RUNNING HEAD: PERCEPTUAL LEARNING IN THE CHEMICAL SENSES

Wine expertise:

Perceptual learning in the chemical senses

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ABSTRACT

Researchers have long been interested in the kinds of perceptual learning that take place in those who acquire wine expertise. However, progress in this field has been hampered by differing accounts of what, exactly, counts as expertise, not to mention the exact nature of any learning taking place. That said, the majority of studies published to date have tended to document more pronounced changes in conceptual knowledge structures than in terms of enhanced smell or taste sensitivity *per se*. Converging neuroimaging research from studies where experts and non-experts taste/evaluate wine in the brain scanner has also highlighted changes in neural activation in those brain areas consistent with enhanced conceptual/synthetic analysis in wine experts. Given the impressive effects that have been demonstrated elsewhere in the literature on perceptual learning, several reasons as to why similar effects have typically not been widely observed in the case of wine expertise are briefly discussed: Relevant factors here likely include everything from the distinctly sub-optimal environment for sensory analysis in the brain scanner, through to the mismatch between the kinds of tasks/training typically involved in the acquisition of wine expertise, and the type of perceptual threshold testing normally used to assess the consequences of perceptual learning.

KEYWORDS: EXPERTISE; PERCEPTUAL LEARNING; CONCEPTUAL KNOWLEDGE; WINE.

1. Introduction

For the last 75 years or so, researchers have been interested in the question of what, if anything, differentiates the performance of wine experts from non-experts (otherwise referred to as social drinkers; see Gibson & Gibson, 1955, for early discussion). In the years since, a steady stream of empirical research by sensory scientists and experimental psychologists has attempted both to probe and to categorise/quantify the precise nature of any differences between wine experts and social wine drinkers (e.g., Ballester et al., 2008; Chollet & Valentin, 2000; Hughson, 2003). However, somewhat surprisingly, differences at the sensory/perceptual level have been limited (e.g., see Parr et al., 2002; Tempere et al., 2011). By contrast, differences at the level of conceptual wine knowledge have tended to be much more readily apparent (e.g., Hughson & Boakes, 2001; Parr, 2018; Solomon, 1997).

At one level, the empirical research can be seen as hanging together quite well in terms of placing the benefits of wine training/expertise more at the conceptual/semantic, rather than at the sensory/perceptual, end of the spectrum. That said, the lack of sensory effects does start to look a little more surprising when contrasted with the rather more impressive perceptual enhancement effects that have been documented elsewhere in the literature on perceptual learning (see Goldstone, 1998; Green et al., 2018, for reviews). Possible reasons for this difference in terms of the complex nature of wine itself, as well as the possibly sub-optimal nature of the training protocols used, etc., are highlighted (though see also Rabin, 1988). Indeed, as Parr et al. (2002) noted some years ago, the kinds of perceptual tests typically conducted to assess tasters' ability to detect threshold concentrations of wine-relevant compounds when presented in isolation is very different from the kind of experience the wine-taster is normally exposed to.

At the outset, though, one might ask why it is that we have chosen to focus primarily on the role of perceptual learning in the world of wine? The answer here is simply that there has been far more research than for any other food or beverage product (though, that said, one does find a few studies of beer/coffee experts; e.g., Chollet et al., 2005; Lelièvre et al., 2009; Peron & Allen, 1988; Valentin et al., 2007). This perhaps emphasizes both the interest in, not to mention the complexity of, wine as a perceptual stimulus (though see Spence & Wang, 2018, on the undoubtedly complex notion of complexity in the chemical senses, including specifically in the case of wine). However, it is the very complexity (and variability) of wine as a stimulus of study that may be part of the reason why there has been less evidence of perceptual learning (specifically, a lowering of sensory thresholds) in the chemical senses than in many other fields of study.

2. Effect of wine expertise

To begin with, it is perhaps worth laying out the different changes in sensory/perceptual ability that might be expected to accompany the development of wine expertise. According to Lawless (1984, p. 120), changes might be expected in a range of different measures/tasks, including: 1) An increased absolute sensitivity, that is, a decrease in the detection threshold for various wine-relevant compounds; 2) An increased ability to discriminate wine-relevant sensory stimuli in the suprathreshold range; this might either show up as an increased ability to discriminate between different qualities (e.g., lemon vs. lime) or different intensity levels (e.g., high vs. low alcohol). Here we might also add an increased categorization ability for wine-relevant stimuli; 3) An increased ability to attend to, or recognize, invariant characteristics of a complex stimulus in the face of a changing background; and 4) An enhanced ability to reliably apply verbal labels to different sensory attributes or characteristics. **Table 1** highlights the evidence that has been documented in support of such effects.

INSERT TABLE 1 ABOUT HERE

2.1 Changes in detection thresholds

Early research demonstrated surprisingly little evidence for changes in the sensory threshold for the detection of wine-(ir)relevant aromas in wine experts (e.g., see Berg et al., 1955). For instance, in standard olfactory threshold tests using 1-butanol, a non-wine-relevant odorant, several studies have documented that wine experts and non-experts have comparable detection thresholds (Bende & Nordin, 1997; Parr et al., 2002, 2004). However, that said, some modest perceptual effects of expertise have, on occasion, been documented in the literature. Bende and Nordin (1997), for example, reporting that professional wine tasters could detect the presence of lemon aroma in a base of clove aroma at a much lower concentration of the former than could their control participants in a two-alternative forced-choice (2AFC) task.

Tempere et al. (2011) measured threshold levels for 10 key odorant compounds in wine in 100-150 wine experts. However, only 2 of 10 odorant compounds showed a lowered threshold amongst the experts, namely diacetyl and a mixture of ethylphenols. These compounds are often detected while tasting wine in context: Diacetyl (which has a buttery smell) results from malolactic fermentation, which is used for some styles of white wine making (Woodhouse et al., 2016). Indeed, professional wine education, such as the Wine and Spirits Education Trust (WSET), focuses on the detection and description of wine-making aromas and flavours, such as diacetyl. Ethylphenols, by contrast, are produced by the spoilage yeast Brettanomyces, which can manifest as a wine fault in high concentrations (Woodhouse et al., 2016). Those with higher wine knowledge have been shown to be more sensitive to Brettanomyces (Schumaker et al., 2017).

Intriguingly, another wine fault, cork taint (2,4,6-trichloroanisole, or TCA), was also tested by Tempere et al. (2011), but experts did not exhibit a lower threshold. This may be due to the possibility that any differences in the ability to detect TCA is more a reflection of genetic differences as opposed to the results of training (Prescott, Norris, Kunst, & Kim, 2005).

2.2 Changes in discrimination ability

The classic test of discrimination abilities involves the triangle test, where participants are presented with a triplet of stimuli, two of which are the same, and are asked to identify the odd-one-out. Walk (1966) conducted one of the first discrimination tests with wine experts and novices. Despite the small sample size (consisting of only 4 experts and 4 novices), the results revealed that, out of 8 trials, only experts performed significantly better than chance (see also Owen & Machamer, 1979). More recently, an aroma-based triangle test with Sniffin' Sticks (Burghart, Messtechnik GmbH) was conducted on members of the Oxford University Blind Tasting team to measure any improvements in olfactory sensitivity with wine training (Wang et al., 2019). A training group (N=19) and a control group (N=13) were tested before and after a five-week blind wine tasting regime. Intriguingly, the preliminary results suggested a significant difference between the training and control groups as far as changes in olfactory discrimination are concerned ($M_{training} = 0.63$, $M_{control} = -1.25$, $p = .02$).

In one of the only true studies of perceptual learning conducted with wine, Walk (1966) trained groups of participants to discern whether two successive sips of white wine were the same or different. Participants (N=30) underwent 40 trials, with the first and 10 judgements used for pre- and post-test analysis. The results revealed that the participants made a small but significant improvement (9%) in the post-test compared to the pretest, after only 20 trials of training. Meanwhile, in a more elaborate training set-up, Wang and Prešern (2018) recently demonstrated that, with training, blind wine tasters (as in, tasting the wine without seeing the label) exhibited significant improvements in several areas of their performance. The participants in question were members of the Oxford University Blind Tasting Society who had attended 9-18 training sessions over a period of five-weeks. On the most basic perceptual level, these individuals became more accurate in terms of assessing the acidity of wines.

2.3 Mental representations and categorization

Contrary to what might have been expected (based on previous research; see Sauvageot & Chapon, 1983), Ballester, Abdi, Langlois, Peyron, and Valentin (2009) failed to demonstrate any difference between experts and novices as far as discriminating the odours of white, red, and rosé wines is concerned. The participants in the latter study were given a total of 18 wines to nose in dark tasting glasses and thereafter to sort into three categories. The results of several experiments demonstrated that while all of the participants correctly identified the red and the white wines, they <u>all</u> failed when it came to correctly categorize the rosé wines.

Elsewhere, Solomon (1997) demonstrated that wine experts tend to group wines by grape variety in a free-sorting task, whereas non-experts tend to group wines by their sensory characteristics, such as sweetness or fruitiness instead. Meanwhile, in Wang and Prešern's (2018) longitudinal study of training on blind wine-tasting, the participants were found to become significantly better at accurately guessing the grape variety, which can be seen as a higher form of perceptual learning in terms of categorisation (see Parr, 2018). Furthermore, wine experts have also been shown to categorise wines more efficiently based on ageing potential (Jaffré et al., 2009) and typicity (Cadot et al., 2010; Perrin & Pages, 2009).

These demonstrated advances in categorisation by experts suggest that experts form stable memory representations of wine categories. Potentially relevant here, then, Hughson and Boakes (2002) revealed that experts used chunk-based memorisation strategy when it came to recalling wine-related words, with better performance when the words were grouped to form possible descriptions of actual wines. The literature also supports enhanced recognition memory amongst wine experts (see Parr et al., 2002, 2004; Zucco et al., 2011), facilitating their performance on sequential same-different matching tasks.

2.4 Recognition of invariant attributes

Arvisenet et al. (2016) reported evidence suggesting that training/expertise modified the nature of taste-aromas interactions in model wines. In particular, wine experts and trained panellists were somewhat less influenced by the addition of sugar to model wines than were the non-experts, thus suggesting an enhanced ability to attend to the various sensory elements contributing to multisensory flavour experiences amongst the more experienced tasters. That said, wine experts are by no means immune to the influence of various product-extrinsic cues (such as background music) when evaluating wine. For instance, Wang and Spence (2017) conducted a crossover-design study at a winemaking conference, where a large group of professionals working in the wine business (N=154) were given a pair of white wines to taste while listening to two soundtracks reliably associated with sweet and sour tastes, respectively. The results revealed that sweetness and sourness ratings were significantly influenced by the soundtrack that happened to be playing in the background during wine tasting, regardless of the number of years of wine-tasting experience the participants' had.

2.5 Wine language/description

More apparent differences between wine experts and non-experts have been reported in terms of the consistency of their use of wine language, and the changes in their knowledge structures relevant to wine (Solomon, 1990; Valentin et al., 2003). And, as one might expect, experts tend to show more pertinent (Zucco et al., 2011), consensual (Croijmans & Majid, 2016), and specific (Chollet & Valentin, 2000; Sauvegeot et al., 2006) use of wine descriptors than do non-experts. Furthermore, enhanced semantic memory has also been reported in wine experts for wine-related words (Hughson & Boakes, 2002). Experts also show enhanced recognition memory for wine-relevant odours, although according to Parr et al. (2002, 2004), the source of the superior performance seems to be based more in perceptual than in semantic memory.[1]

Lawless (1984) demonstrated that a group of participants who were experienced in describing wine flavour used more terms when describing six unlabelled white wines than did another group without any such experience. Similarly, Wang and Prešern (2018) recently demonstrated that, on average, experienced wine tasters write significantly longer tasting notes (23%) than do novices. However, beyond just using more terms, experts have also been shown to be significantly better at matching descriptions to wines too (mean correct = 2.6 for 'experts' vs. 1.8 for 'nonexperts', out of 6, in Lawless, 1984). Meanwhile, various studies have also reported that experts outperformed novices when trying to match wines with their written descriptions (Hughson & Boakes, 2002, 2009; Solomon, 1990, 1991). Moreover, formally trained wine panellists performed better than untrained but experienced wine tasters in the same task (Gawel, 1997).

[1] Here, one might consider the possible role of verbal overshadowing of taste memory being more of a problem amongst the non-expert tasters (see Melcher & Schooler, 1996).

2.6 Changes in neural processing in wine experts

Over the last decade or so, the steadily-growing body of behavioural/psychophysical research has been complemented by the publication of a limited amount of neuroimaging research documenting differences in the patterns of brain activity when experts vs. non-expert drinkers evaluate wine (e.g., see Castriota-Scanderbeg et al., 2005; Pazart et al., 2014). The latter pair of studies highlighted changes (either an increase or a decrease) in neural activity in those parts of the brain that are associated with conceptual/synthetic information processing in the wine experts that can perhaps be considered in terms of neuroplasticity. Castriota-Scanderbeg and colleagues (2005), for instance, documented increased neural activity in the left insula and adjoining orbitofrontal cortex, as well as in the dorsolateral prefrontal cortex in 7 male wine experts (professional sommeliers with at least 5 years working experience) when the brain response to tasting wine (red, white, or dessert) was compared to odourless glucose solution. According to the cognitive neuroscientists, the latter part of the brain is involved in working memory (that is, in the short-term storage and manipulation of information). By contrast, 7 non-expert (naïve) male wine tasters showed greater activity in the primary gustatory cortex and amygdala, a part of the brain that is involved in more emotional information processing instead. In a follow-up study, this time focused on the effect of expertise during the different phases of wine-tasting (i.e., during vs. after tasting), Pazart et al. (2014) observed that wine experts activated those brain regions responsible for sensory integration during the wine tasting itself, whereas for the control participants they were only activated during the after-tasting phase. This result was taken to suggest that experts are able to analyse the sensory properties of wine more efficiently than untrained participants.

Of course, it should not be forgotten that the constraints of the brain-scanning environment meant that the participants in the aforementioned neuroimaging studies were forced to lie flat on their back with a tube (mounted in a dental mould to restrict movement of the mouth and jaw) periodically pumping tiny amounts of wine (2 ml) into their mouth. As such, a proper sensory evaluation of the wine, involving an assessment of visual appearance, aroma, flavour, structure, finish, etc., is simply not possible with current scanning protocols (see Spence, 2010, on this theme).[2] As such, one might well expect that the true extent of any sensory differences between wine experts and non-experts to be obscured in the context of the brain scanner.

3. The nature of wine expertise

3.1 What makes a wine expert?

It is worth noting first of all that there is no agreed upon definition of what exactly constitutes wine expertise across the various studies that have been conducted in the field. Certainly, borrowing from the prolific body of research on expertise (e.g., Ericsson et al., 1993, 2007), few of those categorized as wine experts would necessarily meet the criteria stipulating that experts are defined as those having a minimum of 7,000 hours of practice in a particular field of endeavour. That said, closer to the world of wine expertise, according to the ASTM standards, an expert can be defined as *"a person with extensive experience in a product category who performs perceptual evaluations to draw conclusions about the effects of variations in raw materials, processing, storage, aging, etc."* (see Chollet et al., 2005).

[2] This may also link to the discrepancy between the extensive sets of terms/descriptors that some wine experts appear able to generate on tasting a quality wine. This undoubtedly differs from the two or three terms than non-experts can generate when describing wine odours or unrelated mixtures of odorants. However, the likely explanation relates, at least in part, to the way in which the experts' wine evaluation occurs, namely over time/multiple exposures to the wine which has mostly tended not to be the case in much of the laboratory research (see Spence & Wang, 2018, cited in manuscript).

Indeed, practically-speaking, a quick scan of the literature on wine expertise reveals, at one end of the spectrum of definitions, a study by Hayes and Pickering (2012). The latter researchers simply handed out a questionnaire to 331 individuals, and somewhat arbitrarily split their respondents into two groups, one labelled 'wine experts' (N=111) and the other 'wine consumers' (N=220). Others, meanwhile, have been much more careful to test, and label as experts, only those with very high level expertise. One often-used metric defines wine expertise as fitting particular categories: *(a) established winemakers, (b) wine-science researchers and teaching staff, (c) wine professionals, (d) persons with extensive history of wine involvement, and graduate students in Viticulture and Oenology who had relevant professional experience* (see Ballester at al., 2008, Melcher & Schooler, 1996; Parr et al., 2002; Saenz-Navajas et al., 2013). To this list, one might add trained sensory panelists, trained as part of purely sensory wine evaluation (i.e., with no wine knowledge) which represents another form of expertise.

Note, however, that this wide definition emphasizes an important issue with the definition of wine expertise: that is, there many different kinds of experts. On the one hand, there are the viticulturalists and winemakers themselves; however, there are also the sommeliers, retailers, educators, and wine writers/critics. It would seem unlikely that these groups of experts would necessarily be expert in the same aspects of wine.[3] Nor would they necessarily be expected to have similar levels of familiarity with the wines in question (Sáenz-Navajas et al., 2013), and yet they are often grouped together in cross-sectional studies of expertise (e.g., see Parr et al., 2002).[4]

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[3] In terms of perceptual differences, Pickering et al. (2007) demonstrated lower detection thresholds for 2-isopropyl-3-methoxypyrazine in wine amongst winemakers (than in those having a different profession), presumably due to their familiarity with the associated wine defect.

[4] At the other end of the spectrum, there are also inconsistencies in terms of defining non-experts. Just take, for instance, the 11 participants classified as 'wine novices' in Parr et al.'s (2002, p. 749) study. This group turns out, on closer inspection, to be more like intermediate tasters, including *"those who drank wine regularly but had participated in little formal wine evaluation or winemaking at the time of the study. The novice group included wine and food students…"*, thus potentially minimizing any difference between groups.

3.2 Are wine experts born or bred?

Of course, even should any reliable/robust perceptual differences be detected between wine experts and non-experts in cross-sectional research that would not, in-and-of-itself necessarily demonstrate any role for perceptual learning in wine expertise. One would, of course, first need to rule out the possibility that those with superior tasting abilities did not self-select for a career in wine tasting. Consistent with the latter view, Hayes and Pickering (2012) reported that wine experts were more likely to be a medium taster or supertaster when assessed on PROP sensitivity than were non-experts. (An individual's PROP sensitivity status, note, being genetically determined.) PROP supertasters have been shown to give higher intensity ratings across a range of taste attributes. That said, it is worth noting that the researchers tested a convenience sample of 331 wine drinkers, who were divided into wine experts or consumers based on a questionnaire designed to assess their level of wine involvement. Clearly, such an approach does not guarantee finding any genuine experts at all; rather, it simply segregates those with somewhat more wine drinking experience than others with somewhat less (see also Hughson & Boakes, 2009). Nevertheless, should a stricter criterion for what constitutes wine expertise be used in future research, one might presumably expect to see an even more pronounced genetic differences in tasting ability between groups.

3.3 The multidimensional nature of wine expertise

According to Bell and Paton (2000), wine experts have developed various strategies that facilitate their detection and verbalization of wine (see also Brochet & Dubourdieu, 2001). On the basis of a study in which the preferences of experts and novices for red wines from different origins and grape varieties were assessed, Frøst and Noble (2002) argued that 'genuine' wine experts have acquired at least two skills, namely, a part of their skill is based on wine knowledge, and separately an enhanced ability to provide sensory descriptions relating to wine (see also Rabin, 1998). Furthermore, based on a study of novices, trainee, and professional sommeliers, Zucco et al (2011) hypothesised that the acquisition of expertise occurs at different rates, with perceptual aspects being rapidly acquired while semantic expertise takes longer time to develop.

3.4 On the transfer of expertise

Separate from the question of what benefits, be they perceptual or conceptual, accrue as a result of wine training/expertise, there is the question of the stimulus-specificity of the training-related benefits so acquired. Intriguingly, the majority of the evidence that has been reported to date suggests a certain stimulus-specificity. In particular, the benefits of training in the world of wine, say, or beer, do not necessarily appear to transfer to the other category (Croijmans & Majid, 2016). For instance, in one study, Chollet et al. (2005) trained beer assessors for two years before comparing their performance to novices on trained beers and novel set of beers. Surprisingly there was no transfer of perceptual learning in the discrimination task, and only a modest benefit reported for 'experts' in a matching task. Moreover, sometimes the failure to transfer has even been documented when assessing wines from different regions outside of one's expertise (see Schlich et al., 2015). Such observations are, though, neutral with respect to the nature of any benefits that accrue from training (e.g., as to whether they are conceptual or sensory in nature; see Hughson & Boakes, 2001).

4. Enhancing perceptual learning in the world of wine

While research in the field of perceptual learning rather fell out of fashion in the decades since Gibson and Gibson's (1955) work, the last few years/decades have witnessed an explosive resurgence of interest in the field. However, that interest has primarily been focused on the higher spatial senses (see Goldstone, 1998; Green et al., 2018, for reviews). Much of the interest in perceptual learning has been driven by the sometimes profound threshold changes (specifically improvements) that have been documented in terms of people's ability to perceive visual, auditory, and tactile stimuli. However, at the same time, research on perceptual learning in the spatial senses, has also highlighted the need for training situations that are not too complex. Relevant here, Dosher and Lu (2017) summarized the key factors in visual perceptual learning as follows: *"We now know that the relative specificity versus transfer of training can depend on several factors, including the processing level of the trained task, the task difficulty, precision of the transfer task, the extent of training, the state of adaptation induced by training, and the exact training and transfer procedure. More demanding tasks tend to produce more specificity."* [in-text citations removed]. Indeed, the main feature of the literature on perceptual learning that is relevant for wine tasting is likely attention (see Roelfsema et al., 2010; Watanabe & Sasaki, 2015) - or rather the lack of proper attentional deployment when wine tasting, due to the high complexity of the learning space as many odorants/tastes are combined at once and no tasting experience ever truly repeats (e.g., given bottle variation, not to mention any age-related changes in the wine)!

Given the disappointing nature of sensory enhancement effects reported in much of the early work on wine expertise, one might be tempted to go back and question whether the training conditions were necessarily optimised to promote such sensory enhancement. In other words, the limited enhancements in perceptual thresholds that have been reported might simply reflect the complexity/inconsistency of the training stimuli that have been used. For instance, classic olfactory threshold testing, such as performed by Bende and Nordin (1997) and Parr et al. (2002), were performed with n-butanol, a molecule that is not commonly detected in wine. And even in the case of known odours, wine is a complex mixture (see Spence & Wang, 2018); Wine expertise is not built by the repeated smelling of single odorants, despite the Nez du Vin's claims to the contrary (e.g., see https://www.lenez.com/en/kits/use; https://www.lenez.com/en/ecole_du_nez/one_day_training; https://www.scmp.com/magazines/post-magazine/food-drink/article/2145455/how-train-your-nose-wine-kit-helps-you-become).

And finally, here, it is worth remembering that perceptual learning, in terms of pure sensory thresholds at least, is only a very small part of what expertise consists of in the world of wine. For more complex learning situations, enhanced performance is possible when the assessment matches the training scheme. For instance, people can get better at blind tasting with repeated practice, in terms of improved accuracy of grape varietal and region-of-origin guesses (Wang & Prešern, 2018; see also Tempere et al., 2012).

5. Conclusions

Assessing the impact of wine training on wine perception is, as we have seen, a tricky business. On the one hand, this is because very different definitions of what constitutes expertise have been used in different studies (e.g., winemakers vs. sommeliers). What is more, while various differences have been documented between the more and less expert wine drinker, the most impressive improvements as a result of expertise have typically tended to be in the more cognitive rather than necessarily sensory aspects of tasting. Experts have more developed conceptual knowledge structures concerning constellations of wine sensory attributes, enhanced semantic memory for wine-relevant stimuli, as well as an enhanced recognition memory ability. Nevertheless, by drawing attention to those factors influencing the efficacy of perceptual learning in the spatial senses, it is our hope that more concrete suggestions can be made for ways in which enhanced perceptual learning protocols could potentially be used to deliver enhancements for the wine taster. These can include, for instance, lowering detection thresholds for key wine volatiles as well as improving description/labelling of wine-relevant compounds in the years ahead.

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Table 1. Summary of research showing effect of wine expertise on various perceptual/cognitive tasks.

Study	Type of change	Task	Sample size	Expertise	Effect of expertise?	Details of change
Bende & Nordin, 1997	Threshold	1-butanol detection	16 experts, 16 controls	Professional wine tasters	No	Experts were no better than controls on detection
Berg et al., 1955	Threshold	16 wine-relevant compounds			No	
Parr et al., 2002	Threshold	1-butanol detection	11 experts, 11 novices	Winemakers, researchers, professionals, graduate students, or >10 year involvement	No	Experts were no better than controls on detection
Parr et al., 2004	Threshold	1-butanol detection	14 experts, 14 novices	Winemakers, researchers, professionals, graduate students, or >10 year involvement	No	Experts were no better than controls on detection
Bende & Nordin, 1997	Threshold	Citral odour detection in citral-eugenol mixture	22 experts, 22 controls	Professional wine tasters	Yes	Experts had lower detection thresholds than controls
Tempere et al., 2011	Threshold	Wine odour detection	134 experts	Winemakers, researchers, professionals, graduate students, or >10 year involvement	Yes	Improvement only for diacetyl & mixed ethylphenols
Ballester et al., 2009	Categorization	Red/White/Rose disrimination by odour	23 experts, 27 trained panellists, 26 novices	Winemakers, researchers, professionals, graduate students, or >10 year involvement	No	All could categorise red and white, but not rosé wines
Walk, 1966	Categorization	Same-different judgment	30 trainees	Novices	Yes	Improvement with training

Solomon, 1990	Discrimination	Triangle test (white wines)	4 experts, 4 novices	Wine professionals or long-term involvement	Yes	Experts performed better than chance
Wang & Prešern, 2018	Discrimination	Acidity determination	15 trainees	Competitive blind tasters	Yes	Improvement with training
Wang & Prešern, 2018	Categorization	Grape variety guess	15 trainees	Competitive blind tasters	Yes	Improvement with training
Wang et al., 2019	Discrimination	Triangle test (odours)	19 trainees, 13 controls	Competitive blind tasters	Yes	Improvement with training
Arvisenet et al., 2016	Invariance	Odour intensity judgment	19 experts, 19 trained panellists, 19 untrained panellists	Oenologists or graduate students in V&O	Yes	Trained panels and wine experts showed lower taste-induced aroma enhancement
Wang et al., 2018	Invariance	Sweetness and sourness rating	154 experts	Wine professionals	No	Taste judgments were influenced by music regardless of experience
Solomon, 1990	Verbal	Matching wines to descriptions	3 experts, 3 novices	Wine professionals or long-term involvement	Yes	Experts matched wines to descriptions by experts at better than chance levels
Valentin et al., 2003	Verbal				Yes	
Zucco et al., 2011	Verbal	Verbal description of wine-related odorants	12 professional sommeliers, 12 each second- and third-year trainees, 12 novices	Sommeliers	Yes	The number of pertinent descriptors increased with expertise
Croijman & Majid, 2016	Verbal	Name wine and coffee smell and flavours	22 wine experts, 20 coffee experts, 21 novices	Vinologist or sommeliers	Yes	Experts were more consistent in their descriptions

Hughson & Boakes, 2002	Verbal	Word recall	8 experts, 21 novices	Wine professionals with >10 years experience	Yes	Experts had better word recall when combinations were wine-related
Parr et al., 2002	Verbal	Olfactory recognition	11 experts, 11 novices	Winemakers, researchers, professionals, graduate students, or >10 year involvement	Yes	Experts had better odour recognition
Parr et al., 2004	Verbal	Olfactory recognition	14 experts, 14 novices	Winemakers, researchers, professionals, graduate students, or >10 year involvement	Yes	Experts had better odour recognition
Lawless 1984	Verbal	Matching wines to descriptions	13 experts, 14 control	Wine professionals, appreciators, trained in wine flavour	Yes	Experts matched descriptions to wine better than novices
Gawel 1997	Verbal	Matching wines to descriptions	34 trained panellists, 72 untrained wine tasters	2.5 years formal structured tuition in wine evaluation	Yes	Trained panellists performed better than untrained tasters