RUNNING HEAD: PERCEPTUAL LEARNING IN THE CHEMICAL SENSES

Perceptual learning in the chemical senses: A review

Prof. Charles Spence

Crossmodal Research Laboratory, Department of

Experimental Psychology, Oxford University, Oxford, UK

WORD COUNT: 20,400 WORDS

SUBMITTED TO: *Food Research International*

DATE: MAY, 2019

CORRESPONDENCE TO: Prof. Charles Spence, Department of Experimental Psychology, Anna Watts Building, University of Oxford, Oxford, OX2 6GG, UK. E-mail: charles.spence@psy.ox.ac.uk

ABSTRACT

People have been writing about perceptual learning and expertise in the chemical senses for more than a century now, with a particular focus on the world of wine. However, the problem with many of the cross-sectional studies of wine expertise that have been published to date is that they simply cannot rule out the possibility that those with superior chemosensory abilities end-up gravitating toward a career in wine. Definitions of expertise also tend to vary widely between studies, making direct comparison of the results obtained rather difficult. By contrast, the longitudinal learning studies that have been published have typically only assessed the effects of relatively small amounts of training. And, taken as a whole, the majority of studies in this area tend to look statistically underpowered nowadays in terms of the sample sizes that have been used. Nevertheless, despite these limitations, the literature converges on the conclusion that chemosensory perceptual learning does occur, though the gains (e.g., in terms of lower detection thresholds) are usually modest at best, and tend to be highly stimulus-specific. By contrast, cognitive/semantic improvements in describing/discriminating wines, and wine-relevant compounds, as well as the acquisition of relevant conceptual knowledge, are much more salient differentiators in the cross-sectional empirical literature. Enhanced attention and olfactory recognition memory abilities have also been reported amongst wine experts. Looking to the future, the hope is that the insights garnered from studies of perceptual learning in the higher spatial senses may help to optimize the training regimes for those wishing to enhance their wine-tasting abilities, and perhaps also aid recovery in those suffering from olfactory loss.

KEYWORDS: PERCEPTUAL LEARNING; CHEMICAL SENSES; EXPERTISE; ATTENTION; WINE; BEER; OLFACTION.

1. Introduction

1.1 Expertise in the chemical senses: What role perceptual learning?

Becoming an expert in some aspect of sensory perception (such as, for example, in the case of someone acquiring wine expertise), likely involves perceptual learning. Perceptual learning is defined as the enhanced ability to extract sensory information from the environment following training. Goldstone (1998, p. 585) argues that it involves: "*relatively long-lasting changes to an organism's perceptual system that improve its ability to respond to its environment"*. Curiously, though, the literature is essentially silent on the topic of perceptual learning in the chemical senses (e.g., see Gibson, 1966, 1969, for early neglect; and Green, Banai, Lu, & Bavelier, 2018, for a recent overview of perceptual learning in the different senses that includes only a single study on taste, or rather, flavour, namely Walk, 1966). At the same time, however, there has been an explosive growth of interest in perceptual learning in recent years from those researchers working in the higher spatial senses (e.g., Goldstone, 1998; Green et al., 2018). The lack of interest in the chemical senses in contemporary research is rather ironic, if only because much of the early discourse around perceptual learning was actually framed in terms of tasting, especially wine-tasting (Gibson, 1953, p. 401; Gibson & Gibson, 1955, p. 35; James, 1890). William James, for instance, giving as an example of the improvement in discrimination with practice the suggestion that: *"one man will distinguish by taste between the upper and the lower half of a bottle of old Madeira"* (James, 1890, I, p. 509).

Meanwhile, the husband and wife team of psychologists, James and Eleanor Gibson, illustrated what the benefits of perceptual learning in the world of wine might look like with the following description: *"The gentleman who is discriminating about his wine shows a high specificity of perception, whereas the crude fellow who is not shows a low specificity. A whole class of chemically different fluids is equivalent for the latter individual; he can't tell the difference between claret, burgundy, and chianti; his perceptions are relatively undifferentiated. What has the first man learned that the second man has not? … he has learned to taste and smell more of the qualities of wine, that is, he discriminates more of the variables of chemical stimulation. If he is a genuine connoisseur and not a fake, one combination of such variables can evoke a specific response of naming or identifying and another combination can evoke a different specific response. He can consistently apply nouns to the different fluids of a class and he can apply adjectives to the differences between fluids."* (Gibson & Gibson, 1955, p. 35).

Such suggestions can perhaps be seen as responding to the likes of Shaw (1863), the commentator / sceptic mentioned in Broadbent's (1968), *Wine tasting: A practical handbook on tasting and tastings*, who was convinced that much (if not all) the talk from the so-called 'wine experts' is nothing but 'humbug'. More recently, Gregg Solomon (1990, p. 495) of Harvard University made much the same point, writing that: *"It is a common suspicion that much of what passes for expertise is just so many words."* It is at this point that one might want to ask what the literature demonstrates with regard to the changes in wine-tasting ability that have been documented when the performance of wine experts has been compared to that of non-experts. Non-experts are sometimes referred to as 'wine consumers', 'wine novices', or 'social drinkers'. Intriguingly, threshold differences between these two groups have not always been obtained, especially not when testing odours unrelated to wine (e.g., Bende & Nordin, 1997; Berg, Filipello, Hinreiner, & Webb, 1955; Parr, Heatherbell, & White, 2002; Parr, White, & Heatherbell, 2004; Tempere, Cuzange, Malak, Bougeant, de Revel, & Sicard, 2011).

Significant between-group differences have, though, been documented in the discrimination of wines and wine-relevant odours (Bende & Nordin, 1997; Solomon, 1990). Differences in the accuracy of odour identification have been reported by some (e.g., Tempere, Hamtat, de Revel, & Sicard, 2016), but by no means all, researchers (Parr et al., 2002, 2004). Striking differences have also emerged when researchers have looked at the consistency and breadth of descriptors used when people evaluate/describe wine (e.g., Brochet & Dubourdieu, 2001; Croijmans & Majid, 2016; Herdenstam, Hammaren, Ahlstrom, & Wiktorsson, 2009; Solomon, 1990; Valentin, Chollet, & Abdi, 2003; Wang & Prešern, 2018; Weil, 2007; Zucco, Carassai, Baroni, & Stevenson, 2011). It has been suggested that such differences may be built on an enhanced semantic memory for wine-related terms, as well as an enhanced recognition memory for wine-relevant odours, in wine experts (Parr et al., 2002, 2004; Zucco et al., 2011; see also Wilson & Stevenson, 2003). It has also been suggested that wine experts may direct/focus their attention differently (i.e., more efficiently) than do non-experts. It should be noted that this review, like the field of perceptual learning relating to chemosensory perception on which it is based, will focus primarily on studies of wine. However, research from the world of beer-tasting, perfumery, and general studies of olfactory perception/learnig are introduced where relevant.

The literature on perceptual learning in the higher spatial senses, especially vision (e.g., Dosher & Lu, 2017), but also, to a lesser extent, audition (see Irvine, 2018, for a recent review), and touch (e.g., Dempsey-Jones, Harrar, Oliver, Johansen-Berg, Spence, & Makin, 2016; Harrar, Makin, & Spence, 2014), has revealed a number of important factors modulating the efficiency/generalizability of perceptual learning in the higher senses. It is therefore possible to imagine how the latest insights from the more highly-developed study of perceptual learning in vision and the other spatial senses might, in the years ahead, be adapted to help improve the quality of wine training (i.e., perceptual learning) in the chemical senses (e.g., see Dosher & Lu, 2017). At the very least, it might help to nudge those involved in wine education to question the seemingly widespread belief that simple repeated exposure to individual suprathreshold wine-relevant odorants when presented in isolation (often with immediate feedback),[1] will necessarily lead to enhanced performance (see Tempere, Cuzange, Bougeant, de Revel, & Sicard, 2012, for evidence on this score). Though see Schmidt and Bjork (1992) on the benefits for perceptual learning of reduced feedback training protocols. At the same time, however, the development of enhanced training protocols might also be expected to help a number of those suffering from olfactory loss to recover at least some semblance of olfactory function (e.g., Damm, Pikart, Reimann, Burkert, Göktas, Haxel, Frey, Charalampakis, Beule, Renner, Hummel, & Hüttenbrink, 2014; Hummel, Rissom, Reden, Hähner, Weidenbecher, & Hüttenbrink, 2009; Sorokowska, Drechsler, Karwowski, & Hummel, 2017).

1.2. What changes might one expect to see in wine experts as a result of perceptual learning?

There has been a great deal of research looking to document any differences that might exist between experts and non-experts in terms of their sensory/perceptual/conceptual abilities as far as wine is concerned (see Ashton, 2017; Ballester, Patris, Symoneaux, & Valentin, 2008; Brochet & Dubourdieu, 2001; Hughson, 2003; Hughson & Boakes, 2001; Parr, 2002; Spence & Wang, in press, for reviews). That said, much of the research in this area has highlighted a more semantic/descriptive/conceptual change/enhancement in wine experts when their performance has been compared to that of non-experts (see also Castriota-Scanderbeg, Hagberg, Cerasa, Committeri, Galati, Patria, et al., 2005, for neuroimaging evidence). By contrast, until recently, changes in perceptual thresholds have been less frequently reported. Indeed, writing almost 30 years ago, Gregg Solomon (1991, p. 271) captured the challenge still facing many researchers today when he wrote that: *"Expert and novice wine tasters certainly*

[1] This, the approach promoted by Le Nez du Vin (e.g., see https://www.lenez.com/en/kits/use; https://www.lenez.com/en/ecole_du_nez/one_day_training; Lee, 2018).

appear to be different. But demonstrating that difference reliably has proven to be quite difficult. Tasters differ in subtle ways; the methodological challenge is to set tasks difficult enough to expose meaningful differences between groups but not so difficult as to prove impossible." Nevertheless, to begin with, it is worth listing the different kinds of changes that might *a priori* be expected to accompany the development of wine expertise. According to Harry Lawless (1984, p. 120), changes might be expected in a range of different sensory/perceptual behavioural measures/tasks, including:

1) An increase in absolute sensitivity, that is, a decrease in the detection threshold for various wine-relevant compounds (Tempere et al., 2011);

2) An increase in the ability to discriminate wine-relevant sensory stimuli in the suprathreshold range; note that this might either show-up as an enhanced ability to discriminate different qualities (e.g., lime vs. lemon) or else to discriminate between, or perhaps rank order, different intensity levels (e.g., low vs. high alcohol; see Solomon, 1990, Experiment 4);

3) An increased ability to attend to, or recognize, invariant characteristics of a complex stimulus in the face of a changing background (cf. Wang & Spence, 2017); and/or

4) An enhanced ability to reliably apply verbal labels to different sensory attributes or characteristics (e.g., Croijmans & Majid, 2016; Zucco et al., 2011).[2]

1.3 Principal approaches to the study of perceptual learning in the chemical senses

Over the years, two main approaches have been used to study (or infer) perceptual learning in the chemical senses. One has involved researchers comparing the performance of wine experts to that of non-experts (e.g., Chollet & Valentin, 2000; and occasionally those undergoing training in wine tasting; e.g., Zucco et al., 2011).[3] Meanwhile, another increasingly popular

[2] Note that in his recent review of expertise in the world of wine, Ashton (2017, pp. 65-66) only mentions the first, second, and fourth of these possibilities.

[3] As Gibson (1953) noted long ago, such an approach assumes that any between-group differences reflect the consequences of perceptual learning. However that is by no means the only explanation for such a pattern of results. What is more, research in this area is made all the more confusing as certain authors talk about perceptual learning while actually using a cross-sectional comparison of experts and non-experts. For example, just take

approach to the study of perceptual learning has involved measuring the effects of training on, for example, a wine-taster's chemosensory abilities (e.g., Tempere et al., 2012; Walk, 1966; Wang & Prešern, 2018). We will look at the strengths and weakness of each of these approaches in turn.

2. Cross-sectional comparison of wine experts and non-experts

2.1 Changes in odour detection thresholds

Early research demonstrated surprisingly little evidence of changes in sensory thresholds for the detection of specific olfactants, such as 1-butanol, when presented in isolation to wine experts (e.g., see Bende & Nordin, 1997; Berg et al., 1955; Brand & Brisson, 2012; Parr et al., 2002, 2004). In fact, wine experts and non-experts have comparable detection thresholds for this particular olfactant. That said, 1-butanol (described as smelling 'chemical like') does not actually have any particular relevance to the world of wine. Indeed, Bende and Nordin chose it precisely for this reason (and also because of its widespread use when assessing olfactory sensitivity; see Cain, 1989). Berg et al.'s early study testing the threshold detection of 12 wine-relevant stimuli also failed to demonstrate lowered detection thresholds in wine experts as compared to non-experts for alcohol, sugar, or certain odours (acetic acid, acetaldehyde, and ethyl acetate). Other assessed dimensions included fruit and vegetable aromas on the nose; In terms of taste, body (as measured by amount of glycerol), balance, acidity, sweetness, astringency (tannins), and overall evaluation were assessed; In terms of the finish, the duration, intensity, and pleasantness of the aftertaste were assessed. Overall, though, the experts performed no better than the novices in detecting/discriminating these particular stimuli.

A somewhat different story regarding the impact of expertise on threshold detection has emerged from a couple of other studies. In one, professional wine tasters were found to be able to detect the presence of a lemon aroma (citral) in a base of clove aroma at a much lower concentration of the former than could control participants (non-experts; N = 22 in each group) in a two-alternative forced-choice (2AFC) task (Bende & Nordin, 1997, Experiment 2; see also Laing & Francis, 1989; and Livermore & Laing, 1996, for a similar enhancement in perfumers

---

Bende and Nordin's (1997) article titled *'Perceptual learning in olfaction'*, which does not actually explicitly measure perceptual learning at all!

relative to controls when trying to identify the two or three odorants in odour mixtures). The difference in average dilution steps between groups (1.6) representing a 3.0-fold difference in citral concentration.

Meanwhile, Tempere et al. (2011) measured threshold levels for 10 key odorant compounds in wine (along with tartaric acid and alum thresholds, associated with sour and astringent taste, respectively) in 100-150 wine experts, consisting of enologists, wine growers, wine merchants, and wine brokers. Detection thresholds were determined for all 12 chemosensory stimuli in a total of 51 of the experts. A lowered threshold amongst the experts with specialized training (e.g., qualified enologists specifically trained to taste wine in university institutes with the French academic degree/diploma to match) as compared to the other experts without any such specialized training was documented for two of the ten odorants, namely diacetyl and a mixture of ethylphenols. Diacetyl, which is often described as having a buttery smell (Lawless, Antinone, Ledford, & Johnson, 1994), results from malolactic fermentation, as used in certain styles of white wine making (Woodhouse, Sacks, & Jeffery, 2016).[4] It is particularly interesting in terms of individual differences, with Lawless and his colleagues reporting that mean individual thresholds for the orthonasal detection of diacetyl varied by a factor of 256 (or nine binary dilution steps) amongst the randomly-selected group of 53 participants whom they happened to test.

Ethylphenols, by contrast, are produced by the spoilage yeast Brettanomyces, which manifests as a wine fault if present in high concentrations (Chatonnet, Dubourdieu, Boidron, & Pons, 1992; Woodhouse et al., 2016). Interestingly, those with a higher degree of wine knowledge have been shown to be more sensitive to Brettanomyces (Schumaker, Chandra, Malfeito-Ferreira, & Ross, 2017). Elsewhere, Pickering, Karthik, Inglis, Sears, and Ker (2007) reported enhanced orthonasal/retronasal detection (that is, a lowered detection threshold) for 2-isopropyl-3-methoxypyrazine (this grape- and insect-derived compound, which contributes a green character to wine), amongst those familiar with this wine fault known as ‘ladybug taint’. That said, the difference was only apparent for one of the three wines tested (a Gewürztraminer), and, what is more, no difference in threshold was reported between winemakers and non-winemakers.

[4] In fact, 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.

In summary, the effects of expertise (and, putatively, of perceptual learning) appear to be stimulus-specific, both in terms of only wine-relevant odorants showing threshold changes, but also in the sense that threshold changes have only been demonstrated for a subset of such wine-relevant odorants in experts. Wine experts/professionals, in particular, appear better able to identify wine defects. Taken together, such results support the view that wine experts do indeed have lower detection thresholds, but only for a subset of (mostly) wine-relevant compounds. What is less certain, at least on the basis of the research summarized thus far, is whether such individual differences result from wine-training/experience versus reflecting genetically-determined differences in sensitivity, or perhaps some unknown combination of the two effects (see Bedichek, 1960, p. 61; Engen, 1982, p. 5, for the suggestion that odour expertise results primarily from experience and training).

2.2 Changes in discrimination performance/odour identification in wine experts

Solomon (1990; Experiment 3) demonstrated that experts (N = 4) exhibited enhanced discrimination performance in triangle tests[5] involving four very similar cheap white Bordeaux wines (all very bland and virtually identical in terms of their visual appearance), while novices (N = 4) performed at chance with the wines that had been chosen. In particular, the experts got an average of 5.5 correct out of a possible total of 8, whereas the novices scored only 2.8, the latter not significantly different from chance performance (2.7 correct). Solomon (1990, Experiment 4) also reported that his expert group were significantly better than chance (or better said, they were consensual) when rank ordering five wines on a number of dimensions (sweetness, balance, and tannin). Novices, by contrast, only showed a degree of consensuality when ordering the wines based on their sweetness. Hence, given such a pattern of results, Solomon concluded that wine experts display more precise discrimination performance than do non-experts.

Meanwhile, when Bende and Nordin (1997) assessed the identification accuracy of participants for various household aromas, an expert advantage was only reported for a subset of the olfactory stimuli (specifically lilac, lemon, cinnamon, and orange).[6] On the basis of their

[5] Note that the triangle test has, for many years now, commonly considered to be the most sensitive measure of a taster's discrimination abilities (e.g., Amerine, Pangborn, & Roessler, 1965; see also Weil, 2007).

[6] Though note here that rather than pure identification, the participants were actually required to discriminate between four response alternatives, one of which was always the correct response.

various results, Bende and Nordin concluded that perceptual learning does not generalize from detection/discrimination and identification to threshold detection tasks. Bende and Nordin's suggestion here being that the generalizability of perceptual learning can be demonstrated by showing enhanced performance in wine experts on tests that they have presumably not been explicitly trained on before (i.e., over-and-above any generalization that is seen at the level of the olfactory stimuli themselves). That said, and as has been noted already, the cross-sectional approach adopted by Bende and Nordin, Solomon (1990), and others does not necessarily guarantee that any between-group differences actually reflect the results of perceptual learning.

Elsewhere, Tempere et al. (2016) obtained a similar expert advantage using a range of techniques to probe their participants' odour identification abilities. The 47 odorants tested in this particular study included compounds associated with specific wine defects, key compounds associated with wine sensory attributes or typicality, and non-wine-specific compounds. Overall, wine professionals (N = 39) were more accurate in their olfactory identification responses, but also significantly slower in terms of the speed of their responding, than were the novices (N = 41) who were tested. Adding to the list here, superior olfactory identification abilities amongst experts have also been reported by Mariño-Sanchez, Alobid, Cantellas, Alberca, Guilemany, Canals, De Haro, and Mullol (2010). That said, the documented benefits have not always been that impressive. For instance, Zucco et al. (2011) reported only a very modest benefit, with their experts (professional sommeliers) scoring 12.22 out of 16, as compared to a score of 11.09 amongst the non-experts (N = 12 in each of 4 groups, comprising untrained wine drinkers, second- and third-level trainee sommeliers, and professional sommeliers). The participants in this study were presented with 16 odorants and given a list of four odour descriptors to choose from.

Furthermore, absolutely no difference in identification performance for wine-relevant odorants was reported in a pair of studies by Parr et al. (2002, 2004). In the 2002 study, two groups of 11 participants were presented with 12 wine-relevant odours orthonasally and asked to describe/identify each odorant in turn. However these null results may reflect the fact that the so-called 'novices' tested by Parr and her colleagues were actually wine and food students. As the authors themselves readily admitted in their paper, they might equally well have been called 'intermediates', hence potentially reducing the contrast with the wine experts. However, arguing against this interpretation of the lack of expert advantage in odour identification, a similar pattern of results was also obtained in Parr et al.'s follow-up study in which a more conventional group of novices (i.e., occasional wine drinkers without any formal training) were tested instead.

In summary, wine experts would appear to be somewhat better at identifying/discriminating wine-relevant odorants than are non-experts. However, that said, the benefits are not especially pronounced and, what is more, they generally tend to be restricted to wine-relevant odorants. Taken together, the results reported in this section still clearly demonstrate more apparent differences between expert and non-expert groups as far as the discrimination/identification of wine-relevant odorants is concerned than was seen in the previous section where olfactory detection thresholds were assessed. On occasion, wine experts have also been reported to exhibit better performance in identifying certain everyday odorants as well (Bende & Nordin, 1997; Tempere et al., 2016), thus perhaps hinting at some very modest generalization of olfactory abilities beyond those wine-related odorants where enhanced performance might be expected.

2.3 Cognitive / descriptive changes in wine experts

<u>Describing wines.</u> Experts may well be better at discriminating between, recognizing, and describing wines in a more consistent manner than are those who are less experienced in the world of wine. Certainly, pronounced differences between wine experts and non-experts have been reported in terms of the consistency (or consensuality) of their use of wine language, possibly linked to underlying changes in the structure of their wine knowledge (e.g., Brochet & Dubourdieu, 2001; Solomon, 1990; Valentin et al., 2003). For instance, Lawless (1984) reported that a group of participants who were experienced in describing the flavours of wines (N = 13) used more terms when describing six unlabelled white wines than did another group of participants (N = 14) without any such experience (2.2 odour terms for each wine in experts vs. 0.9 in the non-experts). The wines in this case were made from Spatlese, Riesling, Chardonnay, and Gewürztraminer grapes. Meanwhile, Solomon (1990, Experiment 1) documented that experts used more descriptors for wine (M = 6.3) than did novices (M = 3.4). Further analysis revealed that the experts' descriptions also included mention of more sensory dimensions (M = 4.87) than did those of the non-experts (M = 2.53). A similar pattern of results was also reported in a second experiment (with the same sample size) in which those describing the wine were now restricted to a set expert lexicon. Solomon (1997, Experiment 4) reported

that experts used an average of five flavour terms whereas intermediates and novices used an average of only 3.1 descriptors. And, more recently, Wang and Prešern (2018) found that experienced wine tasters wrote significantly longer tasting notes (23% longer, on average), than did the novices whom they assessed. Elsewhere, it has been reported that wine experts use more pertinent wine descriptors (Zucco et al., 2011) and, what is more, show a higher degree of consensuality in the terms that they choose to use (Croijmans & Majid, 2016) than do non-experts. Experts also tend to use more specific wine descriptors than do non-experts (Chollet & Valentin, 2000; Sauvegeot et al., 2006).

<u>Matching wines to descriptions.</u> However, beyond simply just using more terms, researchers have also wanted to find out whether wine experts are any better at matching descriptions to wines too. In early work reported by Lehrer (1975, 1983/2009), one group of tasters (comprising both experts & novices) wrote descriptions of three wines, before another group of novice tasters tried to match those descriptions to the wines. However, somewhat surprisingly, the tasters in Lehrer's study were unable to perform this matching task at a level that was significantly better than chance (see also Weil, 2007). That said, when Lawless (1985) repeated Lehrer's study, he found that experts (consumer product analysts trained in sensory analysis) could match relatively dissimilar wines to their descriptions at a level that was significantly better than chance. However, the analysts were unable to match wines that were very similar.[7] Lawless (1984) also demonstrated that wine 'experts' performed significantly better than 'non-experts' in this task (mean correct = 2.6 vs. 1.8, respectively, out of a possible six correct responses). Similarly, Hughson and Boakes (2002) reported that experts outperformed novices when trying to match wines with their written descriptions, as did Gawel (1997). In the latter study, Gawel compared the performance of formally trained wine panellists (N = 36)[8] with a larger group of untrained but experienced wine tasters (N = 72) in the same matching task involving three Australian chardonnays from the 1994 vintage. The trained group were significantly better at matching than the experienced wine tasters who had no

[7] One of the fundamental problems in the area, being that no objective measure of the similarity of different wines currently exists.

[8] 4^{th}-year oenology students, with 109 hrs of formal and structured wine education over a period of the preceding 2½ years.

formal training, with both groups performing at a level that was significantly better than chance.

Elsewhere, Solomon (1990; Experiment 1) confirmed the superiority of wine experts over novices in communicating information to each other about wines using a slightly different experimental method. Once again, one group of six participants (three of whom were experts) described a series of five unlabelled red wines (a Californian Pinot Noir, a French Pinot Noir, a Californian Cabernet Sauvignon, a French Cabernet Franc, and a Spanish Rioja/Tempranillo grape). Then, a new group of tasters were presented with one wine and two descriptions, one of which had been written about the wine. The expert group (N = 15) were better at matching the wines to the correct descriptions (69.3% correct, *p.* < .05) whereas the novices (N = 15) were unable to match the descriptions of either the experts or those from the other novices at a level that was significantly better than chance. Nor, as it happened, were the experts able to match the novices' descriptions at a level that was any better than chance either.

Taken together, the cross-sectional results reported in this section would therefore appear to support the view that the language used by wine experts to describe wines is richer (in terms of the number of descriptors and stimulus dimensions mentioned; Lawless, 1984; Solomon, 1990, 1997; Wang & Prešern, 2018) and more consensual (that is, there tends to be greater expert agreement; see Croijmans & Majid, 2016; and Chollet & Valentin, 2001, in the case of beer), as well as being more precise (Chollet & Valentin, 2001; Zucco et al., 2011). What is more, while by no means perfect, wine experts (as well as other sensory experts; Gawel, 1997; Hughson & Boakes, 2002; Lawless, 1985) also seem much better able to take the wine descriptions of other experts and match them to the appropriate wines under conditions of forced choice (e.g., Gawel, 1997; Hughson & Boakes, 2002; Lawless, 1984; Solomon, 1990).

Meanwhile, in the world of beer, Chollet, Valentin, and Abdi (2005) demonstrated that two-years of weekly beer training (totalling in excess of 70 hrs training in beer sensory flavour characterization; N = 19 trained experts, and 20 untrained novices) improved performance on a paired same/different beer discrimination task for old (i.e., well-learned) beers but not when trying to discriminate between new beers that had not been in the training set (cf. Clapperton & Piggott, 1979, for similar results). However, the experts' matching performance (when matching to written descriptions from other experts) was significantly better than that of the novices (M = 70.5% vs. 61.7% correct; N = 19 participants in each groups) both when matching old and new beers given trained assessors' notes. Eighteen beers were presented, one at a time, on two successive occasions. The participants in this study had to choose between two descriptions, one written for that beer, the other for one of the other beers in the set. Elsewhere, Valentin, Chollet, Beal, and Patris (2007) documented better performance amongst beer experts (N = 19, with two years training) in identification and in a recognition memory task than novices (N = 22 & 24) for familiar beers and both familiar and unfamiliar beer odour compounds. That said, the experts exhibited only marginal superiority over the novices in a same/different beer discrimination task.

2.4 Changes in conceptual knowledge and memory in wine experts

Conceptual wine knowledge: Solomon (1997; Experiment 2) reported a study in which participants were presented with 10 moderately-priced wines and instructed to sort them into four groups. The results revealed that while the wine experts initially tended to group the wines by presumed grape type and/or region of origin, the non-experts grouped the wines in terms of their sensory characteristics, such as sweetness or fruitiness instead (see also Sauvegeot, Urdapilleta, & Peyron, 2006; Urdapilleta, Parr, Dacremont, & Green, 2011). These results led Solomon to conclude that wine experts exhibited changes in both conceptual and perceptual knowledge that were likely tied to the explicit schemes that are involved in classifying wine (see also Hughson & Boakes, 2001, 2002). Meanwhile, Hughson and Boakes (2002) reported that experts remembered more wine-related words under incidental learning conditions, but under intentional learning conditions they did so only when words were grouped so as to form possible descriptions of actual wines. Ballester et al. (2008) and Le Fur, Blanquet, Candelon, Ballester, and Uscida (2004) have also noted that wine experts tend to categorize wines by grape variety (Honoré-Chedozeau, Lelievre-Desmas, Ballester, & Valentin, 2016). Elsewhere, researchers have come to the conclusion that experts also have different representations than do non-experts as far as the notion of complexity in wine is concerned (see Parr, 2015; Parr, Mouret, Blackmore, Pelquest-Hunt, & Urdapilleta, 2011; Schlich, Maraboli, Urbano, & Parr, 2015; Spence & Wang, 2018; Wang & Spence, 2018). A similar story has also been reported as far as wine quality judgments are concerned (e.g., D'Alessandro & Pecotish, 2013; Sáenz-Navajas, Ballester, & Pêcher, 2013).[9] Furthermore, wine experts have also been shown to

[9] Minerality is another esoteric wine concept that again appears to be represented differently by different groups of tasters (e.g. Ballester, Mihnea, Peyron, & Valentin, 2013). Several studies have highlighted the more accurate

categorise wines more efficiently based on ageing potential (Jaffré, Valentin, Dacremont, & Peyron, 2009) and typicity (Cadot, Caillé, Samson, Barbeau, & Cheynier, 2010; Perrin & Pages, 2009).

In terms of the cognitive benefits of wine expertise, it is worth noting that if a wine is of a particular type, then it will likely have certain other characteristics as well (see Lawless, 1985; Spence & Wang, 2018). What this means, in practice, is that on tasting a wine from Bordeaux, say, the expert will presumably know to look out for notes of raspberry and/or bell pepper (or 2-isobutyl-3-methoxypyrazine to give it its rightful chemical name). In other words, knowing something of the statistical co-occurrence of specific sensory features – the natural statistics of wine, as it were (see Lelièvre-Desmas, Chollet, Abdi, & Valentin, 2015, on the statistical learning of sensory features in the beer category) – ought to help the expert in cognitive/categorization tasks involving wine. The wine expert may even imagine the notes on nosing the wine that they expect to be there (cf. Brochet, 1999; Gawel, 1997). Potentially relevant here, expert perfumers have been shown to have enhanced olfactory imagery (e.g., Plailly, Delon-Martin, & Royet, 2012; Royet, Plailly, Saive, Veyrac, & Delon-Martin, 2013).[10] Here, it is natural to wonder about the extent to which any perceptual differences in wine experts actually have their basis in memory differences in the ability to remember the relevant sensory characteristics of wines (see Solomon, 1990, p. 514, on this point). Hughson and Boakes (2002) have reported enhanced semantic memory amongst wine experts in their study of wine-related words.

<u>Olfactory recognition memory:</u> Experts show enhanced recognition memory for wine-relevant odours, although the source of the superior performance seems to be based more in perceptual than in semantic memory, according to Parr et al. (2002, 2004). Specifically, in their 2002 study, two groups of 11 participants were presented with 12 wine-relevant odours orthonasally, and asked to describe/identify each in turn. After a delay of 10 minutes, these 12 odorants were presented once again, together with 12 new wine-related odorants in an (old vs. new) odour

---

and consensual judgments of wine typicity amongst experts (Ballester et al., 2008; Parr, Valentin, Green, & Dacremont, 2010; Urdapilleta, Parr, Dacremont, & Green, 2011; see also Lawless, Liu, & Goldwyn, 1997).

[10] Plailly et al.'s (2012) neuroimaging study revealed experience-induced functional reorganization in brain regions including the olfactory, or piriform, cortex, the orbitofrontal cortex, and the hippocampus in professional perfumers when contrasted with student perfumiers.

recognition task. The wine experts were significantly better than the novices at this task (d' = 2.26 vs. 1.63, respectively). In the 2004 paper, some of the participants had to rate the pleasantness of the odorants rather than try and identify them by name. This change was introduced in order to assess a verbal overshadowing account of the poor performance seen in the novices (see Melcher & Schooler, 1996). However, this experimental manipulation had no impact on the pattern of results obtained (see also Hughson & Boakes, 2009). That said, and as reported earlier, no between-group differences were reported in terms of odour identification abilities between the expert and non-expert group. Parr et al. (2002) explained their results in terms of the experts' perceptual, or sensory-based memory. In their 2004 paper, however, they went on to modify their position, suggesting instead that wine experts have enhanced perceptual skill, specifically an enhanced olfactory imagery ability. More recently, Zucco et al. (2011) also documented enhanced expert performance in a delayed-match-to-sample wine recognition task. Intriguingly though, they showed no benefit (or generalization) amongst wine experts when compared to novices for those olfactory stimuli that were unrelated to wine. Elsewhere, in the world of beer, Valentin et al. (2007) have also documented enhanced recognition memory for beers and beer odour compounds assessed orthonasally.

In summary, the results reported in this section once again support the existence of significant differences between experts and non-experts (novices) in terms both of their semantic knowledge/memory (see Hughson & Boakes, 2002; though see also Parr et al., 2002, 2004), as well as in terms of the way in which they structure their conceptual wine knowledge (Solomon, 1997). Next, we look at the possible role that an enhanced ability to direct/focus attention may play in mediating expert-novice differences in the world of wine.

2.5 Attentional changes in chemosensory experts

Several wine writers have, over the years, suggested that expertise may lead to a change in attentional focus (see also Amerine & Roessler, 1976; Broadbent, 1968; see also Frost, Quinones, Veldhuizen, Alava, Small, & Carreiras, 2015; Rabin & Cain, 1989). Certainly, the evidence suggests that wine experts' performance tends to be more adversely affected by changes to the visual appearance of wine (such as miscolouring a white wine so that it takes on the appearance of a rosé or red wine, say (Parr, White, & Heatherbell, 2003; see also Pangborn, Berg, & Hansen, 1963, for early evidence; and Wang & Spence, submitted, for recent findings).

Such results can be taken to suggest that with training/practice, wine experts attend more to the visual aspect of wine, and they exhibit a greater degree of visual dominance (see also Ballester, Abdi, Langlois, Peyron, & Valentin, 2009; Spence, 2010a, b; cf. Lelièvre, Chollet, Abdi, & Valentin, 2009, on visual dominance in the categorization of beers). Relevant here, it would be interesting in future research to determine whether explicit knowledge that the colour of a wine may be misleading would enable the wine expert to direct their attention selectively to the chemosensory attributes of the wine instead (cf. Engen, 1972; Stillman, 1993; Zampini, Sanabria, Phillips, & Spence, 2007; Zampini, Wantling, Phillips, & Spence, 2008).

Linked to the question of attentional focus, several researchers have noted that novice wine consumers rarely make reference to the aromatic components of wines when describing them (see Lawless, 1984; Solomon, 1990; cf. Solomon, 1997, p. 56). Intuitively, this might perhaps be framed as a voluntary failure in the non-experts as far as directing their attention toward the olfactory modality is concerned. It is, however, important to note that non-experts may actually simply be unable to direct their attention selectively to the retronasal olfactory component of mouth flavours (see Ashkenazi & Marks, 2004; Marks & Wheeler, 1998; and Spence, submitted, for a review). Relevant here, Arvisenet Guichard, and Ballester (2016) reported that training/expertise modifies the taste-aroma interactions observed in model wines (see also Boakes & Hemberger, 2012). In particular, wine experts and trained panellists exhibited significantly less sweetness enhancement of the perceived aroma of model wines following the addition of sugar than did non-experts. This result thus suggests an enhanced ability to attend to (or individuate) the various sensory elements contributing to multisensory flavour experiences amongst the more experienced tasters, at least when encouraged to adopt an analytic approach to wine by being presented with separate taste and aroma rating scales.[11] Weil (2007) has also argued that experts can adopt a more analytic strategy whereas novices tend to respond to wines holistically.

Such results can perhaps be considered in terms of the notion of 'unitization' and 'differentiation', as discussed in the literature on perceptual learning. Unitization refers to the idea that following perceptual learning, an individual may come to process perceptual features, that were once treated as distinct, as a single unit (one might be tempted to draw a link here to

[11] At the same time, wine experts, at least according to the neuroimaging research, also show enhanced integration of the various signals giving rise (or contributing) to flavour percept (Pazart, Comte, Magnin, Millot, & Moulin, 2014).

the notion of synthetic olfactory information processing; see Wilson & Stevenson, 2003). Differentiation, by contrast, refers to the idea that the perceptual system may come to treat certain unified sensations as distinct following perceptual learning (see Goldstone, 1998, p. 602; Goldstone & Byrge, 2015). Arvisenet et al.'s (2016) results can certainly be framed in terms of enhanced differentiation amongst wine experts. That said, it is worth noting the similarity in these processes, at least according to Goldstone (1998, p. 604), who suggests that: *"[U]nitization and differentiation are both processes that build appropriate-sized representations for the tasks at hand."*

Another aspect of selective attention concerns the ability to focus on one relevant stimulus, while ignoring others (see Kahneman & Treisman, 1984). One can think of the ability to pick-out a single chemical signal from a rich odorous environment (see Tempere et al., 2011), as a task involving selective attention. Potentially relevant here, McBride and Finlay (1987) suggested that experienced sensory panellists showed less taste-taste interactions (specifically suppression of acidity by sweetness in sucrose/citric acid mixtures) consistent with their being better able to focus their attention (or, given the above discussion, one might say that they are simply better able to adopt an analytic approach to tasting). Here, one might also consider the ability to ignore background noise/music (or, for that matter, other kinds of extrinsic information; D'Alessandro & Pecotish, 2013) while wine tasting as another example of selective attention. However, that said, the following quote from Emile Peynaud, the famous French oenologist, would appear to suggest that even experienced wine tasters struggle to ignore distracting sounds when trying to direct their attention to the wine(s) that they are tasting. *"The sense of hearing can interfere with the other senses during tasting and quiet has always been considered necessary for a taster's concentration. Without insisting on absolute silence, difficult to obtain within a group in any case, one should avoid too high a level of background noise as well as occasional noises which can divert the taster's attention."* (Peynaud, 1987, p. 104). Of course, Peynaud's further suggestion that perfume should not be worn when wine-tasting also hints at the difficulty of segregating sensations within a sense, too (see also Laing & Glenmarec, 1992).

Consistent with the view that wine experts may not be able to eliminate the influence of wine-extrinsic cues when tasting/rating wine, it has recently been shown that their ratings of wine are sometimes influenced by background music in much the same way that non-experts have been shown to be (see Spence & Wang, 2015, for a review). For instance, Wang and Spence

(2017) conducted a crossover-design study at a winemaking conference in the UK, with a large group of those working professionally in the wine business (N = 154). Delegates were given a pair of white wines to taste while listening to two soundtracks (that previous research had shown to be) reliably associated with sweet and sour tastes (Wang, Woods, & Spence, 2015; see also Carvalho, Wang, Van Ee, & Spence, 2016). The results revealed that the soundtrack that happened to be playing in the background during wine tasting exerted a significant influence over the tasters' ratings of sweetness and sourness. What is more, it turned out that those with more years of wine-tasting experience were no less susceptible to the crossmodal influence of music than those with less.[12]

In summary, while there is some evidence of enhanced focused/selective attention abilities in wine experts, even they can be distracted by irrelevant stimuli showing that such an ability is less than perfect. There is also some suggestion of a change in sensory dominance with growing 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). Meanwhile, according to Frøst and Noble (2002) '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). The latter claims based on the results of a study in which the preferences of experts and novices for red wines from different origins and grape varieties were assessed. 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.

2.7 Problems with the cross-sectional approach to studying perceptual learning

Although the cross-sectional approach, namely comparing expert with non-expert groups, has undoubtedly been popular amongst researchers interested in wine in recent decades (as shown by the research that has been reviewed thus far), it is not without its problems. In particular, one of the key issues with this kind of research is that one cannot be sure that those with

[12] Once again, though (e.g., by analogy with the deliberately miscoloured wine example mentioned earlier), it would be interesting in follow-up research to determine whether experts can ignore auditory stimuli more effectively than non-experts once they have been made aware that this extraneous factor might be biasing their judgments.

particular sensory/perceptual abilities do not end-up self-selecting for an interest/career in wine-tasting (cf. Hummel et al., 2004).[13] Here it is worth highlighting the fact that the chemical senses, specifically gustation and olfaction, are somewhat different from the spatial senses inasmuch as there are more profound (often genetically-determined) individual differences in sensory abilities across the population (e.g., see Parr, in press; Stevens, Cain, & Burke, 1988; Tempere et al., 2011). One class of such differences relates specifically to an individual's taster status. Typically assessed with a propylthiouracil (PROP) taste test, populations can be segmented into supertasters, medium tasters, and non-tasters (Bartoshuk, 2000; Newcomb, McRae, Ingram, Elborough, & Jaeger, 2010). While taster status is often assessed on the basis of fairly dramatic individual differences in response to this bitter tastant, supertasters also give higher intensity ratings for the other tastants as well (e.g., Lim, Urban, & Green, 2008). That said, the most pronounced differences tend to be observed for certain bitterants.

There are also significant individual differences in terms of whether or not people are sweet-likers. That is, there is a section (c. 60%) of the population classified as 'sweet-likers'. Another section (c. 30%) are classified as sweet neutral/dislikers, while the remaining 10% of the population appear to show the same response to sweetness regardless of its intensity (e.g., Frayling, Beaumont, Jones, Yaghootkar, Tuke, Ruth, et al., 2018; Keskitalo, Knaapila, Kallela, Palotie, Wessman, Sammalisto, et al., 2007; Kim, Prescott, & Kim, 2014; Looy, Callaghan, & Weingarten, 1992; Yeomans, Tepper, Rietzchel, & Prescott, 2007).

Relevant to the world of wine, an individual's taster status also influences their response to alcohol (Pickering, Simunkova, & DiBattista, 2004). For instance, Pickering et al. reported that the rated astringency and intensity of taste sensations (bitterness and acidity) elicited by three commercial red wines were associated with an individual's sensitivity to PROP (N = 25). Specifically, PROP tasters and supertasters had a higher response than non-tasters. Inter-individual differences in both the quantity and quality of saliva is also an interesting area here, especially as far as it affects astringency (e.g., Taladrid, Lorente, Bartolomé, Moreno-Arribas, & Laguna, 2019; Xu, Laguna, & Sarkar, 2019).

Relevant to the current question of whether or not cross-sectional differences between wine experts and non-experts necessarily reflect perceptual learning, it is worth noting that PROP tasters exhibit not only a heightened response to, but also an increased discrimination between,

[13] Solomon (1991, p. 272) and Hayes and Pickering (2012) both make much the same point.

taste/flavour stimuli (see Hayes & Pickering, 2012; Prescott, Soo, Campbell, & Roberts, 2004). Taster status also affects a taster's response to the oral-somatosensory aspects of food stimuli (e.g., Eldeghaidy, Marciani, McGlone, Hollowood, Hort, Head, et al., 2011; Tepper & Nurse, 1997). That said, there is currently some disagreement in the literature as to the exact nature of the relationship, if any, between PROP taste sensitivity and the density of taste buds (e.g., see Garneau, Nuessle, Sloan, Santorico, Coughlin, & Hayes, 2014; Reed, 2008). It would, though, appear that there may be two factors at play here. One, individual differences in the number of taste papillae, and separately, genetic differences in sensitivity to PROP.

Turning now to the world of olfaction, which likely contributes far more to the multisensory tasting experience than does gustation (see Spence, 2015, for a review), it turns out, once again, that there are widespread genetically-determined differences in sensitivity to a variety of olfactants (e.g., see Amoore, 1977; McRae, Mainland, Jaeger, Adipietro, Matsunami, & Newcomb, 2012; Menashe, Abaffy, Hasin, Goshen, Yahalom, Luetje, & Lancet, 2007; Reed & Knaapila, 2010; Stevens, 1991; Stevens & O'Connell, 1991; Stevens et al., 1988), many of which happen to be relevant to the world of wine. Reed and Knaapila also reported large individual differences in sensitivity to those malodours that are associated with rotting foods. The results of a study by Tempere et al. (2011) are interesting in this regard: These researchers highlighted the existence of widespread differences in detection thresholds amongst wine experts (suggesting hyposmias or hyperosmias) for a variety of wine-relevant odorants, including ß-ionone (often described as a fruity, raspberry, or floral, violet, aroma in wine; see also Plotto, Barnes, & Goodner, 2006),[14] 2-isobutyl-3-methoxypyrazine, 2,4,6-trichloroanisole (TCA, or cork taint, see also Prescott, Norris, Kunst, & Kim, 2005; Suprenant & Butzke, 1997), and linalool (that is characteristic of Muscat wines). Such marked individual differences in chemosensory perception immediately raise two important issues. On the one hand, they draw attention to the issue of statistical power, and might well lead to concerns over the often (very) small sample sizes used in much of the published research that has compared experts with non-experts. In what sense can a sample of 10 (or fewer) wine experts be considered sufficient given the profound individual differences in sensitivity to wine-relevant odorants that undoubtedly do exist?

[14] Those who are least sensitive describe the odour as smelling like plastic, chemical, musty, and reminiscent of a cleaning agent (Tempere et al., 2012).

On the other hand, it is easy to imagine how those with superior sensory abilities with respect to the chemical senses might be more likely to be drawn to, and/or more successful in achieving recognition in, the world of wine-tasting. Indeed, support for the latter suggestion comes from the results of a study reported by Hayes and Pickering (2012) in which a wine-expertise related questionnaire was handed out to a group of 331 individuals in the Ontario region of Canada. The participants were also given the PROP taste test. Based on the results of the questionnaire, respondents were split, somewhat arbitrarily, into one group of wine experts (N=111) while the remainder were labeled as 'wine consumers' instead. Nevertheless, the results still revealed that those classified as 'wine experts' were significantly more likely to be a supertaster or medium taster when assessed on their PROP sensitivity than were those in the 'wine consumers' group (see **Figure 1**). That said, arguing against there being different baseline abilities in sensitivity to olfactory stimuli, Tempere et al. (2012) found that detection thresholds for a range of wine-relevant odorants were as widely dispersed in their expert panel as amongst their non-experts. And although beyond the scope of this review, it is worth noting that there is growing interest in the role that individual differences in wine appreciation may be explained by the microbiome (Koskinen, Reichert, Hoier, Schachenreiter, Duller, Moissl-Eichinger, & Schöpf, 2018).

INSERT FIGURE 1 ABOUT HERE

The other problem with cross-sectional studies, as highlighted by Spence and Wang's (in press) recent review, is the fact that definitions of wine experts, and of non-experts (or wine novices), tend to vary quite dramatically from one study to the next. This means that it can be difficult to interpret any between-groups differences should they be obtained (see also Ashton, 2017). Comparing the results of different studies is also challenging, given that there are likely many different kinds of wine expert (see Ashton, 2017, p. 66, on this point). Here one can think in terms of Shanteau's (1987, p. 99) distinction between sensory (or perceptual) experts on the one hand and cognitive experts on the other. The former considered as relying on *"highly developed sensory skills [to] perceive differences that are not apparent to others,"* whereas the latter apparently rely on superior knowledge and an ability to *"think through problems [to] discover relations not found by others."* While, according to Ashton (2017), wine experts must be both sensory and cognitive experts, it is easy to imagine that the relative weighting of sensory to cognitive skills might well vary between wine makers and wine writers, say. Both, note, typically categorized as wine experts in the cross-sectional research (see Spence & Wang, in press, for a review). That there might be salient differences between these groups was certainly hinted at when we tested a small number of wine writers specialized in Champagne in a blind-tasting of seven sparkling wines where the proportion of white to red grapes varied systematically from blanc-de-blanc to blanc-de-noir (see Harrar, Smith, Deroy, & Spence, 2013). Somewhat surprisingly, we found that these wine experts were not able to determine perceptually the relative proportions of red and white grapes, despite writing intellectually/cognitively at length about the importance that this makes to Champagne. However, that said, the inconsistency that has been identified in wine judges' assessments at professional blind tasting competitions can also be taken to suggest that much of their expertise may be more on the cognitive, rather than perceptual, end of the spectrum too (see Spence, 2010c, for a review).[15]

3 Longitudinal studies of perceptual learning in the chemical senses following training

In terms of longitudinal studies of the effects of training on chemosensory perception, the research that has been published to date can be divided into those studies that have looked at perceptual learning in the fields of orthonasal olfactory, gustatory/trigeminal, and multisensory flavour perception. We will take a look at each of these in turn.

3.1 Olfactory perceptual learning

Several longitudinal studies have reported orthonasal olfactory perceptual learning as a result of training. While some studies have looked at changes in detection threshold, others have assessed any enhancement in identification accuracy instead. Interestingly, significant improvements in participants' performance have been reported in both situations. Furthermore, the odd study has reported an enhancement in aspects of participants' olfactory recognition memory too following training (Chollet & Valentin, 2006; Jehl, Royet, & Holley, 1995). That said, one feature that is key to many of the threshold studies is that explicit training has typically been restricted to the repeated presentation of a single olfactory stimulus. While noting the

[15] That, or the rigorous and unremitting tasting schedules at many competitions (sometimes involving the assessment of a flight of 60 wines at a single sitting) perhaps do not enable a taster to be as precise in their judgments as might otherwise be the case under optimized testing conditions.

complexity associated with trying to understand the dimensionality of olfactory stimuli, Green et al. (2018, p. 14), in their recent review of perceptual learning, suggest that: *"there is strong evidence suggesting that olfactory perception is subject to the same types of perceptual learning effects as are observed in every other sense."*

Olfactory identification: In one early study, Desor and Beauchamp (1974) trained three participants to identify 64 odours orthonasally. The stimulus set included a number of different foods and seasonings (e.g., molasses, dill pickle, soy sauce, celery seed) musty book, ivy, pencil sharpener shavings, as well as the synthetic smell of sweat and lilac. Training involved presenting the odours in a random order, with participants being required to try and name the odorant correctly. The correct name being given by the experimenter immediately thereafter if the participant happened to be mistaken.[16] The results revealed that both the number of errors and the latency of naming responses decreased: After limited training, 32 odorants could be identified perfectly, and near-perfect performance was reported for a larger set of 64 odorants. Desor and Beauchamp quantified this improvement as going from 3.9 to 5.9 bits of olfactory information with training. The suggestion was also made that 'whole' odours might be easier to identify than single compounds (as used in much of the previous research). At the same time, however, it should also be noted that no assessment of how long-lasting the improvement in olfactory identification performance was reported. Hence, it is unclear whether such results necessarily meet the long-lasting component of definitions of perceptual learning (see Goldstone, 1998; Green et al., 2018).

In another study by Rabin (1988; Experiment 1), a group of 14 participants was first given seven target stimuli to smell, and were instructed to generate a label for each one. Note that that stimuli were specifically chosen to be unfamiliar initially. Next, the seven olfactory stimuli were presented repeatedly (11 times in total) over the course of an hour in which the participants had to try and recall the label that they had previously given. Immediate feedback was provided following any incorrect responses. Interestingly, a significant improvement (c. 30%) in participants' performance was highlighted on a subsequently-administered two-interval same-different olfactory discrimination task when compared to the performance of an

[16] Although the exact details are unclear, the methods section of this short paper describes several training sessions being administered on some days. In total, the study would appear to have lasted for something like two months.

untrained group (N = 14) or to a group trained on a different set of seven olfactants (N = 14). The performance of a fourth group (N = 14) required to spend 8 minutes creating an olfactory quality profile of each of the seven stimuli, showed intermediate performance (see also Wilson & Stevenson, 2003). As will become relevant shortly, no sex differences were reported. Furthermore, no transfer of learning to untrained odours was observed. However, that said, there was also no assessment of how long-lasting these benefits were, to ensure that they fit the criteria for genuine perceptual learning.

<u>Olfactory detection thresholds:</u> Dramatic improvements in olfactory sensitivity have been documented in a subset of those individuals who, at the start of testing, were functionally anosmic to compounds such as androstenone (Wysocki, Dorries, & Beauchamp, 1989). In one oft-cited study, Wysocki et al. documented a graded increase in the rated intensity of androstenone in about half of their participants. Meanwhile, a four orders of magnitude decrease in threshold to androstadienone, a steroid present in human sweat, was reported in another study by Jacob, Wang, Jaffer, and McPhee (2006). Elsewhere, Stevens and O'Connell (1995) demonstrated the cross-facilitation to androstenone following repeated exposure to pemenone, which has a urine-sweaty odour (just like androstenone though, in fact, they are chemically unrelated) biweekly to 18 participants. In particular, the latter researchers assessed detection thresholds for four odorants (pemenone, androstenone, isovaleric acid, and phenylethyl alcohol) before and after 7-8 weeks biweekly exposure to 200 mM pemenone in mineral oil. A group of control participants (N = 22) were only exposed to the mineral oil during training. Exposure, in this case, consisting of nothing more complex than two or three full sniffs of the olfactory stimuli. Intriguingly, significant decreases in the detection threshold were seen in the experimental, relative to the control, group only for androstenone; That is, there was no significant change in sensitivity to the exposed stimulus (pemenone). Ten of the 18 participants showed increased sensitivity, eight of whom had initially been anosmic to androstenone. The suggested explanation for this somewhat unusual pattern of results being the putative existence of shared receptor channels giving rise to that urinous-sweaty note in both olfactory stimuli. Taken together, such results lead to the suggestion that olfactory perceptual learning may be specific both in the sense that it might be restricted to biologically-relevant stimuli, and specific also in the sense that only a subset of individuals might demonstrate a lowering of their detection threshold following training.

Much the same conclusion was reached in another study by Cain and Schmidt (2002) in which significant changes were reported in people's sensitivity to glutaraldehyde (a biocide that might appear in disinfected potable water). This flavour component was assessed orthonasally in 30 participants, 16 of whom presented with normal sensitivity to glutaraldehyde on initial threshold testing while a further 14 were found to be anosmic. The former group exhibited a lowering of their detection threshold with training. Meanwhile, eight of those in the latter group showed no improvement, while the remaining six, who were initially anosmic, showed a dramatic improvement in performance with training over the second to fourth training sessions. That said, the latter group's performance never reached the levels of sensitivity of the sixteen participants who had been sensitive to this particular dialdehyde in the first place.

A somewhat different pattern of results was documented by Dalton, Doolittle, and Breslin (2002) in a short paper appearing in *Nature Neuroscience*. These researchers demonstrated some pretty dramatic improvements in olfactory sensitivity to a couple of everyday odorants (benzaldehyde & citralva) in women of reproductive age who started the study with olfactory detection thresholds that were seemingly regular. Intriguingly, however, in this case, no such orthonasal olfactory perceptual learning effects were demonstrated in male participants, nor in pre-menarchal or post-menopausal women. What is more, these changes in sensitivity to benzaldehyde, which has a cherry-almond smell, averaging five orders of magnitude (3-6 log units; the authors using the language "vastly improve", p. 199), were demonstrated across 30 repetitions of a similar threshold assessment test regularly spaced over a period of 60 days. The stimulus specificity of this effect was demonstrated by showing that oral thresholds for saccharin (sweet tastants) were unaffected by repeated testing over the same interval.

In another of Dalton et al.'s (2002) experiments, female participants of reproductive age showed a slight cross-facilitation of sensitivity to 5-methylfurfural (which has a cherry-like odour that is similar to that of benzaldehyde), but not to the more perceptually dissimilar amyl acetate (which smells of apple/banana, a key ester and result of alcoholic fermentation) following threshold testing with benzaldehyde (N = 12 participants; 20 thresholds over 10 sessions). A similarly impressive gender-specific effect of repeated test exposure to citralva (geranyl nitrile, described as having a lemon-orange smell) was documented in another experiment (N = 5 female and 5 male participants) over 8 threshold detection sessions. The stimulus specificity of this particular benefit was demonstrated by demonstrating that participants' detection thresholds for benzaldehyde did not change over the same period (see

Figure 2). Dalton et al. note, albeit only in passing, that enhanced sensitivity following repeated threshold testing for benzaldehyde was still present three months later. The relatively long-lasting nature of such changes, note, consistent with Goldstone's (1998) definition of perceptual learning, as quoted at the start of this piece. And for those wanting to know what long-lasting actually means, according to Green et al.'s (2018, p. 4) recent review, it is any change that lasts on the order of days or weeks. The two aspects of Dalton et al.'s results that are pretty unique, and which have not been observed in much of the other research in this area being the specificity of the learning (restricted to women of reproductive age) on the one hand, and, on the other, the fact that olfactory stimuli without any obvious biological significance were used to demonstrate profound facilitation in terms of lowering of detection thresholds.

INSERT FIGURE 2 ABOUT HERE

Some apparently impressive examples of olfactory perceptual learning were also reported by Tempere and colleagues (2012). These researchers took two subsets of participants, selected on the basis of their relative insensitivity to the wine-relevant odorants linalool (which has been described as smelling of floral, citrus, coriander seed, apricot) and diacetyl (which smells buttery) when tested initially. Note that these two compounds are both structurally and perceptually quite different. Each group of participants was then trained for a month, smelling the supraliminal odorant that they had been pre-selected because they were relatively insensitive to, on a daily basis over the course of a month two or three times for about a minute. The participants had to write notes describing the smell. In total, over the course of the month, the participants had 23-26 days of exposure to the odorant. Thereafter, the two groups were tested once again in order to determine whether the detection thresholds to the trained and untrained odorants had changed. Intriguingly, on retest, thresholds for the trained odorant were significantly lower than at pre-test. For instance, the absolute threshold for diacetyl was reduced by a factor of 13.4. By contrast, no such change was documented in detection thresholds for the compound that the participants had not been preselected for (see **Figure 3** for a summary of the results).

INSERT FIGURE 3 ABOUT HERE

While Tempere et al.'s (2011) results might initially sound impressive, it is important to note that essentially the same pattern of results would also have been predicted due to the phenomenon of regression to the mean (see Barnett, van der Pols, & Dobson, 2004; Senn, 1997). And while it might be argued that detection thresholds should be fixed in an individual, one only needs to go back to the earlier research on olfactory threshold testing to see that that is by no means always the case. Indeed, the variability of test-retest olfactory detection thresholds that are sometimes obtained in the same individual has been specifically commented on previously by both Lawless et al. (1994) and Stevens et al. (1988). As Lawless et al. (1994, p. 54) noted a quarter century ago: "*The study by Stevens et al. (1988) on individual variability should serve as a warning that classifying an individual as "insensitive" may not hold up in later tests. Thus it is prudent for studies that examine individual reactions to flavour compounds to test panellists over an extended time frame if classification of individuals is an experimental goal. Single threshold estimates or in limited replications performed over a few test sessions spaced closely in time may be inadequate to provide prediction of future olfactory perceptions.*" It can, I believe, be argued that such variability adds weight to the possibility that Tempere et al.'s results may have been confounded, if not entirely explained, by regression to the mean.[17]

The results reported in this section would therefore appear to demonstrate that profound perceptual learning is possible in the chemical senses. Such results, obtained in longitudinal studies of orthonasal olfaction, stand in stark contrast to the very modest cross-sectional threshold changes that were documented in **Section 2.1**. The results that have been reported here suggest both that olfactory perceptual learning is largely stimulus-specific. What is more, learning may work best when single odorants are presented in isolation, rather than, say, when a taster is operating in a complex chemically diverse, and chemically varying, backdrop of wine-relevant olfactory stimuli. Note here only that a quality wine will likely contain somewhere in the region of 600-1,000 volatile organic compounds (Rapp, 1990; Tao & Li, 2009), of which, it is suggested, only 30-40 actually contribute directly to the perceived nose/flavour. In this sense, the results of research in the chemical senses would appear to be similar to what has been shown previously in the world of perceptual learning in the so-called higher senses (e.g., see Green et al., 2018). In fact, some researchers have suggested that the extent to which olfactory generalization occurs may depend as much on the protocol adopted as on the stimuli used (see Cain & Gent, 1991; Engen, 1960). Indeed, experience of the testing

[17] While there may well have been some genuine stimulus-specific perceptual learning in Tempere et al.'s (2011) study, the contribution of regression to the mean cannot be easily quantified *a posteriori*.

protocol has itself been shown to influence thresholds – i.e., showing-up as a gain in sensitivity regardless of odour type (Rabin & Cain, 1986).

In conclusion, the literature on orthonasal olfactory perceptual learning that has been reported to date would appear to show that when it occurs, it is very specific. While some of the most dramatic early improvements were shown with certain biologically-relevant odorants (e.g., Wysocki et al., 1989), subsequent research has demonstrated profound enhancements in threshold detection with a number of other orthonasally-delivered olfactory stimuli as well (e.g., Dalton et al., 2002; Tempere et al., 2012). However, the results would also appear to be specific in the sense that olfactory perceptual learning, at least in terms of a lowering of detection thresholds, was only demonstrated in women of reproductive age by Dalton et al. (2002). That said, no such sex differences have been reported in the majority of other studies in this area (e.g., see Rabin, 1988). Some of the most dramatic improvements have been reported in those who were initially anosmic to compounds such as androstenone (Wysocki et al., 1989; see also Tempere et al., 2012), and/or those suffering from olfactory loss (e.g., Hummel et al., 2009). That said, later research has, on occasion, documented improvements for other stimuli too, namely those without any obvious special biological significance/initial problems with detection (e.g., Dalton et al., 2002). Short-term improvements in orthonasal identification accuracy have also been reported (e.g., Desor & Engen, 1974; Rabin, 1988), though, in the latter case, there has been little mention of how 'long-lasting' the results are. There has also been little evidence of generalization beyond the specific stimulus set tested. While the benefits of training have been documented to last for at least 6 weeks in the case of the acquired sensitivity to androstenone (Wysocki et al., 1989), and for three months in the case of benzaldehyde in the female participants of reproductive age who were tested by Dalton et al., many other studies have simply not attempted to assess how long their effects lasted, after the termination of training. What this means, in practice, is that it is unclear whether the effects observed necessarily meet one of the key criteria for classification as perceptual learning or not (see Green et al., 2018).

3.2 Gustatory perceptual learning

Over the years, a number of reports have been published, documenting that regular consumers confuse sour and bitter, specifically reporting bitter when tasting citric acid (e.g., Robinson, 1970). The research shows that training with named taste reference samples immediately eliminates this confusion (Amerine & Roessler, 1976; McAuliffe & Meiselman, 1974; O'Mahony, Goldenberg, Stedmon, & Alford, 1979). What is more, the improvements have been reported to last for several weeks after training. Given the lack of awareness of/knowledge about umami, the fifth taste amongst many western participants, it might also be considered a good target for demonstrating gustatory perceptual learning. It is easy to imagine that there might also be perceptual learning in western participants in relation to this particular tastant (Kobayashi & Kennedy, 2002; Kobayashi, Kennedy, & Halpern, 2006; see also Faurion, Cerf, Pillias, & Boireau, 2005). In Kobayashi and colleagues' studies, students at Cornell University were briefly exposed to monosodium glutamate (MSG) in a potato-flavoured cracker snack, eating a few pieces each day for 10 days. The control group ate a store-bought snack without MSG according to the same schedule. Interestingly, however, the enhanced sensitivity, specifically the lowered detection threshold to MSG, was time-limited, with performance declining when participants were tested 10 days after the MSG-enhanced foods had been stopped. The latter observation thus arguing against these particular changes reflecting perceptual learning, given that the latter has been defined as involving long-lasting changes to an organism's perceptual system (Goldstone, 1998, p. 585; Green et al., 2018).

3.3 Flavour perceptual learning

In one of the few studies of perceptual learning to have been conducted with wine as the stimulus, Walk (1966) trained three groups of participants (again, college students at Cornell University) to discern whether two successive sips of dry white wine (the wines were from New York State) were the same or different. The same wine was presented in half of the trails, while different wines was presented in the remainder of the trials. The blindfolded participants (N = 30) underwent 40 trials, with the first 10 judgments used for pre-test analysis and the last 10 for post-test analysis. One group of participants (N = 10 in each group) was given correct/incorrect feedback, another group was given the same feedback while the wines were also identified by a cardinal number (after the participant had responded), and a third group was given no feedback at all. In this case, a small but significant improvement in participants' performance was reported (mean improvement of 9%, up from 62% to 71% correct) in the post-test as compared to the pre-test, after only 20 trials of training. However, that said, there was no between-groups difference in performance (i.e., as a function of the training regimen).

Closer analysis of the results revealed that the majority of the improvement came on 'same' trials, where performance from pre- to post-test increased from 44% to 70%. Walk (1966, p. 58) himself concluded that: *"some perceptual learning can apparently take place without any particular training"*.[18] One might, however, wonder how much of the improvement reported by Walk reflected a genuine increase in sensitivity versus a change in response bias on the 'same' trials to say different (see also Owen & Machamer, 1979, on this point). Owen and Machamer reported similar results subsequently following training in wine tasting. The latter researchers documenting a 14% improvement in the accuracy of same/different judgments for four dry white wines over three test sessions alternated with two training sessions (involving a total of only 16 trials).

Meanwhile, in a more elaborate study, Wang and Prešern (2018) recently demonstrated that with training, 15 members of the Oxford University Blind Tasting Society improved significantly in several areas of their wine-tasting performance. The participants in question attended between 9 and 18 training sessions over a five-week period. Each session involved members tasting two flights of 10-12 wines in silence. After each flight of white/red wine, the team members discussed their guesses and learned what the correct answers had been (see also Findlay, Castura, Schlich, & Lesschaeve, 2006, on the use of feedback calibration to help reduce the training time for wine panels). These individuals became more accurate in terms of assessing the acidity of the wines. On a more abstract level, they also improved significantly in terms of their accuracy when guessing the grape variety, which can be seen as a higher form of conceptual learning (see also Parr, 2018). There was also evidence of increased consensuality (i.e., within-group agreement), and increased length of tasting notes amongst their more experienced tasters. However, that being said, there was no change in vocabulary size, nor was there any improvement in judgments of the country/region of origin of the wines tasted blind. And, on the downside, training actually reduced the accuracy of the tasters' estimates of the age (vintage) of the wines! Elsewhere, in a recently-submitted conference abstract, Wang, Presern, Fermandes, and Fjældstad (2019) reported beneficial effects on olfactory and taste threshold, discrimination, and identification of blind tasting training assessed by means of triangle tests. Once again, a training group (N=19) and a control group

[18] It is, though, surprising to note that Green et al. (2018) categorize Walk's (1966) study under taste (gustation) – a simple stimulus (or as the authors put it a *"Basic stimulus dimension"*). However, it can be argued that it should rather have been categorized as a study of the perceptual learning of multisensory flavour and, as such, really deserved to have been placed in the latter section of their otherwise excellent chapter dealing with *"Multi-attribute/Complex stimuli"* instead.

(N=13) were tested before and after the former underwent a five-week blind wine tasting regime. The preliminary results suggested a significant difference between the training and control groups as far as changes in olfactory discrimination were concerned ($M_{training}$ = 0.63, $M_{control}$ = -1.25, p = .02).

Several beer training studies have also been published over the last couple of decades. For instance, Peron and Allen (1988) demonstrated a significant improvement in people's ability to discriminate between beers that had initially been indiscriminable, as a result of additional taste experience. No such improvement was documented in another group of participants who were only trained on beer-flavour terminology. Four groups of ten undergraduate participants were tested in this study. The experimental groups comprised: Taste, verbal, taste labelled with descriptive adjectives, and a control group. The participants were pre-selected on the basis that they had initially failed to perform at a level that was better than chance in three triangle tests (i.e., they were 'non-discriminators' who got no more than one correct). The taste training basically involved participants sampling seven beers. Thereafter, the taste group was shown to perform slightly better in a beer-similarity taste task, involving seven pairs of beers. Specifically, the novices in the taste group became better at detecting when they had been presented with identical beer flavours. This was also the only group whose performance in three subsequently-presented triangle taste tests improved. Elsewhere, however, Chollet and Valentin (2001) failed to demonstrate any benefit of 11 hrs of training on beer-tasting and terminology.

That said, several subsequent beer studies have demonstrated modest benefits of training. For instance, Chollet and Valentin (2006) assessed the impact of 15 hrs of training, showing that it led to a non-significant trend toward a reduction in participants' detection threshold for isoamyl acetate (a banana aroma) in triangle tests. No benefit was seen in a paired same-different beer discrimination task, nor was any change noted in a beer sorting task (though see also Lelièvre, Chollet, Abdi, & Valentin, 2008). In another experiment, a series of verbal tasks were given to participants after 0, 8, 24, and 32 hrs of training. The ability of the participants to identify aromas that had been added to beers increased from 25-45% during this time, with evidence suggesting that improvements would have continued even further had training continued. The experts were also better at a beer communication task when matching beers by means of verbal exchange with a partner. However, in this case the amount of training (11, 44, or 61 hrs) did not lead to a significant improvement, suggesting that the benefits had most likely already been established during the first 11 hrs of training. Taken together with other cross-sectional results, Chollet and Valentin argued that their results were consistent with the view that while people acquired beer-relevant vocabulary, and an ability to communicate about beer early on in their training, perceptual abilities are only acquired later on. And, once again, a further cross-sectional study (comparing novices with those with 72 hrs of training) revealed that the perceptual benefits of training were restricted just to the trained beers in matching and discrimination tasks (that is, there was a lack of generalization).

Elsewhere, Hughson and Boakes (2009) attempted to separate out the effects of experience drinking wine from those of wine-training/wine expertise by evaluating the matching performance of one group of participants (labelled ‘intermediates’) who had been drinking wine for an average of 9 years, with that of another group who had only been drinking wine for an average of 1.25 years (the latter were called ‘novices’). The 20 participants in each group tasted one wine, after which there was a delay of four minutes in which they either had to describe the wine that they had just tasted, or else they completed an unrelated crossword. Thereafter, the participants tasted four wines and had to try and pick the wine that they had tasted four minutes earlier. Specifically, the participants were requested to rate each sample on a 7-point scale (where 1 = ‘was definitely not the target’ through to 7 = ‘highly confident that it was the target’). The procedure was then repeated a second time with another selection of four wines. The participants performed better than chance in all conditions and, more importantly for present purposes, the intermediates performed significantly better than did the novices in recognizing the wine. However, contra Melcher and Schooler’s (1996) results mentioned earlier, there was no sign of verbal overshadowing – that is, performance was no worse following participants describing the wines than in the unrelated crossword condition.

In an analogous study of experience (rather than expertise) in the world of fragrance, Hummel, Guel, and Delank (2004) demonstrated that those working in perfume retail outlets performed significantly better in odour discrimination tests (specifically, triangle tests) than did controls (no differences were reported in terms of olfactory identification or *n*-butanol detection threshold). Such results, demonstrating that regular exposure to chemosensory stimuli (be it wine or perfume) leads to enhanced performance even in the absence of explicit training, may then help explain why no significant effect of explicit training has sometimes been observed in previous research. That is, the novice groups used in both cross-sectional and longitudinal studies may sometimes already have improved their performance due to passive exposure. At the same time, however, the behavioural effects of olfactory training of untrained control individuals had also been reported in a study by Royet et al. (2013, p. 8). The latter researchers demonstrated an improvement of olfactory performance in terms of sensitivity, discrimination, memory, and identification, thus showing training effects in addition to any effects of mere exposure to a certain class of stimuli. Intriguingly, here, the latter researchers have also reported neuroimaging results arguing that: "*The structural modifications observed in the brain after intensive practice of an activity are not stable and rapidly disappear when this activity stops (Jancke, 2009).*" Such findings obviously do not bode well for our search for perceptual learning in the chemical senses, given the definition that any training-related changes should be long-lasting.

3.4 Problems with training studies in the case of chemosensory perceptual learning

The limitation with many of the training studies in the world of chemosensory perceptual learning is often that only relatively small amounts of training have been delivered. For example, in the longitudinal studies reported in this section, the amount of training has ranged from just 20 trials on Walk's (1966) wine study, to 23-26 days smelling a specific olfactant once a day (Tempere et al., 2011). The five-weeks of training at blind taste testing (with feedback) delivered to the participants in Wang and Prešern's (2018) study[19] looks positively extensive in comparison. Though, even in the latter case, it is worth noting that training involved exposure to a maximum of a little over 200 wines. Putting this issue into some kind of perspective, it is not unusual for studies of perceptual learning in the higher spatial senses to involve several thousand trials of practice. For instance, in their study of perceptual learning in visual contrast perception, Sowden, Rose, and Davies (2002) presented their participants with a mind-numbing 10,000 trials of practice. One other problem with training studies of perceptual learning highlighted by Green et al. (2018, p. 6), is that they rarely: *"control for participant reactivity effects (e.g., wherein participant performance changes not because of the specific type of experience, but simply because they are aware of being observed or because they have expectations of improvements)"*. And finally, as we have just seen, given the significant beneficial effects of passive exposure to chemosensory stimuli documented in certain studies

[19] Though no information is provided in the paper itself, after each session (actually after each white/red flight) people discussed their guesses and learned what the right answers were.

(e.g., Hughson & Boakes, 2009; Hummel et al., 2004), groups of so-called 'novice' participants may sometimes perform more like 'intermediates' (hence potentially reducing any differences from experts) in those areas, like wine and beer, where people are likely to have come across a number of the relevant stimuli in their daily lives.

4. Conclusions

Kellman and Garrigan (2009, p. 77), in their review, suggested that perceptual learning is *"arguably one of the most, possibly the most, important component of human expertise"* There is little reason to believe that this is any less true when it comes to the world of chemosensory perceptual learning. That said, chemosensory information processing would seem to have been largely neglected by mainstream research on perceptual learning in recent decades. Instead, the literature has tended to focus squarely on the higher spatial senses (e.g., Goldstone, 1998; Green et al., 2018). At the same time, however, a growing body of evidence from research comparing chemosensory experts with non-experts (or novices) hints at the presence of modest sensory/perceptual changes, alongside some much more pronounced semantic/conceptual changes. Enhanced olfactory/flavour recognition memory has often been shown in chemosensory experts, be it in the world of wine or beer. While the majority of the perceptual learning research relating to chemosensory perception has tended to focus on the world of wine expertise, a much smaller parallel body of literature has dealt with the consequences of expertise in the world of beer. Ultimately, though, the two literatures have ended-up coming to many of the same conclusions. That said, it does seem fair to say that there may be more semantic/conceptual knowledge to acquire in the world of wine – think here only of the various sensory associations that a wine expert might have with a wine made from a particular grape variety. From the outside, it does rather feel as though, in the world of beer expertise, the focus is much more on identifying and avoiding faults that are detected perceptually.

It is always important to bear in mind that the orders of magnitude differences in the amount of training in studies of perceptual learning in the higher spatial senses as compared to the chemical senses might reasonably be expected to result in qualitatively different effects being documented in the two cases. Certainly, one of the long-standing questions in research on perceptual learning is the nature of any transfer of learning beyond the specific set of stimuli that the participant has been explicitly trained on (e.g., see Gibson, 1953; Harrar et al., 2014). Much like for the spatial senses, there is, as yet, little published evidence of transfer, or generalization, of perceptual learning, beyond the specific set of chemosensory stimulus on which people have been trained.[20] Once again, looking from the outside, perhaps one of the limitations is that the training regimens in olfactory perceptual learning studies have very often been designed to maximize immediate performance improvement. However, what has become increasingly clear from perceptual learning research conducted in the spatial senses is that those factors that help to maximise immediate improvement do not necessarily maximize long-term learning (e.g., Schmidt & Bjork, 1992; see also Carvalho, & Goldstone, 2015). At the same time, though, what is also apparent is that the difficulty in recruiting a sufficient number of chemosensory experts has resulted in many of the published studies in this area likely being statistically underpowered.

While the majority of the perceptual learning literature has focused on very simple situations, there have been many examples of perceptual learning in more complex and multidimensional areas (see Green et al., 2018, for a review). Indeed, as Green et al. (2018, p. 19) put it, *"one incredibly common finding in the perceptual learning literature is that the improvements that result from training are open highly specific to the exact trained task and stimuli (e.g., in the visual domain, to the exact position, orientation, and spatial frequency of the trained stimuli). In these cases, little or no benefits are observed when even seemingly minor changes are made away from the trained stimuli."* Optimizing perceptual learning/training regimes is undoubtedly an important issue for many professionals in the wine industry (Tempere et al., 2012), as well as in the food industry more generally (e.g., Labbe, Rytz, & Hugi, 2004).

Over the years, some researchers have attempted to distinguish perceptual learning from cognitive learning or attentional learning. However, such distinctions have not necessarily proved easy to maintain (see Green et al., 2018). The same difficulty in making such distinctions likely affects chemosensory perceptual learning too. At the same time, however, there has also been a suggestion that sensory dominance/attentional differences may be observed as a result of extensive training. One of the key findings to emerge from the contemporary literature on perceptual learning in the higher senses (e.g., vision, audition, and touch) concerns the role of attention (e.g., see Roelfsema, van Ooyen, & Watanabe, 2010; Watanabe & Sasaki, 2015). Talk of perceptual learning leading to increased attention to/ interest in (e.g.,) odorous features has also been mentioned when considering the world of wine

[20] As Green et al. (2018, p. 36) concluded recently: *"Thus, which ingredients are most critical to producing generalization (and which are irrelevant) still remain to be fully elucidated."*

expertise (e.g., Bende & Nordin, 1997; see also Walk, 1978). Such claims certainly fit with the claim that perceptual learning leads the expert to attend more to relevant features and to ignore the irrelevant ones (Goldstone, 1998).

On the one hand, there is reason to believe that perceptual learning should operate in the chemical senses in much the same way that it has been shown to do for the other higher spatial senses. It might, for instance, be achieved by turning up the gain on the stimulus representation (equivalent to stimulus enhancement), a reduction of external noise, or possibly some combination of the two (see Dosher & Lu, 1999). That being said, there is also some debate in the literature concerning the consequences of reduced neural resources (relative to the higher spatial senses) for the processing of chemosensory stimuli (e.g., see Stevenson & Attuquayefilo, 2013). Indeed, the latter researchers have made a persuasive case that many of the distinctive features of olfactory consciousness/attention can be linked to the limited processing resources that are available to the olfactory system (cf. Gagnon, Kupers, & Ptito, 2014). One of the other interesting, and perhaps unique, features of perceptual learning in olfaction is the change in odour quality that one sometimes sees as a result of exposure-induced sensitization (Jacob et al., 2006).

Having provided evidence of perceptual learning in the world of chemosensory perception, one of the important questions for future research will be to determine the central vs. peripheral locus of such effects (cf. Green et al., 2018; Wilson Kadohisa, & Fletcher, 2006; Wilson & Stevenson, 2003). It will also be interesting to find out more about the neural mechanisms underlying perceptual learning as far as the chemical senses are concerned (see Dosher & Lu, 1999; Irvine, 2018; Roelfsema, van Ooyen, & Watanabe, 2010; Watanabe & Sasaki, 2015). To date, cross-sectional studies have documented central changes in wine/perfume experts using fMRI (Castriota-Scanderbeg et al., 2005; Pazart et al., 2014; Plailly et al., 2012). Meanwhile, Li, Luxenberg, Parrish, and Gottfried (2006) have also documented neural changes in piriform and orbitofrontal cortex in response to the repeated exposure to a specific odorant. At the same time, however, several researchers have documented exposure-dependent peripheral changes at the level of the receptors in the olfactory mucosa (Wang, Chen, & Jacob, 2004; cf. Yee & Wysocki, 2001), especially in the animal model.[21] Indeed, it is the increased opportunity for changes to take place at the level of the peripheral receptor that are part of what makes the

[21] However, the question of whether such peripheral mediation reflects increased expression of receptors, perhaps increased efficiency of sensory transduction, and/or an increase in the number of responsive neurons in the olfactory mucosa remains to be determined (cf. Jones, Choi, Davis, & Ressler, 2008).

study of chemosensory perceptual learning such a fascinating area. No one, at least not as far as I am aware, is talking about such peripheral changes taking place as a result of perceptual learning in the ‘higher’ spatial senses.

REFERENCES

Amerine, M. A., Pangborn, R. M., & Roessler, E. B. (1965). *Principles of sensory evaluation of food*. New York, NY: Academic Press.

Amerine, M. A., & Roessler, E. B. (1976). *Wines: Their sensory evaluation*. San Francisco, CA: W. H. Freeman and Company.

Amoore, J. E. (1977). Specific anosmia and the concept of primary odors. *Chemical Senses Flavor*, **2**, 267-281.

Arvisenet, G., Guichard, E., & Ballester, J. (2016). Taste-aroma interaction in model wines: Effect of training and expertise *Food Quality & Preference*, **52**, 211-221.

Ashkenazi, A., & Marks, L. E. (2004). Effect of endogenous attention on detection of weak gustatory and olfactory flavors. *Perception & Psychophysics*, **66**, 596-608.

Ashton, R. H. (2017). Dimensions of expertise in wine evaluation. *Journal of Wine Economics*, **12(1)**, 59-83.

Ballester, J., Abdi, H., Langlois, J., Peyron, D., & Valentin, D. (2009). The odor of colors: Can wine experts and novices distinguish the odors of white, red, and rosé wines? *Chemosensory Perception*, **2**, 203-213.

Ballester, J., Mihnea, M., Peyron, D., & Valentin, D. (2013). Exploring minerality of Burgundy Chardonnay wines: A sensory approach with wine experts and trained panellists. *Australian Journal of Grape and Wine Research*, **19**, 140-152.

Ballester, J., Patris, B., Symoneaux, R., & Valentin, D. (2008). Conceptual vs. perceptual wine spaces: Does expertise matter? *Food Quality and Preference*, **19**, 267-276.

Barnett, A. G., van der Pols, J. C., & Dobson, A. J. (2004). Regression to the mean: What it is and how to deal with it. *International Journal of Epidemiology*, **34**, 215-220.

Bartoshuk, L. M. (2000). Comparing sensory experiences across individuals: Recent psychophysical advances illuminate genetic variation in taste perception. *Chemical Senses*, **25**, 447-460.

Bedichek, R. (1960). *The sense of smell*. New York, NY: Doubleday.

Bell, G. A., & Paton, J. E. (2000). Verbal-cognitive strategy can influence odor identification. *Chemical Senses*, **25**, 612-613.

Bende, M., & Nordin, S. (1997). Perceptual learning in olfaction: Professional wine tasters versus controls. *Physiology and Behavior*, **62**, 1065-1070.

Berg, H. W., Filipello, F., Hinreiner, E., & Webb, A. D. (1955). Evaluation of thresholds and minimum difference concentrations for various constituents of wines. *Food Technology*, **9**, 23-26.

Boakes, R. A., & Hemberger, H. (2012). Odour-modulation of taste ratings by chefs. *Food Quality and Preference*, **25**, 81-86.

Brand, G., & Brisson, R. (2012). Lateralisation in wine olfactory threshold detection: Comparison between experts and novices. *Laterality*, **17**, 583-596.

Broadbent, J. (1968). *Wine tasting: A practical handbook on tasting and tastings*. London, UK: Wine & Spirit Publications.

Brochet, F. (1999). The taste of wine in consciousness. *Journal International des Sciences de la Vigne et du Vin: Special Issue Wine Tasting*, **33**, 19-22.

Brochet, F., & Dubourdieu, D. (2001). Wine descriptive language supports cognitive specificity of chemical senses. *Brain & Language*, **77**, 187-196.

Cadot, Y., Caillé, S., Samson, A., Barbeau, G., & Cheynier, V. (2010). Sensory dimension of wine typicality related to a terroir by Quantitative Descriptive Analysis, Just About Right analysis and typicality assessment. *Analytica Chimica Acta*, **660**, 53-62.

Cain, W. S. (1989). Testing olfaction in a clinical setting. *Ear, Nose, & Throat Journal*, **68**, 78-86.

Cain, W. S., & Gent, J. F. (1991). Olfactory sensitivity: Reliability, generality and association with aging. *Journal of Experimental Psychology*, **17**, 382-391.

Cain, W. S., & Schmidt, R. (2002). Sensory detection of glutaraldehyde in drinking water—emergence of sensitivity and specific anosmia. *Chemical Senses*, **27**, 425-433.

Carvalho, P. F., & Goldstone, R. L. (2015). What you learn is more than what you see: What can sequencing effects tell us about inductive category learning? *Frontiers in Psychology*, **6**:505.

Carvalho, F. R., Wang, Q. (J.), Van Ee, R., & Spence, C. (2016). The influence of soundscapes on the perception and evaluation of beers. *Food Quality and Preference*, **52**, 32-41. https://doi.org/10.1016/j.foodqual.2016.03.009

Castriota-Scanderbeg, A., Hagberg, G. E., Cerasa, A., Committeri, G., Galati, G., Patria, F., Pitzalis, S., Caltagirone, C., & Frackowiak, R. (2005). The appreciation of wine by sommeliers: A functional magnetic resonance study of sensory integration. *NeuroImage*, **25**, 570-578.

Chatonnet, P., Dubourdieu, D., Boidron, J. N., & Pons, M. (1992). The origin of ethylphenols in wine. *Journal of the Science of Food and Agriculture*, **60**, 165-178.

Chollet, S., & Valentin, D. (2000). Le degré d'expertise a-t-il une influence sur la perception olfactive? Quelques éléments de réponse dans le domaine du vin. [Does the degree of expertise influence olfactory perception? A few elements of the answers in the field of wine.] *L'Anne Psychologique*, **100**, 11-36.

Chollet, S., & Valentin, D. (2001). Impact of training on beer flavor perception and description: Are trained and untrained subjects really different? *Journal of Sensory Studies*, **16**, 601-618.

Chollet, S., & Valentin, D. (2006). Impact of training on beer flavour perception. *Cerevisia*, **31(4)**, 189-195.

Chollet, S., Valentin, D., & Abdi, H. (2005). Do trained assessors generalize their knowledge to new stimuli? *Food Quality and Preference*, **16**, 13-23.

Clapperton, J. F., & Piggott, J. R. (1979). Flavour characterization by trained and untrained assessors. *Journal of the Institute of Brewing*, **85**, 275-277. doi: 10.1002/j.2050-0416.1979.tb03922.x

Croijmans, I., & Majid, A. (2016). Not all flavour expertise is equal: The language of wine and coffee experts. *PLoS ONE*, **11(6)**:e0155845.

D'Alessandro, S., & Pecotish, A. (2013). Evaluation of wine by expert and novice consumers in the presence of variations in quality, brand, and country of origin cues. *Food Quality and Preference*, **28**, 287-303.

Dalton, P., Doolittle, N., & Breslin, P. A. S. (2002). Gender-specific induction of enhanced sensitivity to odors. *Nature Neuroscience*, **5**, 199-200.

Damm, M., Pikart, L. K., Reimann, H., Burkert, S., Göktas, Ö, Haxel, B., Frey, S., Charalampakis, I., Beule, A., Renner, B., Hummel, T., & Hüttenbrink, K.-B. (2014). Olfactory training is helpful in postinfectious olfactory loss: A randomized, controlled, multicenter study. *The Laryngoscope*, **124**, 826-831. http://dx.doi.org/10.1002/lary.24340.

Dempsey-Jones, H., Harrar, V., Oliver, J., Johansen-Berg, H., Spence, C., & Makin, T. (2016). Transfer of tactile perceptual learning to untrained neighbouring fingers reflects natural use relationships. *Journal of Neurophysiology*, **115**, 1088-1097.

Desor, J., & Beauchamp, G. (1974). The human capacity to transmit olfactory information. *Perception & Psychophysics*, **16**, 551-556.

Dosher, B. A., & Lu, Z. L. (1999). Mechanisms of perceptual learning. *Vision Research*, **39**, 3197-3221.

Dosher, B., & Lu, Z. L. (2017). Visual perceptual learning and models. *Annual Review of Vision Science*, **3**, 343-363.

Eldeghaidy, S., Marciani, L., McGlone, F., Hollowood, T., Hort, J., Head, K., et al. (2011). The cortical response to the oral perception of fat emulsions and the effect of taster status. *Journal of Neurophysiology*, **105**, 2572-2581.

Engen, T. (1960). Effect of practice and instruction on olfactory threshold. *Perceptual and Motor Skills*, **10**, 195-198.

Engen, T. (1972). The effect of expectation on judgments of odour. *Acta Psychologica*, **36**, 450-458.

Engen, T. (1982). *The perception of odors*. New York, NY: Academic Press.

Faurion, A., Cerf, B., Pillias, A-M., & Boireau, N. (2005). Increased taste sensitivity by familiarization to novel stimuli: psychophysics, fMRI, and electrophysiological technical suggest modulations at peripheral and central levels. In C. Rouby, B. Schaal, D. l. Dubois, R. Gervais, & A. Holley (Eds.), *Olfaction, taste, and cognition* (pp. 350-366). Cambridge, UK: Cambridge University Press.

Findlay, C. J., Castura, J. C., Schlich, P., & Lesschaeve, I. (2006). Use of feedback calibration to reduce the training time for wine panels. *Food Quality and Preference*, **17**, 266-276.

Frayling, T. M., Beaumont, R. N., Jones, S. E., Yaghootkar, H., Tuke, M. A., Ruth, K. S., et al. (2018). A common allele in FGF21 associated with sugar intake is associated with body shape, lower total body-fat percentage, and higher blood pressure. *Cell Reports*, **23**, 327-336.

Frøst, M. B., & Noble, A. (2002). Preliminary study of the effect of knowledge and sensory expertise on liking for red wines. *American Journal of Enology and Viticulture*, **53**, 275-284.

Frost, R., Quinones, I., Veldhuizen, M., Alava, J.-I., Small, D., & Carreiras, M. (2015). What can the brain teach us about winemaking? An fMRI study of alcohol level preferences. *PLoS ONE*, **10(3)**:e0119220.

Gagnon, L., Kupers, R., & Ptito, M. (2014). Making sense of the chemical senses. *Multisensory Research*, **27**, 399-419.

Garneau, N. L., Nuessle, T. M., Sloan, M. M., Santorico, S. A., Coughlin, B. C., & Hayes, J. E. (2014). Crowdsourcing taste research: Genetic and phenotypic predictors of bitter taste perception as a model. *Frontiers of Integrative Neuroscience*, **8**:33. doi:10.3389/fnint.2014.00033

Gawel, R. (1997). The use of language by trained and untrained experienced wine tasters. *Journal of Sensory Studies*, **12**, 267-284.

Gibson, E. J. (1953). Improvement in perceptual judgments as a function of controlled practice or training. *Psychological Bulletin*, **50**, 401-431.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin.

Gibson, E. J. (1969). *Principles of perceptual learning and development.* New York, NY: Appleton.

Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: Differentiation or enrichment. *Psychological Review*, **62**, 32-41.

Goldstone, R. L. (1998). Perceptual learning. *Annual Review of Psychology*, **49**, 585-612.

Goldstone, R. L., & Byrge, L. A. (2015). Perceptual learning. In M. Matthen (Ed.), *The Oxford handbook of the philosophy of perception* (pp. 1001-1016). Oxford, UK: Oxford University Press.

Green, C. S., Banai, K., Lu, Z.-L., & Bavelier, D. (2018). Perceptual learning. In J. Wixted (Ed.-in-Chief), J. Serences (Vol. Ed.), *The Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience* (4th Ed, Vol. 2, pp. 755-802). Hoboken, NJ: John Wiley & Sons.

Harrar, V., Smith, B., Deroy, O., & Spence, C. (2013). Grape expectations: How the proportion of white grape in Champagne affects the ratings of experts and social drinkers in a blind tasting. *Flavour*, **2**:25.

Harrar, V., Spence, C., & Makin, T. (2014). Topographic generalization of tactile perceptual learning. *Journal of Experimental Psychology: Human Perception & Performance,* **40**, 15-23.

Hayes, J. E., & Pickering, G. J. (2012). Wine expertise predicts taste phenotype. *American Journal of Enology & Viticulture*, **63**, 80-84.

Herdenstam, A. P., Hammaren, M., Ahlstrom, R., & Wiktorsson, P.-A. (2009). The professional language of wine: Perception, training, and dialogue. *Journal of Wine Research*, **20**, 53-84.

Honoré-Chedozeau, C., Lelievre-Desmas, M., Ballester, J., & Valentin, D. (2016). *Vineyards and grape varieties: What is going on in wine professional and consumer minds?* Paper presented at the XIth International Terroir Congress, July.

Hughson, A. L. (2003). Wine expertise: Current theories and findings regarding its nature and bases. *Food Australia*, **55**, 193-196.

Hughson, A., & Boakes, R. (2001). Perceptual and cognitive aspects of wine expertise. *Australian Journal of Psychology,* **53,** 103-108.

Hughson, A. L., & Boakes, R. A. (2002). The knowing nose: The role of knowledge in wine expertise. *Food Quality and Preference,* **13**, 463-372.

Hughson, A. L., & Boakes, R. A. (2009). Passive perceptual learning in relation to wine: Short-term recognition and verbal description. *Quarterly Journal of Experimental Psychology*, **62**, 1-8.

Hummel, T., Guel, H., & Delank, W. (2004). Olfactory sensitivity of subjects working in odorous environments. *Chemical Senses*, **29**, 533-536.

Hummel, T., Rissom, K., Reden, J., Hähner, A., Weidenbecher, M., & Hüttenbrink, K. B. (2009). Effects of olfactory training in patients with olfactory loss. *Laryngoscope*, **119**, 496-499.

Irvine, N. R. F. (2018). Auditory perceptual learning and changes in the conceptualization of auditory cortex. *Hearing Research*, **366**, 3-16.

Jacob, T.-J. C., Wang, L., Jaffer, S., & McPhee, S. (2006). Changes in the odor quality of androstadienone during exposure-induced sensitization. *Chemical Senses*, **31**, 3-8.

James, W. (1890). *The principles of psychology* (2 Vols.). New York, NY: Henry Holt.Jaffré, J., Valentin, D., Dacremont, C., & Peyron, D. (2009). Burgundy red wines: Representation of potential for aging. *Food Quality and Preference*, **20**, 505-513.

Jancke, L. (2009). The plastic human brain. *Restorative Neurology & Neuroscience*. **27**, 521-538. doi: 10.3233/RNN-2009-0519

Jehl, C., Royet, J. P., & Holley, A. (1995). Odor discrimination and recognition memory as a function of familiarization. *Perception & Psychophysics*, **57**, 1002-1011.

Jones, S. V., Choi, D. C., Davis, M., & Ressler, K. J. (2008). Learning dependent structural plasticity in the adult olfactory pathway. *Journal of Neuroscience*, **3**, 13106-13111.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 26-61). San Diego, CA: Academic Press.

Kellman, P. J., & Garrigan, P. (2009). Perceptual learning and human expertise. *Physics of Life Review*, **6**, 53-84. http://dx.doi.org/10.1016/j.plrev.2008.12.001.

Keskitalo, K., Knaapila, A., Kallela, M., Palotie, A., Wessman, M., Sammalisto, S., Peltonen, L., Tuorila, H., & Perola, M. (2007). Sweet taste preferences are partly genetically determined: Identification of a trait locus on chromosome 16. *American Journal Clinical Nutrition*, **86**, 55-63.

Kim, J.-Y., Prescott, J., & Kim, K.-O. (2014). Patterns of sweet liking in sucrose solutions and beverages. *Food Quality and Preference*, **36**, 96-103.

Kobayashi, C., & Kennedy, L.M. (2002). Experience-induced changes in taste identification of monosodium glutamate. *Physiology & Behavior*, **75**, 57-63.

Kobayashi, C., Kennedy, L.-M., & Halpern, B.-P. (2006). Experience-induced changes in taste identification of monosodium glutamate (MSG) are reversible. *Chemical Senses*, **31**, 301-306.Koskinen, K., Reichert, J. L., Hoier, S., Schachenreiter, J., Duller, S., Moissl-Eichinger, C., & Schöpf, V. (2018). The nasal microbiome mirrors and potentially shapes olfactory function. *Scientific Reports*, **8**:1296.

Labbe, D., Rytz, A., & Hugi, A. (2004). Training is a critical step to obtain reliable product profiles in a real food industry context. *Food Quality and Preference*, **15**, 341-348.

Laing, D., & Francis, G. (1989). The capacity of humans to identify odors in mixtures. *Physiology & Behavior*, **46**, 809-814.

Laing, D. G., & Glenmarec, A. (1992). Selective attention and the perceptual analysis of odor mixtures. *Physiology & Behavior*, **52**, 1047-1053.

Lawless, H. T. (1984). Flavor description of white wine by “expert” and nonexpert wine consumers. *Journal of Food Science*, **49**, 120-123.

Lawless, H. T. (1985). Psychological perspectives on wine tasting and recognition of volatile flavours. In G. G. Birch & M. G. Lindley (Eds.), *Alcoholic beverages*. London, UK: Elsevier Applied Science Publishers.

Lawless, H. T., Antinone, M. J., Ledford, R. A., & Johnston, M. (1994). Olfactory responsiveness to diacetyl. *Journal of Sensory Studies*, **9**, 47-56.

Lawless, H., Liu, Y., & Goldwyn, C. (1997). Evaluation of wine quality using a small-panel hedonic scaling method. *Journal of Sensory Studies*, **12**, 317-332.

Lee, N. M. (2018). How to train your nose for wine – the kit that helps you become an expert taster. *South China Morning Post (The Corkscrew)*, **May 10th**. https://www.scmp.com/magazines/post-magazine/food-drink/article/2145455/how-train-your-nose-wine-kit-helps-you-become.

Le Fur, Y., Blanquet, J., Candelon, M., Ballester, J., & Uscida, N. (2004). Méthodologie sensorielle développée pour la mise en évidence d'un espace sensoriel propreapplication aux vins issus du cépage Sciaccarello [Sensory methodology developed for investigation of Sciaccarello wine concept]. *Journal International des Sciences de la Vigne et du Vin*, **38**, 147-154.

Lehrer, A. (1975). Talking about wine. *Language*, **51**, 901-923.

Lehrer, A. (1983/2009). *Wine & conversation* (2nd. Ed.). Oxford, UK: Oxford University Press.

Lelièvre, M., Chollet, S., Abdi, H., & Valentin, D. (2008). What is the validity of the sorting task for describing beers? A study using trained and untrained assessors. *Food Quality and Preference*, **19**, 697-703.

Lelièvre, M., Chollet, S., Abdi, H., & Valentin, D. (2009). Beer-trained and untrained assessors rely more on vision than on taste when they categorize beers. *Chemosensory Perception*, **2**, 143-153.

Lelièvre-Desmas, M., Chollet, S., Abdi, H., & Valentin, D. (2015). Becoming a beer expert: Is simple exposure with feedback sufficient to learn beer categories? *Acta Psychologica*, **161**, 95-103.

Li, W., Luxenberg, E., Parrish, T., & Gottfried, J. A. (2006). Learning to smell the roses: Experience-dependent neural plasticity in human piriform and orbitofrontal cortices. *Neuron*, **52**, 1097-1108. doi: 10.1016/j.neuron.2006.10.026

Lim, J., Urban, L., & Green, B. G. (2008). Measures of individual differences in taste and creaminess perception. *Chemical Senses*, **33**, 493-501.

Livermore, A., & Laing, D. G. (1996). Influence of training and experience on the perception of multicomponent odor mixtures. *Journal of Experimental Psychology: Human Perception and Performance*, **22**, 267-277.

Looy, H., Callaghan, S., & Weingarten, H. P. (1992). Hedonic response of sucrose likers and dislikers to other gustatory stimuli. *Physiology and Behavior*, **52**, 219-225.

Mariño-Sanchez, F. S., Alobid, I., Cantellas, S., Alberca, C., Guilemany, J. M., Canals, J. M., De Haro, J., & Mullol, J. (2010). Smell training increases cognitive smell skills of wine tasters compared to the general healthy population. The WINECAT study. *Rhinology*, **48**, 273-276.

Marks, L. E., & Wheeler, M. E. (1998). Attention and the detectability of weak taste stimuli. *Chemical Senses*, **23**, 19-29.

McAuliffe, W. K., & Meiselman, H. L. (1974). The roles of practice and correction in the categorization of sour and bitter taste qualities. *Perception and Psychophysics*, **16**, 242-244.

McBride, R. L., & Finlay, D. C. (1989). Perception of taste mixtures by experienced and novice assessors. *Journal of Sensory Studies*, **3**, 237-248.

McRae, J. F., Mainland, J. D., Jaeger, S. R., Adipietro, K. A, Matsunami, H., & Newcomb, R. D. (2012). Genetic variation in the odorant receptor *OR2J3* is associated with the ability to detect the ”grassy” smelling odor, *cis*-3-hexan-1-ol. *Chemical Senses*, **37**, 585-593.

Menashe, I., Abaffy, T., Hasin, Y., Goshen, S., Yahalom, V., Luetje, C. W., & Lancet, D. (2007). Genetic elucidation of human hyperosmia to isovaleric acid. *PLoS Biology*, **5**:e284.

Meilgaard, M. C., Reid, D. S., & Wyborski, K. A. (1982). Reference standards for beer flavour terminology system. *ASBC Journal*, **40**, 119-128.

Melcher, J. M., & Schooler, J. W. (1996). The misremembrance of wines past: Verbal and perceptual expertise differentially mediate verbal overshadowing of taste. *Journal of Memory and Language*, **35**, 231-245.

Newcomb, R. D., McRae, J., Ingram, J., Elborough, K., & Jaeger, S. R. (2010) Genetic variation in taste and odour perception: An emerging science to guide new product development. In S. R. Jaeger & H. J. H. MacFie (Eds.), *Consumer driven innovation in food and personal care products* (pp. 571-591). Oxford, UK: Woodhead Publishing.

O'Mahony, M., Goldenberg, M., Stedmon, J., & Alford, J. (1979). Confusion in the use of the taste adjectives 'sour' and 'bitter'. *Chemical Senses and Flavour*, **4**, 301-318.

Owen, D. H., & Machamer, P. K. (1979). Bias-free improvement in wine discrimination. *Perception*, **8**, 199-209.

Pangborn, R. M., Berg, H. W., & Hansen, B. (1963). The influence of color on discrimination of sweetness in dry table-wine. *American Journal of Psychology*, **76**, 492-495.

Parr, W. V. (2002). Exploring the nature of wine expertise. *Australian and New Zealand Wine Industry Journal*, **17**, 32-36.

Parr, W. V. (2015). Unraveling the nature of perceived complexity in wine. *Practical Winery & Vineyard*, **January**, 5-8.

Parr, W. V. (in press). Demystifying wine tasting: Cognitive psychology's contribution. *Food Research International*.

Parr, W. V., Heatherbell, D., & White, K. G. (2002). Demystifying wine expertise: Olfactory threshold, perceptual skill and semantic memory in expert and novice wine judges. *Chemical Senses*, **27**, 747-755.

Parr, W. V., Mouret, M., Blackmore, S., Pelquest-Hunt, T., & Urdapilleta, I. (2011) Representation of complexity in wine: Influence of expertise. *Food Quality and Preference*, **22**, 647-660.

Parr, W., Valentin, D., Green, J., & Dacremont, C. (2010). Evaluation of French and New Zealand Sauvignon wines by experienced French wine assessors. *Food Quality and Preference*, **21**, 56-64.

Parr, W. V., White, K. G., & Heatherbell, D. (2003). The nose knows: Influence of colour on perception of wine aroma. *Journal of Wine Research*, **14**, 79-101.

Parr, W. V., White, K. G., & Heatherbell, D. (2004). Exploring the nature of wine expertise: What underlies wine experts' olfactory recognition memory advantage? *Food Quality & Preference*, **15**, 411-420.

Pazart, L., Comte, A., Magnin, E., Millot, J.-L., & Moulin, T. (2014). An fMRI study on the influence of sommeliers' expertise on the integration of flavor. *Frontiers in Behavioral Neuroscience,* **8**:358.

Peron, R. M., & Allen, G. L. (1988). Attempts to train novices for beer flavour discrimination: A matter of taste. *The Journal of General Psychology*, **115**, 403-418.

Perrin, L., & Pages, J. (2009). A methodology for the analysis of sensory typicality judgments. *Journal of Sensory Studies,* **24**, 749-773.

Peynaud, E. (1987). *The taste of wine: The art and science of wine appreciation* (Trans. M. Schuster). London, UK: Macdonald & Co.

Pickering, G. J., Karthik, A., Inglis, D., Sears, M., & Ker, K. (2007). Determination of ortho- and retro-nasal detection thresholds for 2-isopropyl-3-methoxypyrazine in wine. *Journal of Food Science,* **72(7)**, 468-472.

Pickering, G. J., Simunkova, K., & DiBattista, D. (2004). Intensity of taste and astringency sensations elicited by red wines is associated with sensitivity to PROP (6-n-propylthiouracil). *Food Quality and Preference,* **15**, 147-154.

Plailly, J., Delon-Martin, C., & Royet, J. P. (2012). Experience induces functional reorganization in brain regions involved in odor imagery in perfumers. *Human Brain Mapping,* **33**, 224-234. doi:10.1002/hbm.21207

Plotto, A., Barnes, K. W., & Goodner, K. L. (2006). Specific anosmia observed for β-ionone, but not for α-ionone: Significance for flavour research. *Journal of Food Science,* **71**, 401-406.

Prescott, J., Norris, L., Kunst, M., & Kim, S. (2005). Estimating a "consumer rejection threshold" for cork taint in white wine. *Food Quality and Preference,* **16**, 345-349.

Prescott, J., Soo, J., Campbell, H., & Roberts, C. (2004). Responses of PROP taster groups to variations in sensory qualities within foods and beverages. *Physiology & Behavior*, **82**, 459-469.

Rabin, M. D. (1988). Experience facilitates olfactory quality discrimination. *Perception & Psychophysics*, **44**, 532-540.

Rabin, M. D., & Cain, W. S. (1986). Determinants of measured olfactory sensitivity. *Perception & Psychophysics*, **39**, 281-286.

Rabin, M. D., & Cain, W. S. (1989). Attention and learning in the perception of odor mixtures. In D. G. Laing, W. S. Cain, R. L. McBride, & B. W. Ache (Eds.), *Perception of complex smells and tastes* (pp. 173-188). Sydney, Australia: Academic Press.

Rapp, A. (1990). Natural flavours of wine: Correlation between instrumental analysis and sensory perception. *Fresenius' Journal of Analytical Chemistry*, **337**, 777-785.

Reed, D. R. (2008). Birth of a new breed of supertaster. *Chemical Senses,* **33**, 489-491.

Reed, D. R., & Knaapila, A. (2010). Genetics of taste and smell: Poisons and pleasures. *Progress in Molecular Biology Translational Science*, **94**, 213-240.

Robinson, J. O. (1970). The misuse of taste names by untrained observers. *British Journal of Psychology,* **61**, 375-378.

Roelfsema, P. R., van Ooyen, A., & Watanabe, T. (2010). Perceptual learning rules based on reinforcers and attention. *Trends in Cognitive Sciences*, **14**, 64-71.

Royet, J.-P., Plailly, J., Saive, A.-L., Veyrac, A., & Delon-Martin, C. (2013). The impact of expertise in olfaction. *Frontiers in Psychology*, **4**:928. http://dx.doi.org/10.3389/fpsyg.2013.00928.

Sáenz-Navajas, M. P., Ballester, J., & Pêcher, C. (2013). Sensory drivers of intrinsic quality of red wines: Effect of culture and level of expertise. *Food Research International*, **54**, 1506-1518.

Sauvegeot, F., Urdapilleta, I., & Peyron, D. (2006). Within and between variations of texts elicited from nine wine experts. *Food Quality & Preference*, **17**, 429-444.

Schlich, P., Maraboli, M., Urbano, C., & Parr, W. V. (2015). Perceived complexity in Sauvignon blanc wines: Influence of domain-specific expertise. *Australian Journal of Grape and Wine Research*, **21**, 168-178.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science*, **3**, 207-217.

Schumaker, M. R., Chandra, M., Malfeito-Ferreira, M., & Ross, C. F. (2017). Influence of Brettanomyces ethylphenols on red wine aroma evaluated by consumers in the United States and Portugal. *Food Research International*, **100**, 161-167.

Senn, S. (1997). Regression to the mean. *Statistical Methods in Medical Research*, **6**, 99-102.

Shanteau, J. (1987). Psychological characteristics of expert decision makers. In J. L. Mumpower, L. D. Phillips, O. Renn, & V. R. R. Uppuluri (Eds.), *Expert judgment and expert systems* (pp. 289-304). Berlin, Germany: Springer-Verlag.

Solomon, G. (1990). Psychology of novice and wine expert talk. *American Journal of Psychology*, **105**, 495-517.

Solomon, G. E. A. (1991). Language and categorization in wine expertise. In H. T. Lawless & B. P. Klein (Eds.), *Sensory science theory and application* (pp. 269-294). New York, NY: Marcel Dekker.

Solomon, G. E. A. (1997). Conceptual change and wine expertise. *The Journal of the Learning Sciences*, **6**, 41-60.

Sorokowska, A., Drechsler, E., Karwowski, M., & Hummel, T. (2017). Effects of olfactory training: A meta-analysis. *Rhinology*, **55**, 17-26.

Sowden, P. T., Rose, D., & Davies, I. R. (2002). Perceptual learning of luminance contrast detection: Specific for spatial frequency and retinal location but not orientation. *Vision Research*, **42**, 1249-1258.

Spence, C. (2010a). The color of wine – Part 1. *The World of Fine Wine*, **28**, 122-129.

Spence, C. (2010b). The color of wine – Part 2. *The World of Fine Wine*, **29**, 112-119.

Spence, C. (2010c). The price of everything – the value of nothing? *The World of Fine Wine*, **30**, 114-120.

Spence, C. (2015). Just how much of what we taste derives from the sense of smell? *Flavour*, **4**:30.

Spence, C. (submitted). Attending to the chemical senses. *Multisensory Research*.

Spence, C., & Wang, Q. (J.). (2015). Wine & music (II): Can you taste the music? Modulating the experience of wine through music and sound. *Flavour*, **4**:33.

Spence, C., & Wang, Q. J. (2018). What does the term ‘complexity’ mean in the world of wine? *International Journal of Gastronomy & Food Science*, **14**, 45-54.

Spence, C., & Wang, Q. J. (in press). Wine expertise: Perceptual learning in the chemical senses. *Current Opinion in Food Science.*

Stevens, D. A. (1991). Individual differences in taste and smell. In H. T. Lawless & B. P. Klein (Eds.), *Sensory science theory and application* (pp. 295-). New York, NY: Marcel Dekker.

Stevens, D. A., & O'Connell, R. J. (1991). Individual differences in thresholds and quality reports of human subjects to various odors. *Chemical Senses*, **16**, 57-67.

Stevens, D. A., & O'Connell, R. J. (1995). Enhanced sensitivity to androstenone following regular exposure to pemenone. *Chemical Senses*, **20**, 413-419.

Stevens, J. C., Cain, W. S., & Burke, R. J. (1988). Variability of olfactory thresholds. C*hemical Senses*, **13**, 643.

Stevenson, R. J., & Attuquayefilo, T. (2013). Human olfactory consciousness and cognition: Its unusual features may not result from unusual functions but from limited neocortical processing resources. *Frontiers in Psychology*, **4**:819.

Suprenant, A., & Butzke, C. E. (1997) Implications of odor threshold variations on sensory quality control of cork stoppers. *American Journal of Enology & Viticulture*, **48(2)**, 269.

Taladrid, D., Lorente, L., Bartolomé, B., Moreno-Arribas, M. V., & Laguna, L. (2019). An integrative salivary approach regarding palate cleansers in wine tasting. *Journal of Texture Studies*, **50**, 75-82. doi: 10.1111/jtxs.12361.

Tao, Y. S., & Li, H. (2009). Active volatiles of cabernet sauvignon wine from Changli county. *Natural Science*, **1**, 176-182.

Tempere, S., Cuzange, E., Bougeant, J. C., de Revel, G., & Sicard, G. (2012). Explicit sensory training improves the olfactory sensitivity of wine experts. *Chemosensory Perception*, **5**, 205-213.

Tempere, S., Cuzange, E., Malak, J., Bougeant, J. C., de Revel, G., & Sicard, G. (2011). The training level of experts influences their detection thresholds for key wine compounds. *Chemosensory Perception*, **4**, 99-115.

Tempere, S., Hamtat, M.-L., de Revel, G., & Sicard, G. (2016). Comparison of the ability of wine experts and novices to identify odorant signals: A new insight in wine expertise. *Australian Journal of Grape and Wine Research*, **22**, 190-196.

Tepper, B. J., & Nurse, R. J. (1997). Fat perception is related to PROP taster status. *Physiology and Behavior*, **61**, 949-954.

Urdapilleta, I., Parr, W. V., Dacremont, C., & Green, J. (2011). Semantic and perceptive organisation of Sauvignon blanc wine characteristics: Influence of expertise. *Food Quality and Preference*, **22**, 119-128.

Valentin, D., Chollet, S., & Abdi, H. (2003). Les mots du vin: Expert et novices different-ils quand ils décrivent vins? [Wine language: Do experts and novices describe wines differently?] *Corpus*, **2**, 183-200.

Valentin, D., Chollet, S., Beal, S., & Patris, B. (2007). Expertise and memory for beers and beer olfactory compounds. *Food Quality and Preference*, **18**, 776-785.

Walk, R. D. (1966). Perceptual learning and discrimination of wines. *Psychonomic Science*, **5**, 57-58.

Walk, R. D. (1978). Perceptual learning. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception: Vol. 9. Perceptual processing* (pp. 257-297). New York, NY: Academic Press.

Wang, L., Chen, L., & Jacob, T. (2004). Evidence for peripheral plasticity in human odour response. *Journal of Physiology*, **554**, 236-244.

Wang, Q. J., Prešern, D., Fermandes, H., & Fjældstad, A. (2019). Does wine training improve tasting ability? Measuring the effect of blind tasting training on olfactory and taste threshold, discrimination, and identification. *Abstract of American Association of Wine Economics Conference*, Vienna, Austria.

Wang, Q. J., & Prešern, D. (2018). Does blind tasting work? Investigating the impact of training on blind tasting accuracy and wine preference. *Journal of Wine Economics,* **13**, 384-393.

Wang, Q. (J.), & Spence, C. (2017). Assessing the influence of music on wine perception amongst wine professionals. *Food Science & Nutrition,* **2017**, 1-7.

Wang, Q. J., & Spence, C. (2018). Wine complexity: An empirical investigation. *Food Quality & Preference,* **68**, 238-244.

Wang, Q. J., & Spence, C. (submitted). Drinking through rosé-coloured glasses: Influence of wine colour on the perception of aroma and flavour in wine experts and novices. *Australian Journal of Grape & Wine Research*.

Wang, Q. (J.), Woods, A., & Spence, C. (2015). "What's your taste in music?" A comparison of the effectiveness of various soundscapes in evoking specific tastes. *i-Perception*, **6(6)**:1-23.

Watanabe, T., & Sasaki, Y. (2015). Perceptual learning: Toward a comprehensive theory. *Annual Review of Psychology*, **66**, 197-221.

Weil, R. L. (2007). Debunking critics' wine words: Can amateurs distinguish the smell of asphalt from the taste of cherries? *Journal of Wine Economics*, **2(2)**, 136-144.

Wilson, D. A., Kadohisa, M., & Fletcher, M. L. (2006). Cortical contributions to olfaction: Plasticity and perception. *Seminars in Cell Development Biology*, **17**, 462-470. doi:10.1016/j.semcdb.2006.04.008

Wilson, D. A., & Stevenson, R. J. (2003). Olfactory perceptual learning: The critical role of memory in odor discrimination. *Neuroscience & Biobehavioral Reviews*, **27**, 307-328.

Woodhouse, A. L., Sacks, G. L, & Jeffery, D. W. (2016). *Understanding wine chemistry*. Chichester, UK: Wiley-Blackwell.

Wysocki, C. J., & Beauchamp, G. K. (1984). Ability to smell androstenone is genetically determined. *Proceedings of the National Academy of Sciences USA*, **81**, 4899-4902.

Wysocki, C. J., Dorries, K. M., & Beauchamp, G. K. (1989). Ability to perceive androstenone can be acquired by ostensibly anosmic people. *Proceedings of the National Academy of Sciences USA*, **86**, 7976-7978.

Xu, F., Laguna, L., & Sarkar, A. (2019). Aging-related changes in quantity and quality of saliva: Where do we stand in our understanding? *Journal of Texture Studies*, **50**, 27-35. doi: 10.1111/jtxs.12356.

Yee, K. K., & Wysocki, C. J. (2001). Odorant exposure increases olfactory sensitivity: Olfactory epithelium is implicated. *Physiology & Behavior*, **72**, 705-711.

Yeomans, M. R., Tepper, B. J., Rietzschel, J., & Prescott, J. (2007). Human hedonic responses to sweetness: Role of taste genetics and anatomy. *Physiology & Behavior,* **91**, 264-273.

Zucco, G. M., Carassai, A., Baroni, M. R., & Stevenson, R. J. (2011). Labeling, identification, and recognition of wine-relevant odorants in expert sommeliers, intermediates, and untrained wine drinkers. *Perception*, **40**, 598-607.

Zampini, M., Sanabria, D., Phillips, N., & Spence, C. (2007). The multisensory perception of flavor: Assessing the influence of color cues on flavor discrimination responses. *Food Quality & Preference,* **18**, 975-984.

Zampini, M., Wantling, E., Phillips, N., & Spence, C. (2008). Multisensory flavor perception: Assessing the influence of fruit acids and color cues on the perception of fruit-flavored beverages. *Food Quality & Preference,* **19**, 335-343.

FIGURE LEGENDS

Figure 1. Differences in PROP distribution across wine expertise. The distributions shown are kernel density estimates (KDE). Note that both distributions were tri-modal, corresponding roughly to the non-taster, medium-taster, and supertaster groupings. [Hayes & Pickering (2012), Figure 1.]

Figure 2. Profound orthonasal olfactory perceptual learning demonstrated amongst women (F) of reproductive age for citralva (Cit.), which has a lemon-orange smell. By contrast, no such threshold reduction was demonstrated in male participants (M). The stimulus specificity of this effect was demonstrated by showing that orthonasal thresholds for benzaldehyde (Benz.; smelling of cherry-almond) were unaffected by repeated threshold testing with citralva. A total of 12 participants were tested in this study. [Dalton et al. (2002), Figure 3.]

Figure 3. Tempere et al. (2012). These results were described as highlighting stimulus-specific olfactory learning. Y-axis reports difference in rank of stimulus dilutions used in individual detection threshold assessment. Positive values = increase in sensitivity. Group 1 trained compound = linalool, untrained diacetyl; Group 2 trained compound = diacetyl, untrained linalool (N = 16 in each group; * $p < .05$; ** $p < .01$) Note, however, that the findings may be contaminated by regression to the mean. See text for details. [Tempere et al. (2012).]

Figure 1.

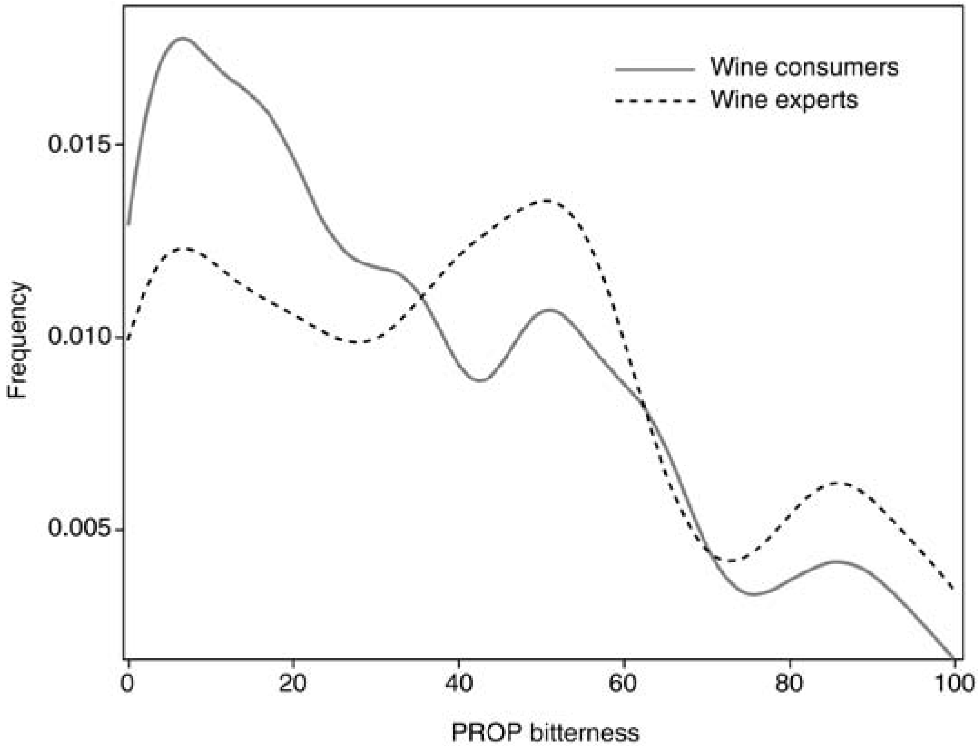

Wine consumers
Wine experts
0.015
0.010
0.005
Frequency
0
20
40
60
80
100
PROP bitterness

Figure 2.

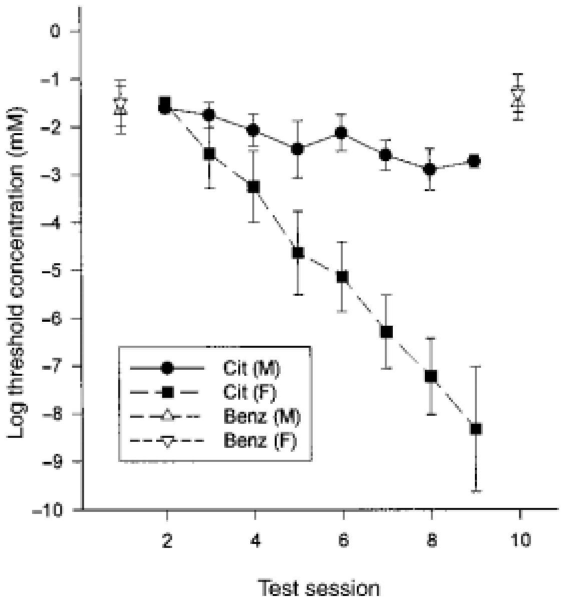
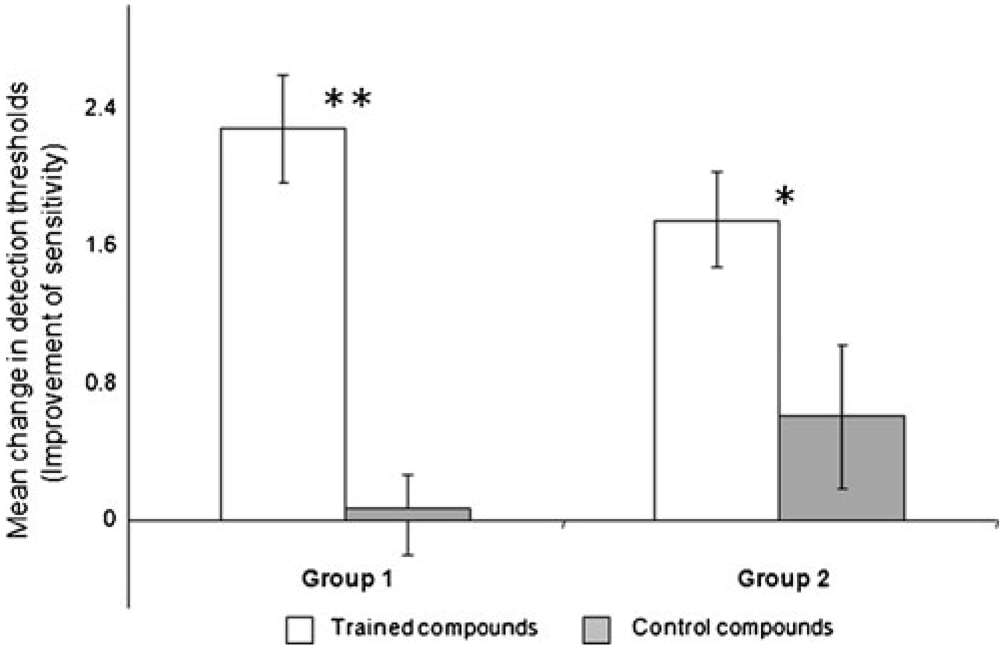

Log threshold concentration (mM)
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
2
4
6
8
10
Test session
Cit (M)
Cit (F)
Benz (M)
Benz (F)

Figure 3.


Mean change in detection thresholds
(Improvement of sensitivity)
2.4
1.6
0.8
0
**
*
Group 1
Group 2
Trained compounds
Control compounds