stimuli is a rather difficult task, were tuned to detect a difference, which resulted in the liberal bias that emerged. This approach would be in line with Morin-Audebrand and colleagues' theorization (Morin-Audebrand et al., 2012) on the functioning of food memory – including olfactory cues. They suggested, that food memory is predominately based on the detection of novelty and change rather than on the holistic recognition of previously encountered items.

Taken together, we have experimentally tested for the first time the influence of *terroir* on uni-modal sensory features of wines and showed human ability to pick-up subtle olfactory signatures. This work opens to a variety of possible research directions including, but not limited to, multisensory (e.g., gustatory-olfactory, visual-olfactory) controlled experiments. Moreover, future research should consider different types of experts. In the present study, we collected standard information related to the panelist, and wine-professionals were defined based on criteria previously suggested in the literature. However, distinct categories (e.g., winemakers vs. sommeliers) could be further compared as they have been reported to show differential ability in detecting specific olfactory compounds (Tempere et al., 2011). It is possible, that certain specific olfactory compounds are reflected more strongly *terroir*-related features and, thus, the difference in detection ability for these compounds is what results in the ability to discriminate different *terroir*s.

The present research provides an important contribution to the global investigation aimed at integrating multiple views, that is merging the ecological standpoint of sustainable agriculture with the high value of the wine product, both from an economical and cultural heritage viewpoint. Notably, the biological activity on soils run by bacteria, fungi, and their drivers – such as endemic anecic earthworms – will greatly influence *terroir*s together with the strains of Saccaromyces circulated by wasps and possibly by other insects (Bokulich, Thorngate, Richardson, & Mills, 2014; Paoletti et al., 2016; Stefanini et al., 2012).

The objective biological markers of *terroir* should be implemented and correlated with our ability to detect, discriminate, and appreciate them in order to value the possible contribution of different *terroirs* to the quality of wine from both expert's and final consumer's point of view.

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