Taste the bass: Low frequencies increase the perception of body and aromatic intensity in red wine

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Abstract

Associations between heaviness and bass/low-pitched sounds reverberate throughout music, philosophy, literature, and language. Given that recent research into the field of crossmodal correspondences has revealed a number of robust relationships between sound and flavour, this exploratory study was designed to investigate the effects of lower frequency sounds (10Hz to 200Hz) on the perception of the mouthfeel character of palate weight/body. This is supported by an overview of relevant crossmodal studies and cultural production. Wines were the tastants – a New Zealand Pinot Noir and a Spanish Garnacha were tasted in silence and with a 100Hz (bass) and a higher 1000Hz sine wave tone. Aromatic intensity was included as an additional character given suggestions that pitch may influence the perception of aromas, which, might presumably affect the perception of wine body. Intensity of acidity and liking were also evaluated. The results revealed that the Pinot Noir wine was rated as significantly fuller-bodied when tasted with a bass frequency, than in silence or with a higher frequency sound. The low frequency stimulus also resulted in the Garnacha wine being rated as significantly more aromatically intense than when tasted in the presence of the higher frequency auditory stimulus. Acidity was rated considerably higher with the higher frequency in both wines by those with high wine familiarity and the Pinot Noir significantly better liked than the Garnacha. Possible reasons as to why the tones used in this study affected perception of the two wines differently are discussed. Practical application of the findings are also proposed.

KEYWORDS; LOW FREQUENCY; WINE BODY; BASS; SONIC SEASONING; CROSSMODAL CORRESPONDENCES.

1. Introduction

From Pythagoras' alleged observation that heavier hammers make lower sounds[1] to the call by promoters of the DMZ dubstep night to "come meditate on bass weight";[2] low-pitched sounds in the bass register (10 Hz to 200 Hz, see Leventhall, Pelmear, & Benton 2003, p. 7) have regularly been associated with ideas of weight, heaviness, and thickness. In terms of research on crossmodal correspondences (see Parise, 2016; Spence, 2011, for reviews), the results of a study by Walker, Scallon, and Francis (2017) demonstrated that heavier objects tend to cross-activate features of lower-pitched sounds; while pitch has been identified as a sonic parameter that can be consistently conceptually, or perceptually, mapped on to tastes/flavours (e.g., Bronner, Bruhn, Hirt, & Piper, 2012; Crisinel & Spence, 2010; Knoeferle, Wood, Käppler, & Spence, 2015; Kontukoski, Luomala, Mesz, Sigman, Trevisan, Rotola-Pukkila, & Hopia, 2015; Mesz, Trevisan, & Sigman, 2011, 2012; Reinoso-Carvalho, Wang, De Causmaecker, Steenhaut, Van Ee, & Spence, 2016a; Wang & Spence, 2016) and odours (Belkin, Martin, Kemp, & Gilbert, 1997; Crisinel & Spence, 2011). Taken together, such findings suggest that pitch might have an effect on somatosensory perception more widely, and potentially extend to the feeling of the weight of a drink (or perhaps even food) in the mouth, known as oral-somatosensory perception (see Spence & Piqueras-Fiszman, 2016, for a review). Certainly, the vestibular system – the sensory system responsible for balance and spatial orientation – has been shown to be highly sensitive to low sound frequencies, even at relatively low volumes (Todd, Rosengren, & Colebatch, 2008). In the exploratory experiment reported here, we hypothesized that a bass sound frequency (low pitch) might be able

[1] This legend is noted in Zbikowski (2002).

[2] Text from a DMZ (Digital Mystikz) dubstep club invitation referenced in Jasen (2017). Dubstep is a bass-heavy genre of electronic dance music.

to alter the perception of the weight (body) of a wine. We aimed to investigate this through participants rating a wine's weight, along with a selection of other wine attributes, under different sound conditions. We additionally investigated aroma intensity, given that earlier research has indicated that pitch appears to influence the perception of odours, and given suggestions that body can be influenced by wine aromas (Jackson, 2009, p. 154; see also Spence, 2019b). Acidity (sourness) is also included as a reference for comparison, given that this property has already been robustly associated with higher pitches (Bronner et al., 2012; Crisinel & Spence, 2010, 2012; Kontukoski et al., 2015; Mesz et al., 2011, 2012; Wang & Spence, 2015), as well as liking in order to examine possible hedonic influence.

1.1 Audio-gravitational arts

Before modern science started to tease out the details of the complex interactions between the senses, philosophers, artists, and musicians were already making connections between low pitch and weight. As reported by Zibkowski (2002, pp. 7-8), the ancient Greek philosopher, Pythagoras was said to have developed his theory of musical tuning through watching blacksmiths at work and noting that the lowest sounds resonated from their heavier hammers. Gravity's intersensory associations with musical pitch are further traced in the synesthetic theories of Galayev (2003). He notes their manifestation in terms such as 'baritone' – the male voice lying between tenor and bass – whose etymological root lies in the Greek for "heavy sound". That low pitch should be regarded as "heavy" and high pitch "light" is "fixed in many languages, as well as conventional musicological terminology", and is linked to physical laws where the tendency is for low-pitched sounds to be generated from large and "therefore heavy" objects and high ones from small, light ones (Galayev, 2003, pp. 130-131). While the dominant Western notion of pitch is characterized by verticality, inspiring Western art music's rising notation from low to high – which has been linked to natural auditory scene statistics (Parise, Knorre, & Ernst, 2014) – bass is nevertheless widely associated with heaviness. This is illustrated by the English Oxford Living Dictionary (2018) definition of heaviness in relation to rock music, as *"the quality of having a strong bass component"*. In other cultures, pitch is more closely encoded to weight or thickness in language. For example, in the Farsi, Turkish, and Zapotec languages, low pitch is understood metaphorically as "thick", while high pitch is "thin" (Shayan et al., 2015). Both height-pitch and thickness-pitch associations would appear to be pre-linguistic and possibly also universal (e.g., see Dolscheid, Hunnius, Cassanto, & Majid, 2014). The ancient Greeks talked of "sharpness" and "heaviness" and in Bali and Java (islands in the Indonesian archipelago), pitches are described as "small" and "large", respectively (see Zbikowski, 1998).

Ideas of heaviness resonate through the language used by, and applied to, bass-driven musical genres, such as Reggae, Drum 'n' Bass, and Dubstep. In these, the dominant bass element is regularly described as being "heavy", with the term applied to basslines, track titles (such as dub reggae pioneer King Tubby's "A Heavy Dub"), and band names (such as drum 'n' bass act, Delta Heavy). It is possible that this language could be linked to the physical feeling of bass. In his investigation of the creative use of bass, Jasen (2017) notes the particular capacity of bass frequencies to provoke vestibular responses, which include bodily sensations such as "heaviness" (Jasen, 2017, p. 110). Jasen evokes the visceral nature of a genre such as dubstep, in which bass is a "vibrational force" that fills, or even overfills bodies on the dancefloor (pp.

180-181). In Henriques' (2003, 2011) sense-led exploration of the "bass culture" of the Reggae sound system, the reggae dancehall session is described as not only engaging audition, but as a "multi-sensory" (p. 20) and corporeal (p. 101) experience, with a "blood pulse" and "powerful low frequencies [that] resonate with embodied movement" (pp. 13-14).

In literature, low pitch and weight have often been yoked. In the case of poetry, for instance, a study by Macdermott (1940) analyzed almost 200 poems and discovered crossmodal sound symbolism between low-pitched vowels and sensory qualities of heaviness. Meanwhile, in Huysman's (1884/1959) novel *Against Nature/À Rebours*, within the orchestra of the palate emanating from the drinks cabinet that the protagonist calls his "mouth organ", the double-bass is described as "*full-bodied*, solid and dark as the old bitters" (p. 59, our italics).

Through the multisensory arts practice of one of this paper's first author, it has also been noted that bass tones appeared to boost the impression of body when creating "oenosonic" [3] compositions – such as *Oenosthesia* (Burzynska, 2018a). These observations were reinforced by responses from participants attending her wine sound matching workshops, such as the "Pinosthesia" presentation made at the Pinot Noir 2017 conference in Wellington, New Zealand in January 2017. At this event, a single Pinot Noir[4] was tasted by those attending the conference with a varied selection of music. This included a composition that Burzynska had created specifically for the wine and a bass-heavy track from the dubstep musical genre (Datsik, 2009). The latter musical work elicited a number of similar observations to her own amongst the

[3] *Oenosonic* is a term coined by Jo Burzynska (2018b) to describe the creative combination of wine and sound in her works.
[4] The wine was the Crown Range Grant Taylor Signature Series Central Otago Pinot 2016.

participants, in that it appeared to increase the perception of wine body. This finding was conveyed both through informal feedback and coverage of the tasting[5] (d'Amato, 2017; see also Moran, 2017).

1.2 Crossmodal pitch-weight connections

Low-pitch and weight associations have begun to be investigated in crossmodal (or cross-sensory) science. In a recent study, subtitled "Heaviness is dark and low-pitched", Walker, Scallon, and Francis (2016) observed that participants lifting unseen objects that were identical in size but varied in terms of their weight expected the heavier object to make lower pitched sounds. This reinforced the association between pitch and weight, suggesting that it exists both as a metaphor, and a perceptual, non-visual and non-linguistic phenomenon, which could be modality-independent (see Walker et al., 2012, for a discussion).

In light of recent research into crossmodal correspondences between sound and taste/flavour (flavour in this paper including mouthfeel characteristics, see Spence & Piqueras-Fiszman, 2016, for a review), the potential for finding correspondences between pitch and body would appear promising. It has now been widely demonstrated that people map taste/flavour characters with both musical and non-musical sounds (e.g., see Knöferle & Spence, 2012). Musical sounds include notes, instruments (Crisinel & Spence, 2009, 2010a, 2012) and music and soundscape compositions (Bronner et al., 2012; Knoeferle et al., 2015; Kontukosi et al., 2015;

[5] *"The heavy bass of the Dubstep music … enhanced the body of the wine and our perception of umami."* Sara d'Amato, sommelier. https://www.winealign.com/articles/2017/03/02/buyers-guide-to-vintages-march-4th-2017/ Accessed 5 November 2018.

Mesz et al., 2011; Reinoso-Carvalho et al., 2016b; Spence et al., 2013; Wang & Spence, 2015, 2018; Wang, Woods & Spence, 2015), while non-musical sounds include pure tones (Holt-Hansen, 1968, 1976; Reinoso-Carvalho et al., 2016a; Wang et al., 2016), eating sounds (Zampini & Spence, 2004; Spence, 2015, for a review) and noise (Spence, 2014; Yan & Dando, 2015). Furthermore, these matches can be more than merely crossmodal associations, with sounds sometimes being shown to modulate the perception of flavours as well (Crisinel et al., 2012). Numerous studies have now robustly demonstrated that high pitches are mapped on to sour tastes (Bronner et al., 2012; Crisinel & Spence, 2010; Kontukoski et al., 2015; Mesz et al., 2011, 2012; Simner, Cuskley, & Kirby, 2010; Wang & Spence, 2015). A number of crossmodal correspondences between sounds (pitch) and odours have also been identified (Belkin, 1997; Crisinel & Spence, 2011).

In recent years, a number of studies have identified that crossmodal correspondences exist between sound and wine (for reviews of the area, see Spence, 2011; Spence & Wang 2015a, b, c, and, for a more general multisensory overview, Spence, 2019a). A number of researchers have demonstrated a high level of agreement in the congruency between pieces of music and wines in forced choice matching exercises (Spence et al., 2014; Spence & Wang, 2015b, c; Wang & Spence, 2015, 2017), and that emotional associations might be mediating these sound-flavour correspondences (Wang & Spence, 2017). Only a few of these studies have included body. For instance, Wang and Spence (2018) found that a staccato soundtrack increased the perception of body amongst wine professionals. Body is an oral somatosensory wine character that is, as yet, still not fully understood (Laguna et al., 2017; Niimi, Danner, Bossan, & Bastian, 2017), but likely resulting from the perception of a combination of alcohol, polysaccharides, sugar, and tannins in a wine (see Gawel, 2006; Gawel, Schulkin, Smith, Kassara, Francis, Herderich and Johnson, 2018). As defined by Grainger (2009, p. 136): *"Body, sometimes referred to as weight or mouth feel, is more of a tactile than a taste sensation. It is a loose term to describe the lightness or fullness of the wine in the mouth."* No studies have specifically investigated body in relation to pitch. The existence of a consensual correspondence between pitch and specific wine aromas was established by Crisinel and Spence (2011). This study presented aromas commonly found in wine, sourced from single presentations or blends of typical molecules in the educational *Le Nez du Vin* wine aroma kit. This study found participants matched much lower pitched sounds with aromas of smoke, musk, dark chocolate, and cut hay, and higher pitches with fruitier aromas. There is currently no crossmodal research that has focused on specific sound-aroma matches using actual wine.

Formal studies of sound-flavour correspondences have also yet to focus on sound stimuli in the bass frequency register. Those studies that have used lower pitches have indicated that bitter tastes are regularly matched with lower-pitched sounds (Crisinel et al., 2012; Crisinel & Spence, 2010a; Knöferle & Spence, 2012). Meanwhile, a study by Wang, Woods and Spence (2015) that used a number of different compositions associated with different basic tastes, found the best-matched 'bitter' composition had the lowest pitch of all the soundscapes that were tested.

According to other studies using alcoholic beverages, beers that had bitter profiles matched with significantly lower pitch ranges when participants were given free range to "tune" a selection of beers across a spectrum of sine tones (Reinoso Carvalho et al., 2016a). Furthermore, a putatively bitter (lower pitched) soundtrack was also found to result in people rating a beer as tasting more bitter, and alcoholic (Reinoso Carvalho, Wang, Van Ee, & Spence, 2016b). It is worth noting that alcohol is a component that plays a key role in the perception of body in alcoholic drinks. This study follows the earlier experiments of Holt-Hansen (1968), which demonstrated for the first time that the matches of two different beers consistently fell within two different narrow frequency bands, replicated by Rudmin and Cappelli (1983). Crucially, no studies with wine and sound reported to date have observed the effect of single frequency sine waves on the characteristics of wine, and have instead used more complex soundtracks/musical pieces with variables that make it difficult to isolate the specific elements that may have been responsible for the perceptual taste/flavour changes. In this experiment, these variables have been reduced through the sole usage of pure tones.

2. Materials and Methods

2.1. Participants – Main study

A total of 50 participants took part in the main study: 25 at Oxford University's Crossmodal Research Laboratory in Oxford, UK in October 2017, and another 25 at the University of New South Wales' faculty of Art & Design in Sydney, Australia in March 2018. This sample size is supported by data gathered by Gacula and Rutenbeck (2006), confirming that 40-100 participants appear to be the ideal sample size for analytical consumer sensory tests. Both groups of participants took part in the same study using identical wines. The study was covered by ethics approval from UNSW's Human Research Ethics Committee (HC17727) and the University of Oxford's Central University Research Ethics Committee (MSD-IDREC-C1-2014-205). All of the participants were aged over 18 years of age, and gave their informed consent prior to taking part in the study. The participants also confirmed that they met the study's criteria: that they did not suffer or have suffered from any taste, olfactory or auditory dysfunction; were not aware of possessing a sensitivity to low frequencies;[6] were not currently suffering from a cold/flu, or other temporary respiratory problems, and had no current or past alcohol dependency issues.

Of the 50 participants, 18 were male and 32 female. They were aged between 22 and 73 years (mean age = 41.18 years, SD=13.23). In terms of self-reported wine expertise; 6 had no expertise, 13 were beginners, 16 intermediate, and 15 were advanced, which when combined was 19 novice/beginners and 31 with some experience. In terms of tasting frequency, one drank wine up to six times a year, 10 drank wine monthly, 19 weekly, and 20 drank wine most days. When combined, 30 were relatively infrequent wine drinkers and 20 were frequent.

2.2. Stimuli

Auditory stimuli. The wine was tasted in silence and with a low and a higher pure tone presented in a randomized order. These tones were sine waves with a bass frequency at 100Hz (approximately the musical note G_2), and, as a contrast, a higher 1000Hz frequency sine wave (approximately the musical note B_5). These were presented at a comfortable headphone level of 60 dB (i.e., similar to the level of everyday speech), with scaled sound pressure levels derived from the IS0 226:2003 Equal Loudness Contours (ISO, 2013): the 100Hz at 68dB, and the 1000Hz at 60dB. The auditory stimuli were downloaded from the wavTones.com Professional Online Audio Frequency Signal Generator – http://www.wavtones.com/functiongenerator.php at a

[6] As noted by Leventhall et al. (2003), it would appear that some people are sensitive to low frequencies (i.e., 10 Hz to 200 Hz) and experience distress in their presence.

sample rate of 192kHz and 32-bit resolution. These were played through Beyerdynamic DT 770 PRO Studio Headphones (80 Ohm).

INSERT FIGURE 1 ABOUT HERE

Wines. The wines were two commercially available red wines, selected as they both possessed a similar medium body, but differing levels of acidity and aromas. Wine 1 was Torres Sangre de Toro 2015: 13.5% abv; pH: 3.82; Total acidity: 4.9 g/L; Residual sugar: 1.2 g/L[7] and with a professional organoleptic assessment suggesting that it possessed a medium (-) aromatic intensity (with subtle notes of ripe plum), medium (-) acidity, medium body and medium (-) tannins. Quality Level: Acceptable – a simple fruity wine with light-to-medium intensity, soft red fruit and spice typical of the variety, fairly short and simple; not suitable for ageing.[8] Wine 2 was a Brancott Estate Letter Series "T" Marlborough Pinot Noir 2015: 14.1% abv; pH: 3.50; Total acidity: 5.7g/l; Residual Sugar: 2.7g/l [9] and with a professional organoleptic assessment reporting that it possessed a medium aromatic intensity (with notes of cherry, cinnamon, spice, and herb), medium (+) acidity, medium body and medium tannins. Quality Level: Good – a medium intensity wine with good freshness and brightness to its ripe fruit, showing clear varietal typicity and some depth and complexity; suitable for mid-term ageing. These were served in six 20ml measures to participants.

2.3 Experimental Design

[7] Technical specifications provided by Bodegas Torres.

[8] Assessed by Jo Burzynska, a professional wine judge and Certified Wine & Spirit Trust (WSET) Educator and holder of a WSET Diploma, using the WSET Systematic Approach to Tasting Wine®.

[9] Technical specifications provided by Pernod-Ricard.

The aim of the present study was to determine whether the perception of body (along with the two additional wine characteristics: aromatic intensity and acidity) would be altered by tasting a wine while listening to a relatively low-frequency sound (100Hz), as compared to when tasting in silence and, by way of contrast, a relatively higher frequency sound (1000Hz). The participants were instructed to rate levels of body, acidity (sourness), aromatic intensity, and liking, in the different sound conditions. Acidity was included in order to offer a point of comparison with previous studies that have robustly demonstrated associations between high acidity and higher pitched sounds in other beverages (Bronner et al., 2012; Crisinel & Spence, 2009, 2010a, 2010b; Knöferle et al., 2015; Kontukosi et al, 2015; Mesz et al., 2011, 2012). Aroma intensity was selected as an extra parameter in order to permit the observation of any olfactory change in an actual wine, given the under-researched nature of this area as noted earlier. The participants rated how much they liked the wine in the different conditions in order to determine whether hedonic factors played any role in determining the participants' responses.

2.4 Experimental procedure

The experimental procedure comprised two separate studies. The main is study covered here in this section (see Figure 1a). The supplementary (RATA) study is detailed in 2.5 (see Figure 1b).

INSERT FIGURE 1 ABOUT HERE

The main experiment in both locations was conducted in an identical manner using the same wines and sound stimuli. This was performed one participant at a time in a quiet room, who was seated in front of a computer screen with a pair of headphones, computer mouse, spittoon and crackers. They completed the electronic survey that had been programmed on the Qualtrics online survey platform. Given the difficulty that inexperienced tasters have in identifying body/viscosity in particular (Niimi et al., 2017), participants were first given a brief training session on the wine characteristics that they were to rate. They were provided with a small selection of training wines to smell and taste that illustrated a higher and a medium rating on the 9-point scale they went on to use (see Figure 2), as well as water, which was used as the example of the lowest rating for aroma, acidity, and body.

The study wines were then presented in a randomized order in black glasses in each sound condition in order to remove any potential visual bias and ensure that each of the wines was evaluated as a fresh sample by the participants in the different sound conditions. Each participant tasted each of the two wines in a silent condition and with both two-minute-length low and higher sine tones, which were also presented in a random order. For each condition, the participants rated their perception of the level of the wine’s aroma, acidity, and body, as well as their liking for the wine, on a 9-point scale (see Figure 2). The questions were presented as an electronic form using Qualtrics Online Survey Software, with the questions on body and acidity randomized following the question on aroma. They were also asked to rate how much they liked the wine in both silence and the different tone conditions. The participants were asked to answer all the questions while the 2-minute tone was presented, with a break of approximately one minute between samples in which participants were advised to cleanse their palates with the water provided.

INSERT FIGURE 2 AROUND HERE

2.5 Rate-All-That-Apply (RATA)

As body is an element of wine whose overall physical dimensions cannot currently be measured objectively, and for which the judgment of levels relies on sensory assessment, the wines used were additionally assessed using a Rate-All-That-Apply (RATA) study in order to obtain additional objective, sensory profiles of the wines that were tasted in the main experiment. For a review of the oral-somatosensory attributes of food and drink, see Spence and Piqueras-Fiszman (2016) and for mouthfeel in general, see Mouritsen, Styrbæk, and Johansen (2017). Further specific overviews are provided for beverages by Szczesniak (1979), and wine, by Gawel (2006) and Gawel et al. (2018). RATA is an intensity-based variant of Check-All-That-Apply (CATA) developed for sensory characterization using untrained panelists (see Danner et al, 2017). RATA assessments of the Torres Sangre de Toro 2015 and Brancott Estate Letter Series "T" Marlborough Pinot Noir 2015 were made within 6 months of the main experiment.[10] The RATA analysis was undertaken by 69 panelists consisting of a mix of staff and students from the University of Adelaide's viticulture and oenology programmes between 20-56 years of age (27 male, 42 female), who possessed some form of wine evaluation training. The study was conducted in individual, computerised sensory booths, using a methodology identical to that outlined in Danner et al. (2017), but covered a range of

[10] As a minimum of six wines are required for multivariate analyses, this study also included another cool climate Pinot Noir from the Adelaide Hills wine region, South Australia and three warm climate Garnachas/Grenaches from McLaren Vale, South Australia which were not examined further in the main study.

58 wine attributes – across colour, aroma, flavour, mouthfeel and aftertaste (see Appendix) – and liking.

2.6 Data analysis

First, Pearson correlation coefficients were calculated between the measures of aroma intensity, acidity, body, and liking. Next, a repeated-measures multivariate analysis of variance (RM-MANOVA) was conducted with wine type (Garnacha, Pinot Noir) and sound condition (silent, 100 Hz, 1000 Hz) as within-participant measures (SPSS, version 23.0, IMB Corp., Armonk, NY). The model included body, acidity, aromatic intensity, and liking as measures (dependent variables). Furthermore, wine familiarity (taken as an average of wine expertise and wine drinking frequency), was introduced as a between-participants factor. Wine familiarity was calculated by taking the average of wine expertise and wine drinking frequency values, and splitting the population into those with low familiarity (N= 21) and high familiarity (N=29) (see Figure 3). Follow-up univariate ANOVAs were conducted on dependent variables where there was a significant main effect or interaction effect amongst the independent variables.

RATA intensity data was analysed using two-way Analysis of Variance (ANOVA) (sample as fixed and panelist as random factor) treating the data as continuous data (a non-selected attribute was treated equivalent to “not perceived” and assigned as intensity = 0), with a post-hoc Fishers LSD and principal component analysis (PCA). Consumer acceptance data were analyzed using ANOVA with post-hoc Tukey's test. Data were analyzed using Senpaq v5.01 (Qi Statistics, 2012) and XLSTAT Version

2016.03.31333 (Addinsoft, New York, USA). All statistical analyses were performed at 5% level of significance.

INSERT FIGURE 3 AROUND HERE

3. Results

Significant correlations were found between ratings of aroma intensity, acidity, body, and liking in the main study (see Table 1). Notably, all pairwise correlations were positive. For instance, wine liking was positively correlated with aroma intensity, acidity, and body. Moreover, perceived body was positively correlated with aromatic intensity and acidity.

INSERT TABLE 1 AROUND HERE

The mean values of the participants' wine ratings for both types of wine and all three sound conditions are shown in Figure 4. Overall, the RM-MANOVA revealed a significant main effect of wine type ($F(4, 45) = 9.21$, $p < .0005$, *Wilks' Lambda* = 0.55), as well as a significant interaction effect between wine type and sound condition ($F(8, 41) = 2.36$, $p = .034$, *Wilks' Lambda* = 0.68). However, there was no significant main effect of sound condition ($F(8, 41) = 1.70$, $p = .13$), nor of wine familiarity ($F(4, 45) = 2.38$, $p = .07$) on the dependent measures (body, acidity, aromatic intensity, and liking). No significant differences were noted between the responses of the Sydney and Oxford participant groups.

In terms of wine type, follow-up univariate tests revealed that there were significant differences between the two wines in terms of their aroma intensity ($F(1, 48) = 24.42$, $p < 0.0005$, $\eta^2 = 0.34$) and participants' liking ($F(1, 48) = 6.72$, $p = 0.013$, $\eta^2 = 0.12$). Overall, the Pinot Noir was rated as more aromatic than the Garnacha (M_{Pinot} *(SD)* =

5.68 (1.82), $M_{Garnacha}$ (SD) = 4.69 (1.51), $p < 0.0005$). In terms of liking, the Pinot Noir was liked significantly more than the Garnacha (M_{Pinot} (SD) = 5.38 (1.68), $M_{Garnacha}$ (SD) = 4.90 (1.44), $p = 0.013$).

Furthermore, there were significant interaction effects between wine type and sound condition for the ratings of aroma intensity ($F(2, 96) = 3.48$, $p = 0.035$, $\eta^2 = 0.07$) and body ($F(2, 96) = 3.84$, $p = 0.025$, $\eta^2 = 0.074$). For aroma intensity, the interaction was driven by the fact that the Garnacha was rated to be significantly more aromatically intense while participants were listening to the 100 Hz low tone rather than the 1000 Hz higher tone (M_{100Hz} (SD) = 5.14 (1.64), M_{1000Hz} (SD) = 4.38 (1.43), $p = 0.007$). No such differences were found for the Pinot Noir. In terms of body, wines were rated as being significantly fuller while listening to the 100 Hz low tone as compared to silence for the Pinot Noir (M_{100Hz} (SD) = 5.54 (1.64), $M_{Silence}$ (SD) = 4.96 (1.59), $p = 0.021$). However, the same effect was not observed for the Garnacha, in which there was little change between the different conditions.

INSERT FIGURE 4 AROUND HERE

While there was no main effect of wine familiarity, we did observe a significant interaction effect between sound condition and wine familiarity when it came to ratings of acidity ($F(2, 96) = 3.84$, $p = 0.025$, $\eta^2 = 0.074$). As Figure 5 illustrates, this interaction was driven by the difference in acidity ratings in the high frequency (1000 Hz) condition, with those with high wine familiarity perceiving the wines as much more acidic compared to those with low wine familiarity (M_{Low} (SD) = 5.21 (1.57), M_{High} (SD) = 6.40 (1.61), $p = 0.004$). Non-significant trends suggested that those with high wine familiarity rated the wines to be the *most* acidic in the 1000 Hz condition out of all sound conditions, whereas those with low wine familiarity rated the wines to be the *least* acidic in the 1000 Hz condition out of all sound conditions.

INSERT FIGURE 5 AROUND HERE

The RATA analysis revealed that the Garnacha and Pinot Noir wines were perceived as similar in most attributes. Relevant to the main study, this included comparable perceptions of acidity, body and viscosity in both wines (see Figure 6). However, there were six significant differences ($p < 0.05$) discovered. The Garnacha was rated higher in chocolate aroma, chocolate and dark fruit flavours, and astringency, while the Pinot Noir was rated higher in red fruit and savoury notes (see Figure 4). Liking was similar across all six wines in the RATA study, with the mean liking rating of the Garnacha 5.25 and the Pinot Noir 5.12 on a 9-point hedonic scale. A further visual examination of a biplot of the Principal Component Analysis, which explained 82.08% of the variation of the data in the sensory space in the first two components (data not shown), of all the six wines in the RATA study showed the Garnacha positioned in the sensory space towards the left of the plot, which contained attributes such as confectionary and jammy flavours, while the Pinot Noir was situated to the right, closer to savoury and earthy/dusty flavours.

INSERT FIGURE 6 AROUND HERE

The results of the experiment reported here demonstrate a significant crossmodal interaction between sound conditions (silence, low tone, or high tone) and wine type (a Spanish Garnacha and a New Zealand Pinot Noir). In the case of the Garnacha, this wine's aromatic intensity was perceived as being significantly higher when tasted while listening to the low tone than when tasted while listening to the high tone. In the case of the NZ Pinot Noir, the body of the wine was rated on average as being significantly fuller while listening to the low-pitched tone than when tasting in silence. However, there was no effect of the low-pitched tone on the perception of body for the Garnacha nor on the perception of the aromatic intensity of the Pinot Noir.

4. Discussion and Conclusions

In the study reported here, listening to a bass tone (100Hz) was shown to elicit significant changes in the perception of characters of both red wines tested. This pattern of results suggests that pitch not only affects the perception of basic tastes, but also of aromatics and the mouthfeel character of body in a wine as well. As suggested by widely-held associations and metaphorical connections between weight and low pitch, in the case of the NZ Pinot Noir, a low frequency sound significantly increased perceptions of body in a wine. Bass also created a significant augmentation in the perception of aromatic intensity in the Spanish Garnacha. However, as to the question of why the shifts in perception of these attributes should have been different for the two wines the answer is currently less clear.

When looking for possible reasons behind the difference in aromatic augmentation between the two wines, it should be noted that the Garnacha was rated as the lower of the two wines in terms of its aromatic intensity in the silent condition and in the professional organoleptic assessment. It could therefore be proposed that in possessing less aromatic intensity there would be more scope for movement within aromatic ratings for this wine as compared with that of the NZ Pinot Noir, which was a more aromatic wine to begin with. Given previous research examining associations between pitch and aroma, ascertained matches between different aromas and different pitches (see Belkin, 1997; Crisinel & Spence, 2011), it could be that the different aromatic characters found in the wines could have had an effect on perceived intensity. The RATA study identified that the aromatic profile of the Garnacha different significantly from that of the Pinot Noir in possessing higher levels of chocolate aromas. Crisinel and Spence's study, which used samples from the *Nez du Vin* wine aroma kit as olfactory stimuli, found chocolate aromas were associated with low-pitched notes. From this, it could be surmised that presence of chocolate aromas in the Garnacha, in being congruent with low frequencies, caused the aromatic intensity to be perceived as greater with the bass tone in this particular wine.

While the wines possessed different levels of aromatic intensity, their body was comparable in both the silent condition of the study, the professional assessment, and the RATA study. This makes the increase in perceived body in the low pitch condition for the Pinot Noir, but not the Garnacha (where very little change in all conditions was apparent), harder to unravel. Complexity, which the authors noted as an "essential factor" in the choice of pitch in Crisinel and Spence's (2012) study of crossmodal associations between musical notes and odours, is another factor that could be promoting the different responses to a similarly weighted attribute (body) in this study. As noted by Lavie (2005), more complex perceptual stimuli increased the effect of attention on awareness, although effects are somewhat mixed for audition (Murphy, Spence, & Dalton, 2017). The various assessments of the Garnacha reveal it to be less complex than the Pinot Noir. It was judged to be "a simple fruity wine" of "acceptable" quality in the professional organoleptic assessment, and located closer the area of simple ("jammy" and "confectionary") fruit flavours on the RATA biplot. In contrast the Pinot Noir was identified in the professional assessment as possessing some complexity and judged as "good", while in the RATA results it was situated closer to what could be considered more complex "savoury" and "earthy/dusty" flavours on the biplot. This could have lessened attention to body in the case of the Garnacha and increased it in the case of the Pinot Noir.

Emotion has been put forward as a mechanism mediating crossmodal correspondences between taste and sound (Wang et al., 2016), odour and pitch (Crisinel & Spence, 2012), and taste and shape (Turoman et al., 2018; Velasco et al., 2015). It could be surmised that emotional factors (what is known as emotional mediation) may have played a role here, given that there was a difference in the liking of the two wines. The Pinot Noir, which elicited responses to the bass frequency in the manner hypothesized, was the significantly better-liked wine of the two. This suggests that hedonic mediation might be a factor in the different responses related to the interaction between bass and body with the two wines. However, it should be noted that there were no significant differences in hedonic ratings of the wines between the different sound conditions. As no emotional values were collected for the two auditory pitches used in this experiment – the wines were only rated for liking – the possibility of emotional mediation cannot be extrapolated from within this experiment itself. Some illumination, however, could be provided by cross referencing the pitches used in our study with those investigated in another study by Wang et al. (2016) that investigated the role of emotion in mediating correspondences between basic tastes.[11] This suggests that while mediation might not have been hedonic in our study, arousal could have been a factor mediating the correspondence between low pitch and full body in the Pinot Noir in our study. The Pinot Noir could

[11] Wang et al. (2016) used the dimensions of valence and arousal, which were mapped by the study's participants to pitch (using a piano sound). Cross-referencing the closest pitches used in our experiment with those of Wang et al.'s (2016: Appendix B) study, the lower pitch note was less liked than the higher pitch note, which casts some doubt over hedonic mediation in our study. However, in terms of arousal, the lower pitch was rated as more arousing than the higher pitch.

feasibly be regarded as the more exciting wine in both being better liked, and more complex than the Garnacha. In light of this, in future experiments it might be advisable if more emotional dimensions are included in relation to the sounds, as well as the wines.

While the complexity of the wine (see Spence & Wang, 2018, on the challenging topic of wine complexity) offered the potential for multiple correspondences, its complex multidimensional nature also makes it a challenging stimulus to assess. Given the diversity and complexity of the wine chemistry and the perception of its sensory characters in both wines in this study, there could have been a number of attributes that had an influence on each other, and consequently on the way their flavour (and aroma) profiles were perceived when accompanied with the sounds. As greater viscosity tends to be associated with a lessened perception of intensity of flavours and volatile components in model solutions, depending on the compounds (Tournier, Sulmont-Rossé, & Guichard, 2007), that there were significant pairwise correlations between ratings of aroma intensity, acidity, body, and liking, could suggest that people might be transferring high intensity across attributes. This could also be due to learned associations that link high levels of attributes, as demonstrated by novice wine drinkers associating fuller bodied wines with greater flavor intensity and vice versa (Niimi et al., 2017). However, no research examining these specific taste-aroma interactions in wine has been published to date. Furthermore, it should be noted that the area of taste-aroma interactions is a complex one (Paravisini & Guichard, 2016; Tournier et al., 2007) and study into crossmodal correspondences between sound and wine is still at a nascent stage, more research is required into how the different attributes of both wine characters, and wine and sound interact.

When the data from the participants was segmented into groups, correlations between higher acidity and higher pitch emerged as a trend in the group with greater wine familiarity. This is a mapping demonstrated in numerous other studies that would therefore have been expected in this one. A recent study by Wang and Spence (2018) indicated crossmodal effects between music and wine were similar across experts and non-experts. However, its authors also proposed that experts may be better placed to detect the subtle attentional effects of music on their taste perception, which one could surmise might have been the case in our study. Why the sour-pitch correspondence did not emerge so clearly in this study could also – as previously discussed – potentially be due to the complexity of wine, in which acidity is just one of many salient perceptual attributes.

From looking at these different participant categories, it can also be noted that the more experienced tasters performed in a far more consistent manner in their judgments than did the beginners. This could suggest that the methodology of the experiment was better suited to those with more wine experience. It could be hypothesized that experts might be more used to conceptualizing levels of the attributes selected in the study, rating these on a scale. This was perhaps more of a challenge to novices (see discussion of rating scales by Meilgaard et al., 2006, pp. 55-60). Regular wine drinkers could also be more confident in their interactions with wine, given that it is a regular part of their lifestyle, in contrast with those for whom wine constituted an occasional drink. It should be noted that some less experienced tasters among participants voiced concern to the invigilator with regards to their accurate use of the scale. It could be that any changes needed to be more overt for them to be rated more decisively, in which case, the fact that there is such a strong result for the low frequency increasing perceptions of the Pinot Noir's body suggest that this is particularly strong crossmodal correspondence.

Issues with rating on scales could be overcome, and the results clarified, by running an additional study using a different methodology in order to further explore possible correlations between bass and body through, for example, a matching exercise. In this case, the participants would be given three wines of varying body (light, medium, and full), but with their other main parameters (i.e., acidity, tannins) matched as far as possible, to match with three tones of varying pitch (low, medium, and high). In this simple matching exercise any correlations between pitch and body should become more apparent.

When interpreting the data, it is also worth considering the relationship between pitch and body in light of current discussions regarding the relative versus absolute nature of the crossmodal correspondences (see Brunetti, Indraccolo, Del Gatto, Spence, & Santangelo, 2018; and Spence, 2018, in press). Past research suggests that most crossmodal correspondences involving the metathetic pitch dimension are relative (Ben-Artzi & Marks, 1995; Brunetti et al., 2018; Chiou & Rich, 2012; Stevens, 1957). The range of responses in this study suggest that the pitch-body and pitch-aroma correspondences identified are not absolute. The completely randomized presentation of the tones with the two wines in this study could mean that for some participants the same, rather than a contrasting, tone was presented sequentially. The first tone presented might also have been difficult to categorize as being either high or low. Brunetti et al.'s (2018) investigation highlighted the flexibility and sequential influence of stimuli presentation in relation to the absolute versus relative nature of pitch-size correspondences. From this, it could be deduced that the randomization in our study could have lessened the correspondences discovered. To overcome these possible effects, future experiments could expose participants to the range of tones used before the start of the experiment. Using a tone higher in frequency than 1000 Hz might presumably also assist in greater differentiation between the tones by participants.

The perception of low pitch would appear, in some wines at least, to significantly increase the perception of body. This finding highlights that this approach should be a fruitful avenue for further research to clarify the prevalence of this correspondence in wine, as well as in other beverages and foodstuffs. That bass notes were able to shift the perception of aromatics in one wine (the Garnacha) and increase the perception of the attribute of body in another (the Pinot Noir), provides a step towards the greater understanding of the web of relationships between the complex flavour profiles of wines and the influence of sounds on their perception.

These findings could be used to inform the wine and sound/music combinations created by those working with wine and sound creatively – such as artists, musicians, designers and chefs. This could permit greater control in the shaping of multisensory environments through using more targeted “sonic seasoning” (Spence, 2017). This knowledge could be of particular significance in bass-heavy environments, such as clubs and bars, in highlighting that the music played will likely be having a significant impact on the taste experiences of their clientele. Conversely, when people are making their beverage selections in these clubs, they might use these observations to choose a drink that improves with the perception of increased body, such as a fuller bodied red wine, rather than one that is adversely effected by it, for example, a Champagne or light white wine. These findings could also be of value for consideration in the acoustic design of spaces where fine wine is to be consumed, suggesting attention needs to be paid to controlling bass frequencies through the use of appropriate low frequency sound absorbing materials.

Given the growing trend of playing music at both wine tastings and even during the judging of professional wine competitions, these crossmodal correspondences between flavour/aroma and sound may also be applicable for consideration by those organizing such events. Music is played at competitions during the judging process, at competitions such as the UK's International Wine Competition (IWC) and Australia's Adelaide Review Hot 100. This is despite ISO 8589 (2007) guidelines for the design of test rooms intended for the sensory analysis of products, which advises in such spaces "noise level shall be kept to a minimum". These findings reinforce the need for quiet environments to minimize not only the possibility for distraction, but sonic influence on the perception of flavour and aroma characters during wine assessment. This would appear particularly relevant to professional tastings, where a consistent evaluation of the wines is desired. Conversely, in more entertainment-based consumer wine events, where music can play positive roles in priming moods and creating an appropriate ambience, these correspondences can be applied to the sound mix to emphasize desired wine characters.

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FIGURE LEGENDS

Figure 1. a) Illustration of the methodology applied in the main (pitch-based) study. b) Illustration of the methodology applied in the RATA study.

Figure 2. a) Example of the 9-point scales used for participant ratings; b) Example of the questionnaire presented on a computer as seen by the participants.

Figure 3. Histogram of participants' self-reported wine familiarity rating. Participants were divided into two equal groups, those with low familiarity (with rating < 3, N=21) and those with high familiarity (with rating ≥ 3, N=29).

Figure 4. Mean ratings of body (A), acidity (B), aroma intensity (C), and liking (D) for both wines in the three sound conditions: Silence, low pitch (100 Hz), and high pitch (1000 Hz). Error bars indicate standard error. Asterisks indicate statistical significance at $p < .05$.

Figure 5. Mean ratings of acidity in the three sound conditions: silence, low pitch (100 Hz), high pitch (1000 Hz), grouped by wine familiarity (low, N=21 or high, N=29). Error bars indicate standard error. Asterisks indicate statistical significance at $p < .05$.

Figure 6. Mean intensity ratings of selected attributes from RATA analysis rated on a scale of 1-7. Those differences that are statistically significant (at $p < .05$) are marked with an asterisk.

Table 1. Pearson correlation coefficients (*N* = 189) amongst participants' ratings of aroma intensity, acidity, body, and liking. * indicates significance at <.05 level, ** indicates significance at <.01 level.

	Aroma intensity	**Acidity**	**Body**	**Liking**
Aroma intensity	1	0.21 **	0.21 **	0.20 **
Acidity		1	0.23 **	0.14 *
Body			1	0.43 **
Liking				1

Figure 1a

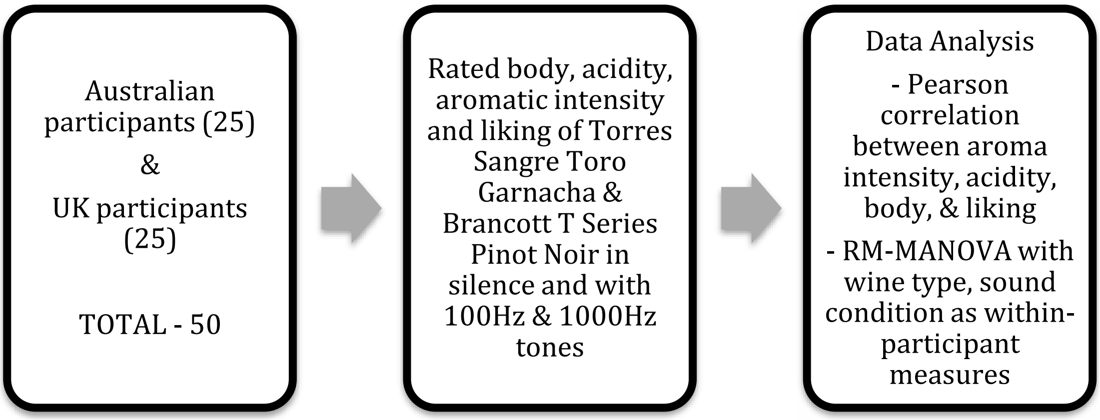


Figure 1b

Figure 2.

a)

Low acidity/ body/ aromas				Moderate acidity/ body/ aromas				High acidity/ body/ aromas
1	2	3	4	5	6	7	8	9

b)

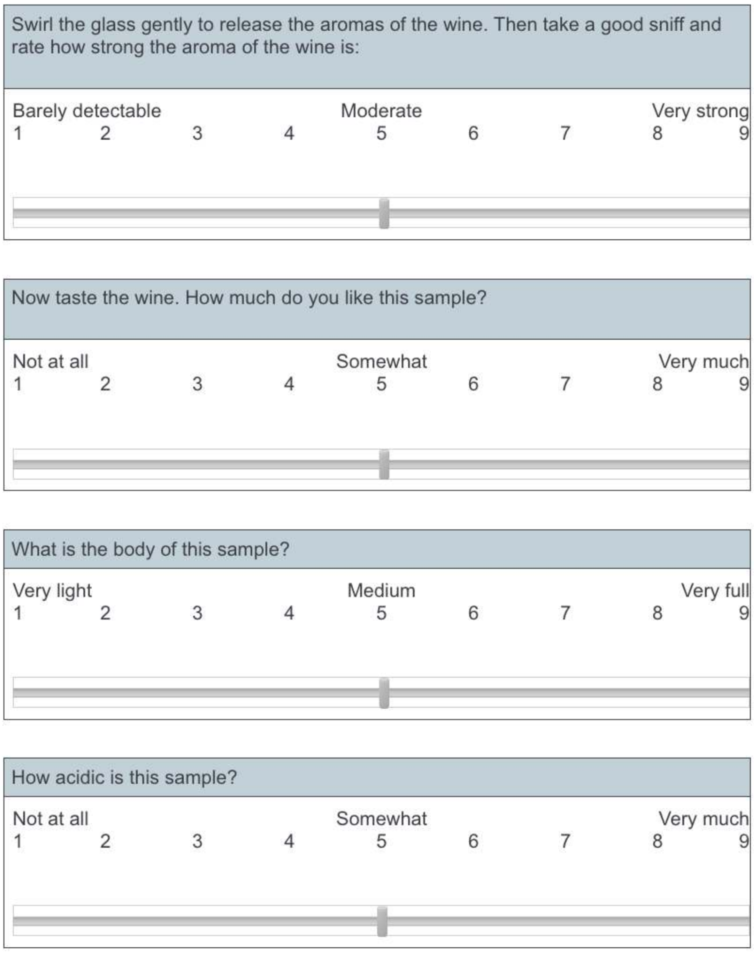


Figure 3

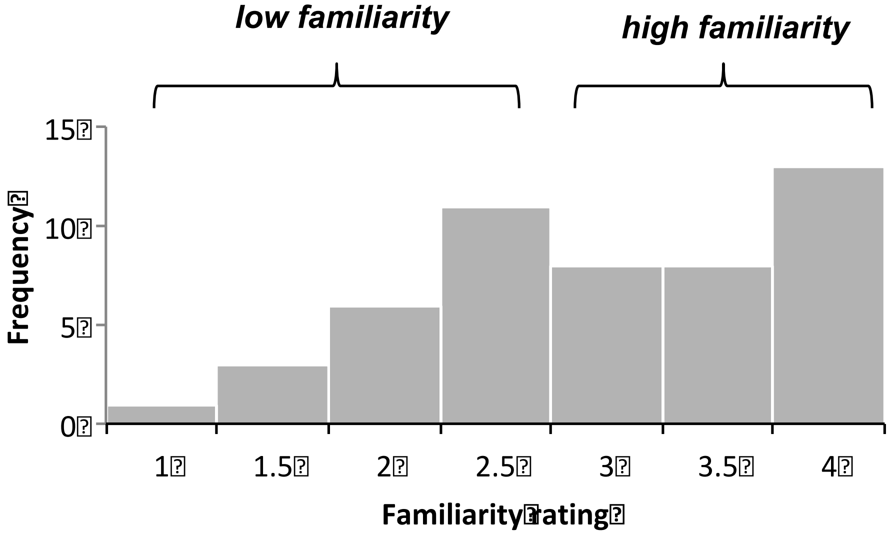

low familiarity
high familiarity
15
10
5
0
Frequency
1
1.5
2
2.5
3
3.5
4
Familiarity rating

Figure 4

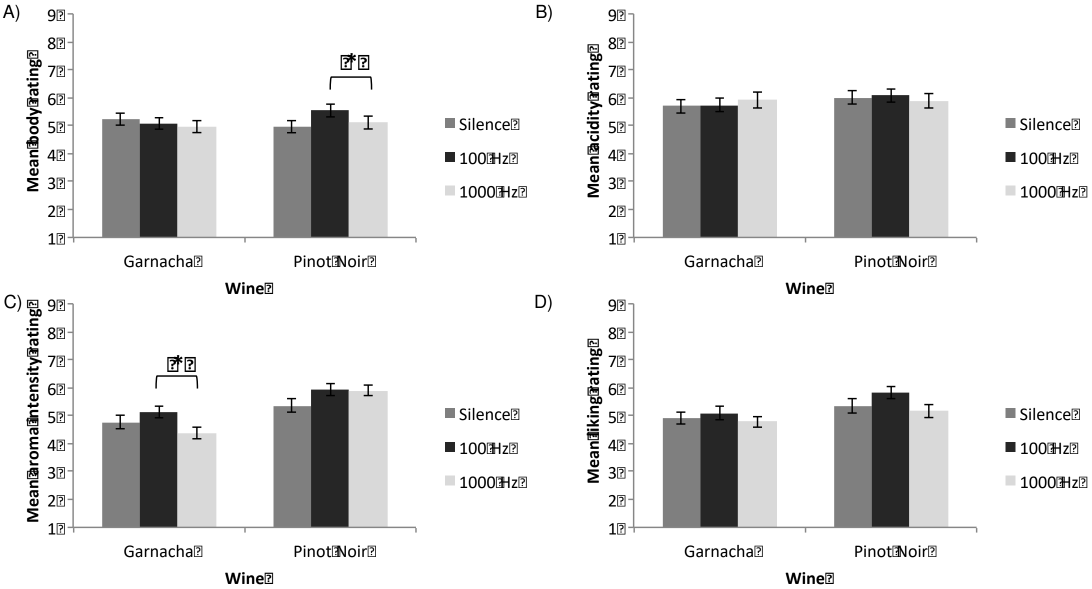
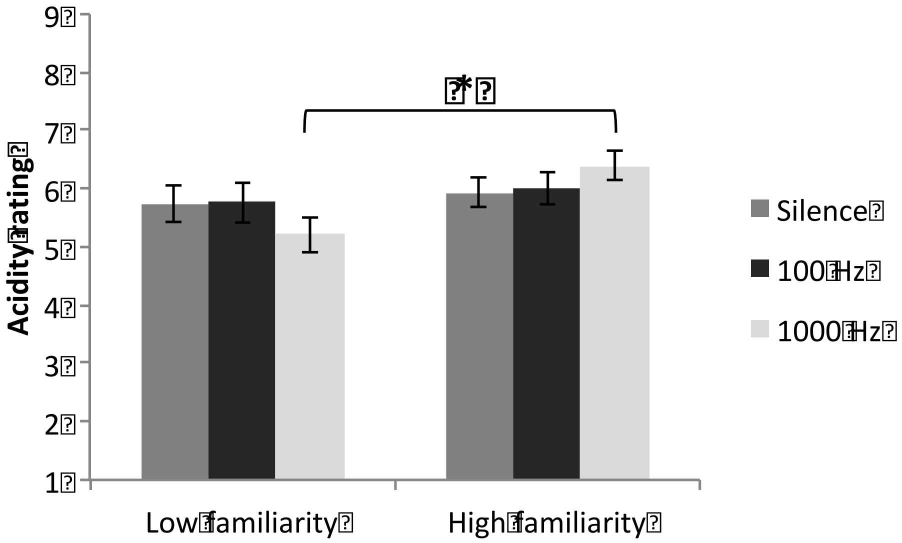
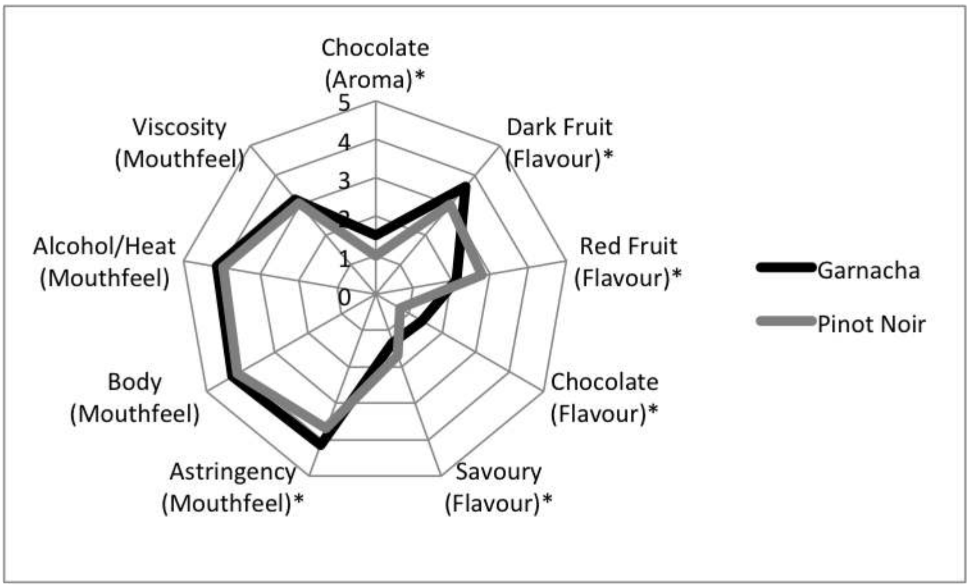

A)
B)
C)
D)
Mean body rating
Mean acidity rating
Mean aroma intensity rating
Mean liking rating
Garnacha
Pinot Noir
Wine
Silence
100 Hz
1000 Hz
*

Figure 5



9
8
7
6
5
4
3
2
1
Acidity rating
*
Silence
100 Hz
1000 Hz
Low familiarity
High familiarity

Figure 6


Chocolate (Aroma)*
Dark Fruit (Flavour)*
Red Fruit (Flavour)*
Chocolate (Flavour)*
Savoury (Flavour)*
Astringency (Mouthfeel)*
Body (Mouthfeel)
Alcohol/Heat (Mouthfeel)
Viscosity (Mouthfeel)
0
1
2
3
4
5
Garnacha
Pinot Noir

APPENDIX - Attributes rated in the RATA study

Colour	**Aroma**	**Flavour by mouth**	**Mouthfeel**	**Aftertaste**
Red	Dark fruit *blackberry, blackcurrant, plum, dark cherry*	Dark fruit *blackberry, blackcurrant, plum, dark cherry*	Body	Length of fruit flavours
Purple	Red fruit *raspberry, strawberry, red cherry, redcurrant*	Red fruit *raspberry, strawberry, red cherry, redcurrant*	Alcohol/Heat	Length of non-fruit flavours
Brown	Dried fruit *prune, raisin, figs, dates*	Dried fruit *prune, raisin, figs, dates*	Astringency	
	Jammy *any fruit jam*	Jammy *any fruit jam*	Smoothness	
	Confectionary	Confectionary	Roughness	
	Chocolate	Chocolate	Viscosity *the resistance of the wine when you move it around on the palate*	
	Coconut	Coconut		
	Cooked vegetables *cooked cabbage and beans*	Cooked vegetables *cooked cabbage and beans*		
	Earthy/Dusty	Earthy/Dusty		
	Eucalypt/Mint	Evolved/Mature		
	Floral/Perfume/ Musk	Floral		
	Forest floor *including mushrooms*	Forest floor *including mushrooms*		
	Green pepper/Capsicum	Green pepper/Capsicum		
	Herbaceaous	Herbaceaous		
	Leather	Leafy		
	Pepper *black or white*	Pepper *black or white*		
	Savoury *savoury, meaty and gamey*	Savoury *savoury, meaty and gamey*		
	Spice *anise, clove, cinnamon, licorice, nutmeg*	Spice *anise, clove, cinnamon, licorice, nutmeg*		
	Stemmy/Stalky	Stemmy/Stalky		
	Toasty/Smoky	Toasty/Smoky		
		Vanilla		
		Woody *cedar, pencil shavings, cigar box, tobacco*		

Text in italics indicates description given to panelists for that particular attribute.