It is the paper published as:

Author: D. Ryan, P. Prenzler, A. Saliba and G. Scollary
Title: The significance of low impact odorants in global odour perception
Journal: Trends in Food Science & Technology **ISSN**: 0924-2244
Year: 2008
Volume: 19
Issue: 7
Pages: 383-389

Abstract: Low impact odorants are generally considered unimportant in aroma perception; however, recent evidence establishes the significance of these compounds in global odour perception. We hypothesise that the perception of high impact odorants is modified by sub- and peri-threshold odorants, even those with low odour activity. In order to fully evaluate the importance of low impact odorants, and better understand the complexities of global odour perception, a new multidisciplinary approach is needed incorporating chemical, sensory and neurological model studies.

Author Address: dryan@csu.edu.au

pprenzler@csu.edu.au

asaliba@csu.edu.au

URL: http://dx.doi.org/doi:10.1016/j.tifs.2008.01.007

http://researchoutput.csu.edu.au/R/-?func=dbin-jump-full&object_id=8383&local_base=GEN01-CSU01

http://bonza.unilinc.edu.au:80/F/?func=direct&doc_number=000527168&local_base=L25XX

CRO Number: 8383

The significance of low impact odorants in global odour perception

by

Danielle Ryan*, Paul D. Prenzler, Anthony J. Saliba, Geoffrey R. Scollary

National Wine and Grape Industry Centre,

School of Wine and Food Sciences, Charles Sturt University, Locked Bag 588,

Wagga Wagga, New South Wales 2678, Australia

Viewpoint manuscript

Submitted to

Trends in Food Science and Technology

*address for correspondence

Danielle Ryan

email: dryan@csu.edu.au

Tel: + 61-2-69334382   Fax: + 61-2-69332737

Abstract

Low impact odorants are generally considered unimportant in aroma perception; however recent evidence establishes the significance of these compounds in global odour perception. We hypothesise that the perception of high impact odorants is modified by sub- and peri-threshold odorants, even those with low odour activity. In order to fully evaluate the importance of low impact odorants, and better understand the complexities of global odour perception, a new multidisciplinary approach is needed incorporating chemical, sensory and neurological model studies.

Introduction

General approaches of identifying 'important' or high impact odorants are based on odour activity values (OAV). Gas chromatography-olfactory (GC-O) may facilitate the process of determining OAVs, and elucidation of the most odour-active compounds are generally achieved using GC-O aroma extract dilution analysis (AEDA), which is a dilution to threshold approach that measures odour potency via the maximum dilution of an extract that an odour is perceived in (Delahunty, Eyres & Dufour 2006). Odorants with low OAVs, or low impact odorants (ie typical values ≤ 1) are generally considered to be unimportant to global sensory perception. However reconstituted model mixtures are often lacking when compared to the original odorant mixtures. This may be partly attributed to the fact that the GC-O technique considers the impact of isolated aroma compounds in the extract, "overlooking their joint effects in the original food product. Consequently, GC-O should be considered an essential but partial procedure” (Lorrain, Ballester, Thomas-Danguin, Blanquet, Meunier & Le Fur 2006). In light of these aforementioned limitations, combined with recent evidence, we hypothesise that compounds with low OAVs have the potential to play a critical role in the global odour characterisation of a sample. Further we present evidence that compounds with relatively low OAVs may act as significant impact odorants (Escudero, Gogorza, Melus, Ortin, Cacho & Ferreira 2004). What is needed is a new multidisciplinary approach in tackling global odour characterisation. In this review, wine is used as the subject model to support our hypothesis, although other foods and beverages are discussed where relevant.

Reconstructed mixtures do not always equate to the original mixture

Most literature regarding the aromatic profile of various wines as determined by GC-O have shown that the vast majority of wine volatiles have little to no odour activity, and that specific aromatic profiles may be explained by relatively few odorant compounds (Escudero, Campo, Farina, Cacho & Ferreira 2007). Atanasova et al. (Atanasova, Thomas-Danguin, Chabanet, Langlois, Nicklaus & Etievant 2005a) have hypothesised that “huge” aromatic bouquet differences in wines may in fact arise due to differences in concentration levels and proportions of the same odorants in wine mixtures. Nevertheless, perceptual interactions between volatile compounds combined in a mixture are difficult to predict both in wine and synthetic models (Atanasova *et al.*, 2005a), and reconstituted model mixtures of odorants do not always equate to the original mixture. In fact, Bult et al. (Bult, Schifferstein, Roozen, Voragen & Kroeze 2001) have introduced the term ‘reconstruction discrepancy’ to describe the phenomenon that the perceived smell of GC-O reconstructed mixtures differ from that of the original aroma of the whole sample, despite the fact that concentrations of the key odorants are identical in both mixtures. It is feasible then that reconstruction discrepancy could arise from sub-threshold components which cannot be detected at the olfactory sniff port.

Omission tests are commonly used to establish the sensory importance of a component or family of components in a reconstituted mixture (Escudero *et al.*, 2004). Complementary to this, addition tests can be performed on synthetic bases or real matrices (Escudero *et al.*, 2004). Reiners and Grosch iterate that the only way to verify if odorants identified in a sample contribute to flavour is via reconstitution tests (Reiners & Grosch, 1998). As such, they used reconstitution tests in addition to omission tests to determine potent odorants of Italian (I), Spanish (S) and Moroccan (M) extra virgin olive oils. Odorants were determined by AEDA using GC-O. Potent odorants (defined as those showing a flavour dilution factor ≥ 8 in at least one of the three oil samples, and a OAV >5 based on either nasal or retronasal odour values) were then dissolved in a refined plant oil in their corresponding concentrations found in the three olive oils to represent the model oils I0, S0 and M0. Additional model oils I1-I9, S1-S5 and M1-M9 were prepared as per I0, S0 and M0 with the omission of one or several compounds with the same odour quality. Comparison of the original oils with I0, S0 and M0 showed M0 to be most similar to its respective original oil based on retronasal evaluation scoring 2.8 (± 0.4) on a similarity scale of

0 (no similarity) to 3 (identical with the original), with I0 and S0 scoring 2.5 (± 0.3) and 2.5 (± 0.4), respectively. Such discrepancies may be attributed to the presence of low impact odorants since only odorants with OAVs > 5 were considered significant to oil flavour and aroma, and included in the model mixtures.

Odorants in a mixture should interact in a predictable and straightforward way (Olsson)

According to Olsson, the perceived intensity and quality of a mixture can be predicted from the perceived intensity of its components presented separately (Olsson, 1994), and that odour interaction reduces to a set of simple rules that are consistent across levels of intensity and combinations of odorants (Olsson, 1998). Such research suggests that if both odorants in a mixture have approximately equal unmixed intensities, both will be perceived in the mixture, and the quality of the mixture should be intermediate between the qualities of its unmixed components.

Evidence contrary to the predictive model exists

Even in simple binary mixtures, qualitative and quantitative odour perception is not straightforward, and evidence contrary to Olsson's predictive model exists (Atanasova *et al.*, 2005a; Atanasova, Thomas-Danguin, Langlois, Nicklaus, Chabanet & Etievant 2005b; Atanasova, Thomas-Danguin, Langlois, Nicklaus & Etievant 2004; Cain, Schiet, Olsson & Dewijk 1995). Atanasova et al. (Atanasova *et al.*, 2005a) investigated the qualitative perceptual interaction of three binary mixtures of wine odorants including isoamyl acetate (fruity note)/whisky lactone (woody note); ethyl butyrate (fruity note)/whisky lactone (woody note); ethyl butyrate (fruity note)/guaiacol (woody note). Results showed the qualitative dominance of the woody note in the three fruity-woody binary mixtures when the perceived intensities of each unmixed compound were equal. The authors developed their own linear logistic model to account for this phenomenon, since the Olsson predictive model, by its very construction, could not account for the woody quality dominance of iso-intense components. Quantitative results for the same three binary mixtures at supra-threshold levels showed quantitative perceptual interactions were non-level independent, non-symmetrical, and reached the compromise level of hypo-addition (Atanasova *et al.*, 2004). For the latter, compromise was generally reached when mixtures contained a high proportion of woody odorant, however this was not replicated in mixtures with high proportions of fruity odorant. As such, woody notes had a higher hypo-additive effect such that the overall perceived intensity was less than the sum of the mixture components.

Modelling Odour Interaction

It is clear that strong evidence exists to refute Olsson's predictive model and other models that claim odour interactions can be reduced to a set of simple rules. Such models fail to account for odorant interactions. One model that does attempt to account for interactions is the vector model (Berglund, Bergland & Lindvall 1973). However, this model assigns odorant interactions as a consistent summation regardless of the compounds in question. The vector model has received little criticism and in fact remains one of the best predictive models. One of the reasons why Berglund et al.'s (Berglund *et al.*, 1973) vector model and models like it (e.g. Patte & Laffort, 1979) have come under little criticism is that they do provide reasonable approximation of odour perception using simple mixtures. Perhaps a more appropriate explanation of their apparent lack of scrutinisation is that these models fail honourably. Cain et al. (Cain *et al.*, 1995) point out that the vector model lacks any theoretical base. It is true that the model is a mathematical solution not based on psychophysics for example. The advantage of the vector model approach is that there is little penalty when perceptual changes do not accompany mixture changes, such as when a compound is increased in concentration within a solution but where human subjects fail to detect any change in odour. Such facts are hardly an endorsement of these models because it follows that they do not completely account for the opposite of suppression – hyper-additivity. The mathematical elegance of these approaches not withstanding, they offer a crude approximation of a broad range of complex mixtures.

The literal meaning of a *model* takes connotations depending on context and the field in which the term is used, but the general understanding of a model is a small or incomplete replica of the real thing. In an attempt to model the *real thing*, it became popular in Perceptual modelling research to embrace the underlying Physiology or Psychology, or even the combination of the two. This endeavour has clearly been limited by what is known about human odour perception, perhaps the least studied of all human perceptual phenomenon. This is reflected in the simplicity of Psychological models (e.g. Olsson, 1994) that are based on a linear summation of the perception of compounds added to a mixture. Derby et al. (Derby, Ache & Kennel, 1985) have used electrophysiological techniques to demonstrate that two different odorants of moderate intensity may not sum to produce an intense mixture. This phenomenon is known as **mixture suppression**. Until now, the only explanation for mixture suppression has been based on physiology and is best encapsulated by the type of theory proposed by Laing (Stevens, 1957). Laing proposed that compounds are differentially absorbed by the olfactory mucus and that this accounts for their perception in a mixture. There is good psychophysical evidence that differential absorption, whatever the mediation, is an important part of the Psychophysics of odour perception. Where a compound is perceived but to a lesser extent than a linear addition might suggest, saturation is a possible explanation. We 'know' that where subjective intensity of some stimuli increases in a linear fashion, the actual intensity grows exponentially (originally proposed by Stevens (Stevens, 1957)).

What *has* been discovered about human perception of odours has largely been focused on intensity perception using simple mixtures. Cain et al., (1995) propose the use of quality as a metric to augment intensity perception. This approach is limited twofold. Firstly, the assessment of quality is subjective and influenced by many things that have proven difficult to control. Quality is perceived through comparison of stimuli and is implicated with satisfaction (Oliver, 1997), such that different combinations of stimuli and idiosyncratic preferences will produce different results. Secondly, the notion of quality as a measure of odour interaction within a mixture presupposes that all key compounds are supra-threshold. That is, quality will only explain interaction effects between compounds where those compounds can be perceived. While this is an assumption with little or no penalty for simple mixtures with few compounds, in complex mixtures such as wine and food, chemical reactions could render a compound sub-threshold. The presumption of perception limitation is in fact shared with all models reviewed above, except for the purely mathematical-based vector approach which makes no presupposition in terms of underlying theory. What of compounds that do not have a strong odour themselves, yet interact to produce an intense odour experience? The authors contend that no model currently exists that reliably and accurately accounts for this phenomenon.

Reports highlight the importance of sub and peri-threshold in perceived odour

Investigations by Atanasova et al. (Atanasova *et al.*, 2005b) using the same combinations (see above) of binary mixtures showed that sub- and peri-threshold concentrations of woody compounds modify the perception of supra-threshold fruity odour (Atanasova *et al.*, 2005b). Such results illustrate that knowledge of the odour threshold of a volatile component in a food or beverage matrix may not sufficiently indicate its impact on the whole aroma. Critically, perceptual interactions of sub- and peri-threshold components must be considered in order to ascertain the total odour intensity and quality of the particular matrix (Atanasova *et al.*, 2005b).

The findings of Bult et al. (Bult *et al.*, 2001) relating to the impact of sub- and peri-threshold odorants on mixtures of apple odorants were not as clear cut as those of Atanasova et al. (Atanasova *et al.*, 2005b). The authors hypothesized that manipulating a mixture of odorants (MIX) by adding sub-threshold components will result in a mixture (MIX+) that is more easily discriminated from MIX than the sub-threshold components (BLANK+) can be discriminated from a blank stimulus (BLANK; water). Generally, addition of three sub and peri-threshold components (MIX+) did not significantly alter the aroma of the apple standard mixture containing eight odorants (MIX). However, when the level of concept refinement was considered, subjects with highly refined stimulus concepts (13 out of the 23 subjects) showed improved discrimination ability and could successfully differentiate the apple standard mixture from that also containing the sub- and peri-threshold components.

Atanosova et al. (Atanasova *et al.*, 2005b) have attributed the different impacts of sub- and peri- threshold components on the global perception of mixtures observed by themselves and by Bult et al. (Bult *et al.*, 2001) to the relatively high intensity level of the reconstructed apple aroma used (Bult *et al.*, 2001) compared to the relatively low supra-threshold intensities of the fruity compounds used in their own investigations (Atanasova *et al.*, 2005b). Furthermore, Bult et al have used more complex mixtures as compared to binary mixtures wherein sensory suppressive effects may occur. Such discrepancies highlight the need for careful planning when dealing with sensory models in that results gained are dependent upon experimental design. This is a confounding difficulty inherent in sensory analysis.

The contribution of sub-threshold aroma constituents to the global odour impression of a Chinese jasmine green tea infusion has been evaluated using sensory evaluation (Ito & Kubota, 2005). This research was motivated by the apparent lack of work focussed on sub-threshold odour compounds and their mutual interaction among food flavour constituents. Recognition odour thresholds (ROT) of 14 individual odorants in aqueous solutions were determined. Following this, 5% of each odorant was replaced by 4-hexanolide, and in all cases the concentration of the latter was below it's ROT. Sensory evaluation showed that the addition of 4-hexanolide caused the odour intensity of (*E*)-2-hexenyl hexanoate, (Z)-3-hexenol and indole to increase from sub-threshold to supra-threshold levels, with odour descriptions of pungent, green and camphoraceous, respectively. The structural homologues of (*E*)-2-hexenyl hexanoate and (Z)-3-hexenol, namely (*Z*)-3-hexenyl hexanoate and hexanol, respectively, were also investigated, however no significant change in odour intensity was apparent upon addition of 4-hexanolide. Based on these results, the authors concluded that there was no relationship between the functional groups of an odorant and its mutual interaction with 4-hexanolide. Experiments were then repeated in real jasmine tea infusions, and odour synergism was apparent between each of the three odorants and 4-hexanolide, all at sub-threshold concentrations, yielding enhanced sweet and astringent notes. Such results demonstrate the existence and importance of a synergistic effect between the sub-threshold aroma compounds in jasmine tea infusion, and serve to highlight the significance of sub-threshold or low impact odorants in the global sensory characterisation of food and beverage products.

Matrix impact on global odour perception

Any model studies targeted at understanding the role of low impact odorants in global odour perception must also take into account the matrix of the "real system" and target the model accordingly. This is because matrix is known to exert a significant effect on aroma profile (Buettner & Mestres, 2005); The physico-chemical properties of the particular odorants combined with the chemical composition of the matrix and the formed matrix structure can modify the concentration of the aroma compounds in the headspace (Bezman *et al.*, 2003). For example, matrix effects were evident in the SPME (solid-phase microextraction) and static headspace quantitation of marker odorants in a buffer solution compared to the same markers calibrated in a green tomato matrix. Generally there was a higher retention of aroma by the tomato matrix compared to the buffer, and only minor differences were observed between the SPME and static headspace analyses. Differing proportions of odorants in the headspace of the tomato and buffer matrices indicate that selected interactions of each odorant with the matrix components determine odorant volatility, and that differences cannot simply be explained by the inferior mass transfer of odorants from the green tomato matrix (Bezman *et al.*, 2003). Such results highlight the significant role of the matrix in determining the overall profile of odorants in the headspace.

Of particular relevance is the perceptual impact of matrix ethanol on the perception of wine flavour and aroma. Most recently, Le Berre et al. (Le Berre, Atanasova, Langlois, Etievant & Thomas-Danguin 2007), in an extension of their previous research (ie Atanasova et al. (Atanasova *et al.*, 2005a)) sought to assess the physico-chemical and perceptual impact of ethanol on the volatility of woody and fruity aromas. Woody (whiskey lactone) and fruity (isoamyl acetate) odours in aqueous and dilute ethanol solutions were investigated. Physico-chemical results showed both chemical and sensory interactions between the three components, and reduced whiskey lactone volatility was observed in the presence of ethanol. This was not the case however for isoamyl acetate. Perceptually, a synergy effect of the woody on the fruity odour was noted in aqueous solutions, which disappeared in the presence of ethanol. Contrary to this, woody odour was masked by the fruity odour in both aqueous and ethanolic solutions, and significant ethanol odour masking by the fruity and woody odours was observed in the ethanolic solutions. Collectively, such results show that perceptual interactions of odorants can be affected by alcohol content through modification of the chemical proportions of odorants. As such, the importance of the ethanolic matrix composition in the perception of wine bouquet cannot be underestimated.

Critically, evidence suggests that compounds with low OAV play a key role in odour perception

Since 1963 it has been documented that sub-threshold addition or synergy can occur between volatile compounds such that sub-threshold volatiles which have no odour when assessed individually, may in fact contribute or possess odour activity in mixtures (Day, Lillard & Montgomery 1963). More recently, Escudero et al. (Escudero *et al.*, 2004) have reported that compounds with relatively low OAVs can have an unexpectedly high effect on aroma. This study began as a "traditional" aroma analysis of Maccabeo wine involving AEDA, followed by quantification of odour active compounds, reconstitution, addition and omission tests. The authors report throughout the sensory analysis of reconstituted wines that the results were "disappointing"; this was largely due to the fact that reconstitution C (containing all aroma compounds quantified by AEDA) was found to be significantly different from the original wine, and addition tests yielded positive results only two odorants. Two compounds not included in the original quantitation and model analyses *vis*. 4-mercapto-4-methylpentan-2-one and 2-methyl-3-furanthiol, were subsequently quantified and found to be present in quantities slightly above their threshold concentrations. When added to the reconstituted wine (10 ng/L and 5 ng/L, respectively), the effect was pronounced. In particular the authors report for 4-mercapto-4-methylpentan-2-one: "it is surprising how with an apparently low value of aroma it can play such a predominant role in the aroma of a mixture that contains tens of other aromas with much greater potencies. It is also remarkable that this component affects the aroma of wine, but it cannot be described as a proper impact component, because it does not communicate to the wine its primary aromatic characteristics (boxwood, mango), but gives the wine a citric and fruity note.” The authors conclude that “new tools, in addition to FDs and OAVs” are needed “for the evaluation of the potential importance of the individual odorants in complex mixtures.”

Even more surprising is a later report from the same group (Escudero *et al.*, 2007) where the addition of compounds at or below their threshold level made a significant difference to perceived aroma. In one case, dimethyl sulfide was added to a dearomatized wine (at 10 μg/L, its threshold level), and although it could not be perceived on its own, its presence with other added compounds made it possible to detect “complex sweet-fruity or green olive notes”. In another test, isobutyl 2-methoxypyrazine was added to a dearomatized wine at the level found in the commercial wine and was detected as an “earthy aroma”. When added together with (*Z*)-3-hexenol and 1-hexanol the sensory effect was more easily recognised and a “pepper odour nuance (could) be recognized, which (suggested) that the three components may interact synergistically.” The two alcohols were added at concentrations (1-hexanol, 1.48 mg/L and (*Z*)-3-hexenol, 234 μg/L) well below their threshold levels (1-hexanol 8.00 mg/L and (*Z*)-3-hexenol 400 μg/L (Guth, 1997).

Collectively, these results demonstrate that high impact odorants do not necessarily guarantee an effect on wine aroma, and that compounds with relatively low OAV may act as impact odorants. Significantly, low impact odorants may act to change the perception of other odorants in a mixture, and may interact synergistically. Escudero et al. (Escudero *et al.*, 2004) have concluded that the ability of a particular compound to impact the aroma of wine is due to the "specificity of the aromatic note" of such a compound. The fact that most compounds were found to have no individual effect on wine aroma, despite concentrations in excess of their odour thresholds with high OAV, implies that it is not the aroma of the individual components which is perceived but rather the aroma of the mixture. The authors hypothesise that wine forms some kind of aromatic buffer towards a wide range of aromas. This buffer, formulated through the presence of high concentrations of ethanol, ethyl esters, volatile phenolics etc in wine, may only be broken by the presence of an aroma with distinct aromatic properties such as 4-methyl-4-mercaptopentan-2-one (Escudero *et al.*, 2004).

Therefore, the importance of low impact odorants and matrix must be considered when determining food/beverage sensory profile.

We hypothesise that the perception of high impact odorants is modified by sub- and peri-threshold odorants, even those with low OAVs. While the evidence we present points to this new understanding gradually evolving, we know of no fundamental, multidisciplinary studies of the type proposed that are designed to test this hypothesis. We believe a new multidisciplinary approach is needed, incorporating chemical, sensory and neurological model studies to evaluate global sensory perception. Critically, traditional AEDA and GC-O approaches must be extended to incorporate model neurological studies. Ultimately, such approaches should be undertaken concurrently.

Model neurological studies

Electroencephalograph (EEG) studies have been used in assessing sensory preference ie for comparing sensory and brain activity responses to flavour components (Patterson, Owen, Frank, Smith & Cadusch 2004); we believe this technology could be utilised to evaluate the role of low impact odorants on sensory perception. Patterson et al. (Patterson *et al*., 2004) aimed to link traditional sensory techniques with EEG (an electrophysiological technique), to further understand brain response to odour. This study was designed to find possible differences in brain activity in cohorts from two different cultural backgrounds (overseas "OS" and Australian) when presented with different odours. Four odour compounds were used in the study: p-cresol, 2-heptanone, methional, and dimethyltrisulfide (DMTS), which were ranked according to hedonic (emotional like/dislike) and strength response during EEG recordings. While there were no significant differences between cohorts for the subjective like/dislike and strength responses, some significant differences in objective EEG recordings were found. The most significant difference was for p-cresol in the right frontal response. Similar trends were observed (but not statistically significant) for 2-heptanone in both right and left frontal response; and for DMTS in the left frontal response. No significant differences or trends were found between the cohorts for methional. The authors concluded that "the differences…between the OS and Australian groups may (therefore) be consistent with the utilization of different physiological processes involved in the early sensory response to the odours”. As different cohorts display different physiological responses to the same odour; it is possible that a single subject may display different physiological response when presented with 2 odours – one at threshold level. In any case the methodology used by Patterson et al. (Patterson *et al*. 2004) may be used to explore this phenomenon and simultaneously obtain both subjective and objective data on model odour compounds and mixtures.

Functional magnetic resonance imaging (fMRI) has found widespread application in various sensory research investigations, and work continues to model olfaction and optimise signal response in single odour stimulation, for example in odorant-induced primary olfactory cortex (POC) signal changes in response to prolonged stimulation (Tabert *et al*., 2007). Significantly however, fMRI and EEG techniques are complementary (Menon & Crottaz-Herbette; Freeman 2004); each method has its strength where the other has limits. fMRI is a hemodynamic based method with a spatial resolution in the range of millimeters, whilst EEG has a time resolution range of milliseconds. EEG approaches thus offer good temporal resolution whilst fMRI achieves good spatial resolution (Mulert *et al*., 2004). Freeman (Freeman 2004) suggests that simultaneously recorded, multichannel beta-gamma EEG may assist in interpreting images derived by fMRI; this hypothesis has been realized in the work of Mulert et al. (Mulert *et al*., 2004) who have investigated auditory-evoked potential in 9 human subjects simultaneously using EEG and fMRI. Generally, due to technical and practical challenges, EEG and fMRI data are acquired in isolation in separate sessions. Simultaneous measurement requires special EEG hardware that can be used inside the MRI without inducing artefacts or posing safety risks to the subject. The results gained suggest simultaneous EEG and fMRI permits improved understanding of the spatiotemporal dynamics of brain activity (Mulert *et al*., 2004).

Recommendations and future directions

Mounting evidence indicates the importance of low impact odorants on global odour perception. The question is, how do we ascertain the apparent synergistic effect of low impact odorants, and how do we determine which low impact odorants have the capacity for synergism? By their very nature low impact odorants may go “undetected” in traditional studies (eg., GC-O), hence their importance may not be established. The task of simply identifying such species, particularly in real systems/matrices, is challenging to say the least. A new approach is needed, and we propose that the significance of low impact odorants may be evaluated using neurological studies to assess brain response during olfaction. Figure 1 proposes a ‘holistic’ approach incorporating traditional GC-O (and GC-O-MS) analyses coupled with dynamic EEG monitoring (GC-O-EEG) for objectively monitoring sub-conscious response to low impact odorants. In this approach, the human sniffer would be fitted with EEG apparatus, and brain activity would be monitored during the GC-O run. We believe this approach would yield valuable information in identifying low impact odorants with the potential for odorant synergism. Furthermore, this information would be the first step in ultimately understanding if or how low impact odorants modify the perception of the high impact odorants in a global odorant mixture. Of course this GC-O-EEG approach would need considerable optimisation using model binary mixtures, however its potential is considerable. Similarly, traditional sensory studies could benefit through the incorporation of EEG/fMRI investigations to facilitate an improved and 'objective' understanding of neurological odour perception – to our knowledge there does not appear to be any fMRI studies where binary mixtures of odorants have been studied. Improved understanding of the chemical and neurological basis of odour perception will facilitate the design of improved odour models which should ultimately yield a wealth of new information for a better appreciation of the complexities of global odour perception.

References

Atanasova, B., Thomas-Danguin, T., Chabanet, C., Langlois, D., Nicklaus, S. & Etievant, P. (2005a) Perceptual Interactions in Odour Mixtures: Odour Quality in Binary Mixtures of Woody and Fruity Wine Odorants. Chemical Senses, 30, 209-217.

Atanasova, B., Thomas-Danguin, T., Langlois, D., Nicklaus, S., Chabanet, C. & Etievant, P. (2005b) Perception of Wine Fruity and Woody Notes: Influence of Peri-Threshold Odorants. Food Quality and Preference, 16, 504-510.

Atanasova, B., Thomas-Danguin, T., Langlois, D., Nicklaus, S. & Etievant, P. (2004) Perceptual Interactions Between Fruity and Woody Notes of Wine. Flavour and Fragrance Journal, 19, 476-482.

Berglund B., Bergland U. & Lindvall, T. (1973) A quantitative principle of perceived intensity summation in odor mixtures. Journal of Experimental Psychology, 100, 29-38.

Bezman, Y., Mayer, F., Takeoka, G.R., Buttery, R.G., Ben-Oliel, G., Rabinowitch, H.D. & Naim, M. (2003) Differential Effects of Tomato (Lycopersicon Esculentum Mill) Matrix on the Volatility of Important Aroma Compounds. Journal of Agricultural and Food Chemistry, 51, 722-726.

Buettner, A. & Mestres, M. (2005) Investigation of the Retronasal Perception of Strawberry Aroma Aftersmell Depending on Matrix

Composition. Journal of Agricultural and Food Chemistry, 53, 1661-1669.

Bult, J.H.F., Schifferstein, H.N.J., Roozen, J.P., Voragen, A.G.J. & Kroeze, J.H.A. (2001) The Influence of Olfactory Concept on the Probability of Detecting Sub- and Peri-Threshold Components in a Mixture of Odorants. Chemical Senses, 26, 459-469.

Cain, W.S., Schiet, F.T., Olsson, M.J. & Dewijk, R.A. (1995) Comparison of Models of Odor Interaction. Chemical Senses, 20, 625-637.

Day, E. A., Lillard, D. A., & Montgomery, M. W. (1963) Autoxidation of Milk Lipids. III. Effect on Flavor of the Additive Interactions of Carbonyl Compounds at Subthreshold Concentrations. J. Dairy Sci. 46, 291-294.

Delahunty, C.M., Eyres, G. & Dufour, J.P. (2006) Gas Chromatography-Olfactometry. Journal of Separation Science, 29, 2107-2125.

Derby, C.D., Ache, B.W. & Kennel, E.W. (1985) Mixture suppression: Electrophysiological evaluation of the contribution of peripheral and central neural components. Chemical Senses, 10, 301-316.

Escudero, A., Campo, E., Farina, L., Cacho, J. & Ferreira, V. (2007) Analytical Characterization of the Aroma of Five Premium Red Wines. Insights into the Role of Odor Families and the Concept of Fruitiness of Wines. Journal of Agricultural and Food Chemistry, 55, 4501-4510.

Escudero, A., Gogorza, B., Melus, M.A., Ortin, N., Cacho, J. & Ferreira, V. (2004) Characterization of the Aroma of a Wine From Maccabeo. Key Role Played by Compounds With Low Odor Activity Values. Journal of

Agricultural and Food Chemistry, 52, 3516-3524.

Freeman, W. J. (2004). Origin, Structure, and Role of Background EEG Activity. Part 1. Analytic Amplitude. Clinical Neurophysiology, 115, 2077-2088.

Guth, H. (1997) Quantitation and Sensory Studies of Character Impact Odorants of Different White Wine Varieties. Journal of Agricultural and Food Chemistry, 45, 3027-3032.

Ito, Y. & Kubota, K. (2005) Sensory Evaluation of the Synergism Among Odorants Present in Concentrations Below Their Odor Threshold in a Chinese Jasmine Green Tea Infusion. Molecular Nutrition & Food Research, 49, 61-68.

Le Berre, E., Atanasova, B., Langlois, D., Etievant, P. & Thomas-Danguin, T. (2007) Impact of Ethanol on the Perception of Wine Odorant Mixtures. Food Quality and Preference, 18, 901-908.

Lorrain, B., Ballester, J., Thomas-Danguin, T., Blanquet, J., Meunier, J.M. & Le Fur, Y. (2006) Selection of Potential Impact Odorants and Sensory Validation of Their Importance in Typical Chardonnay Wines. Journal of Agricultural and Food Chemistry, 54, 3973-3981.

Mulert, C., Jager, L., Schmitt, R., Bussfeld, P., Pogarell, O., Moller, H., J., Juckel, G., Hegerl, U. (2004) Integration of Fmri and Simultaneous EEG: Towards a Comprehensive Understanding of Localization and Time-Course of Brain Activity in Target Detection. Neuroimage, 22, 83-94.

Menon, V. & Crottaz-Herbette, S. (2005) Combined EEG and fMRI Studies of Human Brain Function. International Review of Neurobiology, 66, 291-321.

Oliver, R.L. (1997). Satisfaction: A Behavioral Perspective on the Consumer. New York: Irwin/McGraw-Hill.

Olsson, M.J. (1994) An Interaction-Model for Odor Quality and Intensity. Perception & Psychophysics, 55, 363-372.

Olsson, M. J. (1998) An Integrated Model of Intensity and Quality of Odor Mixtures. Annals of the New York Academy of Sciences, 855, 837-840.

Patte F. & Laffort P. (1979) An alternative model of olfactory quantitative interaction in binary mixtures. Chemical Senses and Flavor, 4, 267-274.

Patterson J., Owen, C.M., Frank, D., Smith, R. & Cadusch, P. (2004) Flavour Sensory Qualities and Consumer Perceptions - A Comparison of Sensory and Brain Activity Responses to Flavour Components in Different Populations. International Journal of Food Science and Technology, 39, 481-490.

Reiners, J. & Grosch, W. (1998) Odorants of Virgin Olive Oils With Different Flavor Profiles. Journal of Agricultural and Food Chemistry, 46, 2754-2763.

Stevens, S.S. (1957) On the psychophysical law. Psychological Review, 64, 153-181.

Tabert, M.H., Steffener, J., Albers, M.W., Kern, D.W., Michael, M., Tang, H.Y.,Brown, T.R. & Devanand, D.P. 2007 Validation and Optimization of Statistical Approaches for Modeling Odorant-Induced Fmri Signal Changes in Olfactory-Related Brain Areas. Neuroimage, 34, 1375-1390.

Figure caption

Figure 1. Holistic odorant analysis incorporating GC-O-EEG. i) shows the potential neurological perception of three different odorants, A, B and C. Compound B shows a very small ‘chemical response’, and would be referred to as a low impact odorant. However its corresponding neurological response (conscious) may induce high brain activity. Compound C would also be classified as a low impact odorant, however its subsequent impact on brain activity may be negligible. ii) demonstrates hypothetical brain activity induced by sensory analyses of a binary mixture of Compounds A and B, and the possible disparity in brain response that may arise due to the contribution of the low impact odorant B.