Sweeter together? Assessing the combined influence of product-related and contextual factors on perceived sweetness of fruit beverages

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Abstract

It is well-known that multiple sensory cues influence flavour perception and liking. The present study aimed to combine and compare the relative influences of product-related and contextual factors on taste perception and liking, with a focus on the perception of sweetness. Participants tasted samples of the same base fruit beverage with one of three different levels of added aroma, while the contextual cues (either visual or auditory) were displayed simultaneously using iPads. The results revealed that both added aroma and background music significantly influenced participants' sweetness ratings, with a medium level of added aroma enhancing sweetness significantly as compared to no added aroma, and with the sweet-congruent soundtrack enhancing perceived sweetness significantly as compared to the bitter-congruent soundtrack. Moreover, there was a potentially additive effect from the combination of aroma and soundtrack. These results are discussed in terms of potential mechanisms underlying multisensory flavour perception.

Practical Applications

Consumers are nearly always exposed to a multisensory environment whenever they consume food and drink. It is therefore important to acknowledge that, beyond the food itself, what people happen to be exposed to in the environment while eating or drinking can influence their multisensory flavour experiences as well. These results are of relevance for those working on understanding a theoretical model of human sweetness perception, as well as those working on the design of healthier, sugar-reduced food products. Indeed, the knowledge that multiple sensory cues can, at least under the appropriate conditions, work in conjunction to deliver a greater modulation of perceived taste will allow designers to come up with more effective sugar-reduced products without reducing consumer satisfaction. Moreover, the increasing prevalence of sensory and augmented reality applications means that manufacturers can now incorporate external visual and auditory content as part of the total multisensory product experience.

Keywords: Crossmodal correspondences, sweetness perception, product intrinsic factors, product extrinsic factors, contextual factors, additive effects,

1. Introduction

The experience of eating is a multifactorial and dynamic phenomenon, one that often involves all of the senses. A large body of research now supports the notion that food acceptance and perception can be determined by intrinsic product-related factors (e.g., product colour, aroma, flavour, texture, etc.; see Delwiche, 2004; Hewson et al., 2008; Mielby et al., 2016;), extrinsic product-related factors (e.g. visual and tactile properties of packaging; see Ares & Deliza, 2010; Kobayashi & de benassi, 2015; Piqueras-Fiszman & Spence, 2012b), as well as contextual factors (e.g., background music, lighting conditions, etc.; see Crisinel et al., 2012; Oberfeld et al., 2009). What is less clear, however, is how these different factors interact, and the relative importance of product-related and contextual factors to our perception of, and behaviour towards, food and drink. In the present study, we focused on interactions among aroma (as a product-intrinsic factor), colour, and sound (the latter two introduced as contextual factors) on product liking and the perception of basic taste qualities, especially sweetness. Sweetness was the target here because the consumption of sweet foods has been argued to be one of the major contributors to the current obesity epidemic (Johnson et al., 2007; Malik et al., 2006; Meier et al., 2015; Vartanian et al., 2007), and a multisensory, psychological model of sweetness perception is crucial when it comes to the design of healthier sugar-reduced/replaced foods.

1.1 Influence of aroma on sweetness perception

Perception does not work in a unisensory manner. When it comes to food and drink, the myriad of sensory cues provided by the product itself can potentially influence the perception of information presented in any modality, including the taste of sweetness (e.g., Delwiche, 2004; Poinot et al., 2011; Spence, 2015). Additionally, the perception of sweetness has been shown to be affected by different factors depending on the sweetener (Hewson, Hollowood, Chandra, & Hort, 2008). For instance, Hewson et al. found that flavour perception in citrus-flavoured systems increased upon the addition of tastants (citric acid, lactic acid and fructose), but beverages sweetened with either glucose or fructose resulted in different flavour profiles despite being equally sweet.

In terms of the effect of aroma on sweetness perception, the body of research supporting the modifying effects of aromas on sweetness perception is certainly not new. Aromas such as those associated with caramel, vanilla, and berries have been found to increase the perception of sweetness, at least in Western participants (e.g., Delwiche, 2004; Frank & Byram, 1988; Schifferstein & Verlegh, 1996; Stevenson & Boakes, 2004; see Auvray & Spence, 2008, for a review). Here, it is important to note that previous experience of co-exposure is key to taste enhancement, which can differ with participants from different cultural backgrounds. For instance, vanilla aroma was found to enhance perceived sweetness in French participants more than in Vietnamese participants, but the reverse was true when lemon aroma was added to a model system (see Nguyen et al., 2001; cf. Spence, 2008). Furthermore, Frank and Byram (1988) studied the perception of sweetness and saltiness in different food matrices: Sucrose-sweetened whipped cream and strawberry aroma, sucrose-sweetened whipped cream and peanut butter aroma, sodium chloride salted whipped cream and strawberry aroma, and finally sucrose-sweetened whipped cream and strawberry aroma evaluated with the nose pinched. These researchers found that strawberry aroma tended to enhance the perception of sweetness; that an aroma's ability to enhance sweetness was aroma-dependent; that an aroma's ability to enhance taste was tastant-dependent; and that the influence of the strawberry aroma on sweetness perception was olfactory rather than gustatory in origin. However, other researchers have found both ortho- and retronasal enhancements effects of certain aromas on tastes such as sweetness (Delwiche & Heffelfinger, 2005; Frank, Ducheny, & Mize, 1989; Spence 2012).

1.2 Influence of non-product-related colour on sweetness perception

The general (putatively learned) associations between colours and basic tastes have been well-studied (see Spence et al., 2010, 2015, for reviews). What is perhaps more surprising, is the role of contextual colour cues on influencing perceived tastes. For instance, Harrar and colleagues (2011) reported that salty popcorn was perceived as sweeter when served in a red or blue bowl, as compared to a white bowl. In another study, strawberry mousse was rated as roughly 15% sweeter when served on a white plate than on a black plate (Piqueras-Fiszman et al., 2012). Harrar and Spence (2013) replicated these results using black versus white spoons with different coloured yoghurts. Furthermore, they posited that the contrast between the colour of the cutlery and the colour of the food may help to explain differences in consumer liking and thus the perceived value of the food, even if the effect on sweetness was based on the colour of the cutlery alone. When it comes to beverages, a hot chocolate drink was rated as slightly sweeter when served in a dark cream coloured cups as compared to orange, red, or white cups (Piqueras-Fiszman & Spence, 2012).

Elsewhere, Van Doorn et al. (2014) have reported that the same café latte tasted less sweet in a transparent glass cup with a white sleeve as compared to cups with a blue sleeve or no sleeve at all (see Spence, 2018, for a review of the literature on background colour's influence on taste/flavour perception).

1.3 Influence of background sound on sweetness perception

"Sonic seasoning", the idea that certain soundtracks can be used to alter people's taste perception, is becoming an increasingly popular topic in both the academic literature and the popular press (e.g., Reinoso Carvalho et al., 2015; Spence 2015; Spence & Wang, 2015; see Spence, Reinoso-Carvalho, Velasco, & Wang, submitted, for a review). Previous research has shown that specific auditory attributes are associated with basic tastes, both when presented as taste words (for instance, "sweet"), and in the form of tasting solutions (Crisinel & Spence, 2009, 2010a, b, 2011; Mesz et al., 2011, 2012; Simner et al., 2010; Wang & Spence, 2016; see Knöferle & Spence, 2012, for a review). For instance, both sweet and sour tastes are mapped to high pitch whereas bitterness is mapped to low pitch (Crisinel & Spence, 2010; Knoeferle et al., 2015; Mesz et al., 2011; Wang et al., 2016). Crisinel and her colleagues (2012) first demonstrated that beyond any crossmodal associations between sounds and taste words, auditory stimuli could also affect people's taste evaluations. The participants in their study were given samples of bittersweet cinder toffee to evaluate while listening to one of two soundtracks that had been specifically composed to correspond to either sweet or bitter tastes. Crucially, the participants rated the cinder toffee samples higher on the sweet-bitter scale[1] (i.e., more sweet and less bitter) while listening to the sweet soundtrack than while listening to the bitter soundtrack. Similar sonic seasoning effects using independent taste scales[2] (i.e. separate scales for sweet, bitter, sour, etc) using non-food-sound-related soundtracks have since been found in food and beverage stimuli ranging from beer, chocolate, salsa, and wine (Reinoso Carvalho et al., 2016, 2017; Wang et al., 2017; Wang & Spence, 2015).

[1] It should be noted that the practice of putting two tastes on the same scale (i.e. a sweet-bitter scale) is never done in food sensory science because of the potential for confusing panelists/participants. This might account for the failure to replicate Crisinel's original study by Höchenberger and Ohla, (2018).

1.4 Existing research on reported interaction effects between different factors on sweetness perception

In terms of interactions between only food-intrinsic factors, it has been demonstrated that taste-aroma interactions are moderated by the nature of the food matrix in question. Labbe and his colleagues (2016) tested the taste enhancement effects of cocoa and vanilla flavouring in cocoa and caffeinated milk. They found that in the cocoa beverage, cocoa flavouring led to an enhancement of bitterness while vanilla flavouring enhanced sweetness. However, when it came to the relatively less familiar caffeinated milk product, the addition of vanilla flavouring unexpectedly enhanced bitterness instead of sweetness. In another example, Alcaire et al. (2017) found that while an increase in vanilla flavour had a minor effect on the sweetness enhancement effect for a milk dessert, the combination of increasing vanilla concentration together with increasing starch concentration led to an increase in vanilla flavour intensity as well as sweetness perception.

Elsewhere, Fairhurst et al. (2015) manipulated both plate shape and the arrangement and shape of the food in a restaurant setting. Participants rated the sweetness, sourness, intensity, and pleasantness of two beetroot salads served on either round or angular plates, with the beetroots cut into either angular or round shapes. One group of participants were served beetroot salads only from round plates, and the other group only from angular plates. Serving the salad in the round plate plus round food shape led to significantly higher ratings of sweetness than the congruent angular plate plus angular food shape condition, with the incongruent conditions (where plate shape did not match food shape) being rated somewhere in-between.

In terms of interactions between non-product-related contextual factors, Spence et al. (2014) conducted a study in which the participants tasted the same red wine in an opaque black glass under different lighting and music conditions. In Experiment 1, the wine was liked more in the combined sweet music and red lighting condition (approximately a 5% increase), compared to red lighting alone without music and compared to the control condition (white light, silence). However, there were no changes in rated flavour intensity or freshness (compared to fruitiness). In Experiment 2, the wine was rated as being significantly fresher (an increase of approximately 14%) when tasted under green lighting while listening to sour music, as compared to green lighting alone and to the control condition. What the studies did not assess, however, was the individual effect of music, which leaves the question of whether both visual and auditory cues are required for a joint effect on wine perception.

However, there has been no study to date assessing the interaction between food intrinsic factors and contextual factors.

1.5 Hypothesis and aims

The present study was designed to assess whether and how the combined effects of product intrinsic (added aroma) and contextual (non-product-related colour and sound) factors influence consumer perception and liking for fruit beverages. While it may seem strange at the outset to include these extrinsic or contextual factors (such as the colour one happens to be looking at, or background music), it should be kept in mind that for virtually every real food and drink encounter, the consumer is exposed to both intrinsic and extrinsic factors. It is therefore important to acknowledge that, beyond the sensory properties of the food itself, what people are exposed to in the environment while eating or drinking can influence and change the flavour experience as well. Our underlying hypothesis was that all factors - added aroma, background soundtrack, and colour presented on a screen - could influence consumers' sensory and hedonic evaluation of the beverages. However, we would expect product intrinsic factors (aroma) would have a greater effect than contextual cues (background soundtrack, colour seen on a screen), in terms of effect size and significance. Moreover, we predicted that the different factors might have an additive effect - in other words, multiple sensory stimuli might be capable of inducing a greater modulation of taste perception or effect on liking when combined, as compared to when applied singly.

2. Materials and methods

2.1 Experimental setup

There were six individual designs in the experiment (T1-6, see Figure 1 for a schematic). Each study (design) consisted of 5 conditions - a control condition with no audio or visual stimuli, and four conditions with either auditory or visual stimuli (T1, T2, and T3) or with both auditory and visual stimuli (T4, T5, and T6). The level of added aroma differed between each test. The product with no added aroma (P1) was used in T1 and T4, the product with a moderate amount of added aroma (P2) was used in T2 and T5, and the product with a higher amount of added aroma (P3) was used in T3 and T6. The added aroma is described below in Section 2.3.1.

< INSERT FIGURE 1 ABOUT HERE>

2.2 Participants

A total of 331 adult participants (111 males, total mean age of 32 years ±13.2 years) were recruited to take part in the experiment at Aarhus University's stand at a large food festival over a two-day period in September 2017 in Aarhus, Denmark. All of those who took part were recruited at the actual test site. After agreeing to participate, the participants were asked to take a seat at a table in front of an available iPad. Participants were randomly assigned to one of six individual designs.

2.3 Stimuli

2.3.1 Beverages

Three different beverages, P1-3 varying in the concentration of added pomegranate aroma (Bolchehuset, Albertslund, Denmark) were used in the experiment. The base product used for all beverage products was an apple elderflower fruit beverage (Rynkeby Foods A/S, Ringe, Denmark) currently available to only one Danish retail chain (COOP) and otherwise not commercially available (see ingredient details of the apple elder flower fruit beverage in Table 1). The pomegranate aroma used was a natural food grade aroma suited for food and beverages such as hard candies (see Table 1 For the content of the experimental beverage products). The apple elderflower fruit beverage was chosen as a base beverage since it was relatively sour and somewhat unfamiliar as compared to other fruit beverages available on the Danish market. The choice of base product, the aroma, as well as concentration of added aroma was determined through several pilot-tasting sessions conducted between the experimenters. Pomegranate aroma was chosen since it complemented the base beverage well while adding an unfamiliar aroma to the product. Note that the intention behind using an unfamiliar aroma was to prevent participants from guessing the nature of the juice sample and hence perhaps feeling overconfident, especially given the within-participants nature of the experimental design (see Mielby et al., 2016, and Wang & Spence, 2015, for similar approaches in previous research). Pomegranate aroma has previously been described as being both sweet and sour (Koppel & Chambers, 2010). However, in combination with the relatively sour base beverage, the particular pomegranate aroma resulted in a “sweet fruity aroma”, as reported from the pilot tasting sessions. The aroma concentrations were determined in the pilot-tasting sessions in order to reflect product ranges one could expect on the market. The goal was to use aroma concentrations that created perceivably different levels of aromas (according to the pilot session participants) while keeping the highest concentration from being overpowering. A similar approach was used for design of products in previous study (Mielby et al., 2016).

To make beverages P1-3, the aroma was added under hygienic conditions and mixed thoroughly, then the beverage was immediately poured into transparent cylindrical containers (height = 7 cm, diameter = 3 cm, volume = 40 mL) with red sealable lids (Gosselin, Hazebrouck, France). Each container was filled with 20 mL of the product the day before the study, and stored at 5 °C until usage to ensure optimal storage conditions with regards to shelf life. Each container was then labelled with a 3-digit identifier (see Figure 2A). The products were served to participants in the same containers at 5°C.

< INSERT TABLE 1 ABOUT HERE>

2.3.2 Visual stimuli

The visual stimuli consisted of coloured rectangles (748 x 470 px) presented on an iPad. The control colour was a pale yellow (R=255, G=255, B=128, hue=40, saturation=240 and luminance=180), designed to match the colour of the beverage. The other colour, a pale pink (R=255, G=174, B=201, hue=227, saturation=240 and luminance=202) was chosen, based on research (Saluja & Stevenson, 2018; Woods and Spence, 2016), as the one best at communicating sweetness. We chose to assess the impact of colour displayed on a screen as the contextual visual cue because it is increasingly common for people to look at devices while eating (Spence et al., 2016). Furthermore, research has shown that people's perceived sweetness can be influenced by looking at shapes and words displayed on a computer screen (Liang et al., 2013) or by the angularity of typeface (Velasco et al., 2018).

2.3.3. Auditory stimuli

Two 60-second soundtracks, one corresponding to sweetness and the other to bitterness, were chosen based on Wang et al.'s (2015) study comparing how well people associated basic tastes (sweet, bitter, sour, salty) to soundtracks which had been designed to correspond to specific tastes.

The soundtracks were both composed by Jialing Deng and Harlin Sun, as part of Deng's MA thesis project *Synaesthetic Appetiser* (June, 2015). Both the sweet soundtrack (assigned as sweet by 89/100 people, $p < .0005$) and bitter soundtrack (assigned as bitter by 39/100 people, $p = .004$) were significantly matched with their intended tastes, compared to chance.

2.4 Questionnaires and procedure

The experimenters provided the participants, who were seated in front of an iPad with connected headphones, with the five beverages and water (Figure 2B). Given the public nature of the food festival, the participants were seated inside a tent away from foot traffic to minimise distractions. In addition, we used noise-cancelling over-ear headphones to reduce any background noise. The participants were instructed to put the headphones on after a short introduction to the test was given. The questionnaires which were presented on iPads first contained questions regarding the participant's gender and age. Then, for each stimulus, questions regarding the participant's beverage liking on a nine point hedonic scale, and perception of sourness-, sweetness-, and bitterness intensities were given using nine point scales with endpoint categories ranging from not at all (1) to extremely (9). Participants were provided with all 5 beverage samples in the beginning, and were asked to match the 3-digit identifier given in each trial with the 3-digit identifier labelled on each sample. To control for presentation bias, the order of presentation of the stimuli was randomised as were the questions related to the perception of sweetness, bitterness, and sourness of the stimuli. All of the participants were offered sweet treats and apples after having taken part in the study. The questionnaires presented on iPads, were collected using Compusense online data collection software (Compusense, Guelph, Canada). The study lasted for around 10 minutes.

< INSERT FIGURE 2 ABOUT HERE>

2.5 Data analysis

First, a multivariate analysis of variance (MANOVA) was conducted on all the data (T1-6) with levels of aroma, visual cue, and soundtrack type as the between-participants factors, with reported liking, reported intensities of sweetness, sourness, and bitterness as measures (SPSS, version 23.0, IBM Corp., Armonk, NY). To test whether separate sensory stimuli have an additive effect on sweetness perception, we compared the sweetness enhancement effect of the conditions in which the soundtrack and colour were combined with the effect of soundtrack alone and colour alone. Similarly, we compared the sweetness enhancement effects of combined soundtrack and aroma factors with the effects of soundtrack alone and aroma alone.

3. Results

3.1 Overall results over T1-6 - influence of aroma, colour, and sound on product evaluation

A MANOVA was conducted with levels of aroma (P1-P3), visual cue (none, yellow, pink), and soundtrack type (none, sweet, bitter) as the between-participant factors. Liking, intensities of sweetness, sourness, and bitterness were used as measures. The analysis revealed significant main effects of aroma level (F(8, 3252) = 3.19, p = .001, Wilks' Lambda = .98) and music (F(8, 3252)=2.67, p = .006, Wilks' Lambda = .99), but no significant effect of colour (F(8,3252)=0.54, p = .83), and no interaction effects between any of the factors. Follow-up univariate tests revealed significant effects of aroma on intensities of perceived sweetness, sourness, and bitterness; and a significant effect of music on sweetness (see Table 2). Analysis of the data revealed that the effect size of the soundtrack (η_p^2 = 0.011) was nearly double than that of aroma on perceived sweetness (η_p^2 = 0.006). Nevertheless, both effect sizes are classified as small (Cohen, 1988). However, there were no observed effects on liking. Post-hoc tests with Bonferroni correction (see Table 3) revealed that, for aroma, P2 was significantly sweeter (p = 0.011, d = 0.17) and less bitter (p = 0.001, d = 0.22) than P1, and significantly less sour than P3 (p = 0.007 , d = 0.18); and for music, perceived sweetness was lower when the participants listened to the bitter soundtrack, as compared to the sweet soundtrack (p < 0.0005 , d = 0.27) or the control condition (p = 0.034, d = 0.16) .

Figure 3 illustrates the influence of each sensory modality (visual, auditory, olfactory) on sweetness enhancement.

< INSERT FIGURE 3 ABOUT HERE>

< INSERT TABLES 2 AND 3 ABOUT HERE>

3.2 Comparison of single vs. combined multisensory factors - are they additive?

It should be noted that our experimental design allows for the testing of single versus combined multisensory factors in two different ways. First, by comparing extrinsic factors of colour and soundtrack, and second, by comparing the extrinsic factor of soundtrack with the intrinsic factor of added aroma. The discussion here is limited to sweetness ratings since we are interested in modelling sweetness perception. In addition, sweetness was the only rating influenced by both intrinsic and extrinsic cues in the present study.

3.2.1 The role of colour vs. soundtrack

First, we compared the extent of sweetness enhancement from single extrinsic stimulus conditions (T1-3), where the audio/visual stimuli were presented one-at-a-time, against the extent of sweetness enhancement from two-stimuli conditions (T4-6), where the audio/visual stimuli were presented in pairs (see Figure 4A for an illustration of the method). From T1-3, we calculated D_{music}, the difference between the sweetness soundtrack condition and the control condition (M = 0.26, SE = 0.12), and D_{colour}, the difference between the pink soundtrack condition and the control condition (M = 0.04, SE = 0.13). From T4-6, we calculated $D_{music+colour}$, the difference between the sweet soundtrack + pink colour condition and the control condition (M = 0.35, SE = 0.12). An independent samples t-test to determine whether $D_{music+colour}$ differs from D_{music} + D_{colour} revealed that they are not significantly different, $t(329) = -0.21$, $p = .83$. That said, one-sample t-tests comparing D values against zero revealed that both D_{music} and $D_{music+colour}$ have significant effects on sweetness enhancement ($t(165) = 2.26$, $p = 0.025$, for music; $t(165) = 2.84$, $p = 0.005$, for music+colour), but D_{colour} does not ($t(165) = 0.33$, $p = 0.74$). In other words, since colour does not have a sweet enhancement effect, it is likely that the sweet enhancement effect we observed in the combined music+colour condition comes only from the influence of the soundtrack.

<INSERT FIGURE 4 ABOUT HERE>

3.2.2 Aroma vs. Soundtrack

In addition to the extrinsic factors of colour and music, we also observed an overall sweetness enhancement effect attributable to the presence of aroma. Specifically, Table 3 revealed that the medium level of aroma was perceived to be the sweetest compared to the no aroma condition and high concentration conditions. The fact that medium concentration of added aroma was perceived to be sweeter than both no aroma and high concentration of aroma might be due to the fact that there is an inverted U-shaped function between perceived sweetness and aroma concentration. This is the case, for instance, in terms of visual preference and perceived complexity in foods (Mielby et al., 2012). Therefore, we decided to assess the relative influence of aroma and sountrack, since both factors have been shown to elicit sweet enhancement effects (see Figure 4B for a schematic).

We focused on the P2 and P1 conditions in terms of aroma, since P2 (medium concentration of aroma) was shown to be the sweetest and P1 (no added aroma) the least sweet. Likewise, we focused on auditory conditions of M1 and M2, since M1 (sweet soundtrack) was shown to be the sweetest and M2 (bitter soundtrack) the least sweet. First, the joint sweetness enhancement effect by both aroma and soundtrack was confirmed via an independent samples t-test comparing sweetness rating conditions in P2M1 and P1M2 (M_{P2M1} = 6.43, *SE* = 9.18; M_{P1M2} = 5.44, *SE* = 0.21; $t(109)$ = 3.56, p = 0.001). Next, we tested the influence of aroma alone, by comparing P2M1 and P1M1 (M_{P1M1} = 5.80, *SE* = 0.21; $t(109)$ = 2.28, p = .025). This result implies that aroma played a significant role in sweetness enhancement, on top of any effects of soundtrack. Similarly, we tested for the influence of the soundtrack by itself, by comparing P2M1 and P2M2 (M_{P2M2} = 5.80, *SE* = 0.24; $t(55)$ = 2.82, p = .007). This result implies that the soundtrack played a significant role in sweetness enhancement, on top of any effects of aroma. In terms of the degree of sweetness enhancement, the % enhancement of combined added aroma and sweet soundtrack is roughly twice that of aroma alone or soundtrack alone (see Figure 5). This result suggests, although by no means confirms for certain, that there seems to be a linearly additive sweetness enhancement effect by extrinsic (aroma) and intrinsic (soundtrack) factors.

< INSERT FIGURE 5 ABOUT HERE>

4. Discussion

The results of the present study revealed that overall, aroma and soundtrack both exerted a significant influence over the perceived sweetness intensity of a fruit drink, and the combined effect of aroma and soundtrack was greater than either aroma or soundtrack alone. Specifically, the same fruit drink was rated as significantly sweeter with the medium concentration of added aroma (compared to no added aroma), and while listening to a sweet soundtrack (as compared to the bitter soundtrack). These results support the growing body of literature on aroma sweetness enhancement (e.g. Delwiche, 2004, Frank & Byram, 1988) as well on sonic seasoning effects (e.g., Crisinel et al., 2012; see Spence et al., submitted, for a review). Furthermore, added aroma also had a significant effect on reducing the perceived bitterness and sourness of the beverage. While there appears to be a linearly additive relationship between the sweetness enhancement effects of aroma and soundtrack, more comprehensive studies (for instance, studies where both aroma and sound are varied on a within-participant basis) will be needed in order to draw any definitive conclusions concerning such a possible additive relationship.

It should be noted that, in the present study, we did not observe any main effect of colour on the participants' evaluation of the beverage. While there was no influence of colour, this was likely due to the fact that the colour cue was presented on the iPad screen, which was removed from the actual product itself. In addition, participants were not told about any possible relationships between the coloured rectangle on the iPad screen and the drink samples. Most of the studies that have been conducted so far on the influence of colour has either dealt with the colour of the product itself or the colour of servingware (which is close to the food being served). Therefore, it is plausible that we did not see a taste enhancement effect because the pink colour cue was simply too far removed from the food itself. In a study that showed visual cues on iPad screens, Becker et al. (2011) observed that images of different packaging shapes influenced taste ratings of yogurt samples, but the effect was mediated by the participants' sensitivity to design aesthetics. And unlike in the Becker study, participants in the present study were also able to see the colour of the samples through the clear containers. This arguably gave participants less reason to be influenced by the colour cue displayed on screen. Furthermore, while we observed differences in perceived tastes between the sweet and bitter soundtrack, it is possible we did not observe any differences in colour because pink and yellow are not associated with similarly opposing tastes. While pink strongly communicates sweetness, yellow is not associated with bitterness (Saluja & Stevenson, 2018; Woods & Spence, 2016). It would be interesting to conduct a further study with colour cues of pink and black (a colour strongly associated with bitterness, see Ares & Deliza, 2010; Woods & Spence, 2016; see Spence et al., 2015, for a review), in order to test the relative effects of visual cues.

There is a subtle point to be made here concerning the distinction between product-extrinsic (but still somehow product-related) cues and contextual cues. In the framework of the present study, sound and colour cues were used as contextual factors. Moreover, the participants were not explicitly told about the connection between sound/colour and the product they were tasting. However, if the same soundtracks or colours were used as part of a sensory marketing app (e.g., if the consumers were told something along the lines of “the soundtrack was specifically designed to enhance the consumption experience”), then they would be considered product-related extrinsic factors.

Interestingly, we did not observe any overall effects of extrinsic or intrinsic effects on consumer liking. Analysis of singly presented audiovisual factors (T1-3) revealed that the beverage consumed in the bitter soundtrack condition was liked less than the beverage consumed in the sweet soundtrack condition or the pink colour condition, but this effect did not reveal itself when the combined audiovisual factors (T4-6) were taken into consideration. This was possibly because the combinations of colour and soundtrack conditions did not have clear emotional associations, whereas it was easier to associate positive or negative feelings with a single audiovisual factor. Wang and Spence (2017) performed a comparative analysis of sweetness vs. liking enhancement by soundtracks across six studies, and hypothesised that only soundtracks with clear emotional associations influenced both participants’ hedonic evaluations and sweetness ratings.

Intriguingly, our findings revealed that the sweet soundtrack enhanced perceived sweetness when compared to the bitter soundtrack condition, but not when compared to the control no music condition. It would seem to imply that the bitter soundtrack *lowers* sweetness rather than the sweet soundtrack necessarily *enhancing* sweetness. This brings up the possibility of a distraction model, where an incongruent soundtrack can distract the taster from perceiving a specific taste as intensely, rather than a congruent soundtrack focusing one’s attention on a particular taste (Yan & Dando, 2015). Moreover, the suggestion that sound-taste crossmodal influences require explicit contrast in stimuli (for instance, between the sweet and bitter soundtrack) has already been raised in literature (e.g. Reinoso Carvalho et al., 2016; Wang & Spence, 2016).

The present study has several limitations stemming from the fact that we used a convenience sample of consumers recruited from a large food festival. For instance, rather than having approximately equal numbers of males and females, only about one-third of our participants were male. This was due to the fact that the attendees at the festival were skewed towards females. We could have artificially created gender balance, but we did not want to turn away female participants in favour of male participants. In the future, we can consider setting separate gender quotas for males and females. Another drawback was that while we were interested in contextual factors (i.e. background sound), we could not control the exact environment inside the testing area (e.g., time of day, humidity, lighting, the number of people who happened to be in the testing area, etc). The use of closed ear headphones did help towards isolating excessive background noise, but it was not the ideal distraction-free environment. Further studies in carefully controlled laboratory conditions will be needed, for instance, to validate the linear additive effects of aroma and sound, but we believe the present study makes an valuable contribution to literature as an ecologically valid study with real Danish consumers.

5. Conclusions

The results of the present study suggest that varying the intensity of product aroma, as well as the background sound, changes the consumer's perception of sweetness in a non-carbonated apple-elderflower beverage. Specifically, the beverage with a medium level of added pomegranate aroma was perceived to be sweeter and less bitter than a beverage with no added aroma. Additionally, tasting the beverage while listening to a putatively bitter soundtrack resulted in lower perceived sweetness as compared to listening to a sweet soundtrack or in silence. Furthermore, in our assessment of various sensory cues, we found aroma and sound to be additive attributes when it comes to the perception of sweetness intensity. In other words, the combination of a medium concentration of a aroma (which was perceived to be sweet) plus exposure to a putatively sweet background soundtrack enhanced perceived sweetness more than just aroma alone or soundtrack alone.f

While we also altered the colour of the visual cue that participants were exposed to on an iPad screen while they tasted the beverages, we did not find any significant effects of colour. This was possibly because the colour cues were too far removed from the beverage itself to have any meaningful effect. Similarly, we did not observe any overall influences of any factors (colour, sound, or aroma) on consumer liking, potentially due to the fact that the groupings of multiple sensory factors did not have clear affective associations.

These results are of relevance for those working on understanding a theoretical model of human sweetness perception, as well as those working to design healthier, sugar-reduced food products. While it may seem strange at the outset for those working in food research and development to consider contextual factors (such as background sound), it should be kept in mind that real world eating/drinking scenarios do not take place in isolated tasting booths. On the contrary, food-extrinsic and contextual factors are always present and should be taken into account as part of the (designable) flavour experience (e.g. Biswas et al., 2018; see Spence, 2017, for a review). The prevalence of sensory and augmented reality applications (see Spence, 2019 for a review) makes clear that what people happen to be seeing or hearing while consuming a product can be incorporated by the food manufacturer as a part of the total purchasing or eating experience. The knowledge that multiple sensory cues can, at least under the appropriate conditions, work in conjunction for a greater taste modulation effect will allow product manufacturers to come up with more effective sugar-reduced products without taking away consumer satisfaction. It also presents a convincing argument for food researchers, packaging designers, and marketing agencies to work together, in order to optimally balance product-intrinsic and extrinsic cues for maximal sweetness enhancement (or, at the very least, avoid sending conflicting messages between what's communicated by product packaging, advertising, and the content itself).

The results of the present study represent a starting point for a multisensory approach when it comes to psychological enhancement of sweetness perception. Granted, the results so far have been limited to a single population, namely Danish adults attending a food festival. Further research development will focus on collecting data from different populations, such as adolescents (who are, some might argue, especially susceptible to advertisement for sugary foods), to study the role of gender, age, and culture in crossmodal perceptual effects. This will pave the way for the development of custom healthy interventions (in terms of product colour/flavour, packaging design, and advertisement) for specific populations.

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Figure Legends

Figure 1. Schematic demonstrating the different test conditions used in Tests 1-6. For each test (T1-6), the 5 columns refer to the different conditions. P refers to product, where P1 = original product, P2 = moderate concentration of added aroma, P3 = high concentration of added aroma. V refers to visual condition: V1 = pink cue, V2 = yellow cue. M refers to auditory condition: M1 = sweet soundtrack, M2 = bitter soundtrack.

Figure 2. A) Experimental stimuli presented to the participants. Each sample was labelled with a 3-digit blinding code. B) Experimental setup: Each participant sat at a chair facing an iPad and wearing a pair of headphones. A carafe of water for rinsing in between trials was shared between all of the participants sitting at the table.

Figure 3. Participants' average ratings of sweetness for each sensory condition. Error bars indicate standard errors. Asterisks denote statistical significance (* $p < .05$).

Figure 4. A) Methods for comparing the effect of: A) combined versus individual auditory and visual stimuli; and B) combined versus individual aroma and auditory stimuli. Blocks of the same colour indicate that they are conditions that were experienced by the same participant. P* stands for products at all aroma levels (P1-P3). P1 = product with no added aroma; P2 = product with medium concentration of added aroma. M1 = sweet soundtrack condition, M2 = bitter soundtrack condition. V1 = pink condition.

Figure 5. Sweetness enhancement effects (in terms of %) due to soundtrack only, aroma only, or combined soundtrack and aroma conditions. The baseline condition reflects no added aroma and bitter soundtrack. The comparison condition reflects medium level of added aroma and sweet soundtrack.

Figure 1

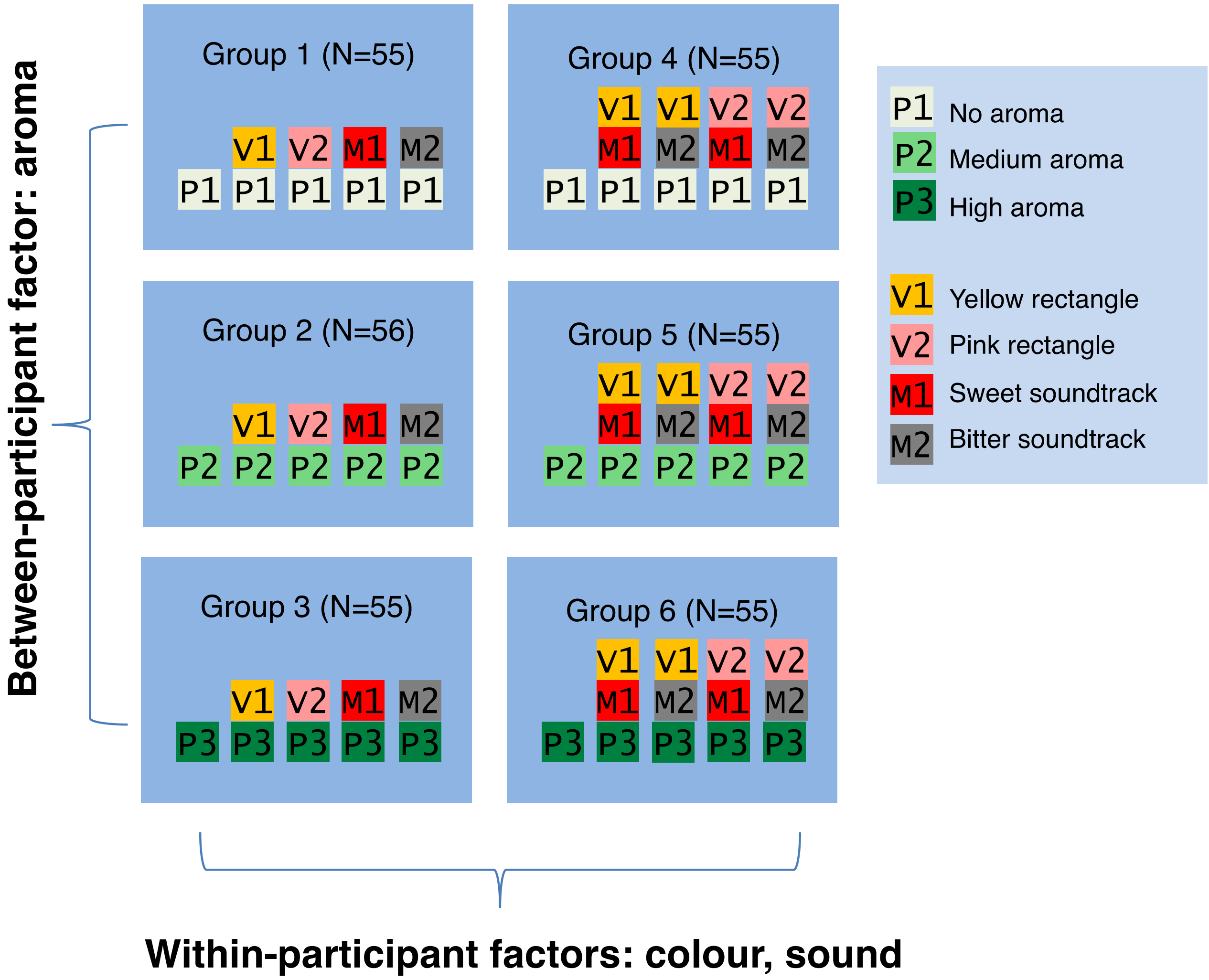

Between-participant factor: aroma
Group 1 (N=55)
V1 V2 M1 M2
P1 P1 P1 P1 P1
Group 4 (N=55)
V1 V1 V2 V2
M1 M2 M1 M2
P1 P1 P1 P1 P1
Group 2 (N=56)
V1 V2 M1 M2
P2 P2 P2 P2 P2
Group 5 (N=55)
V1 V1 V2 V2
M1 M2 M1 M2
P2 P2 P2 P2 P2
Group 3 (N=55)
V1 V2 M1 M2
P3 P3 P3 P3 P3
Group 6 (N=55)
V1 V1 V2 V2
M1 M2 M1 M2
P3 P3 P3 P3 P3
P1 No aroma
P2 Medium aroma
P3 High aroma
V1 Yellow rectangle
V2 Pink rectangle
M1 Sweet soundtrack
M2 Bitter soundtrack
Within-participant factors: colour, sound

Figure 2

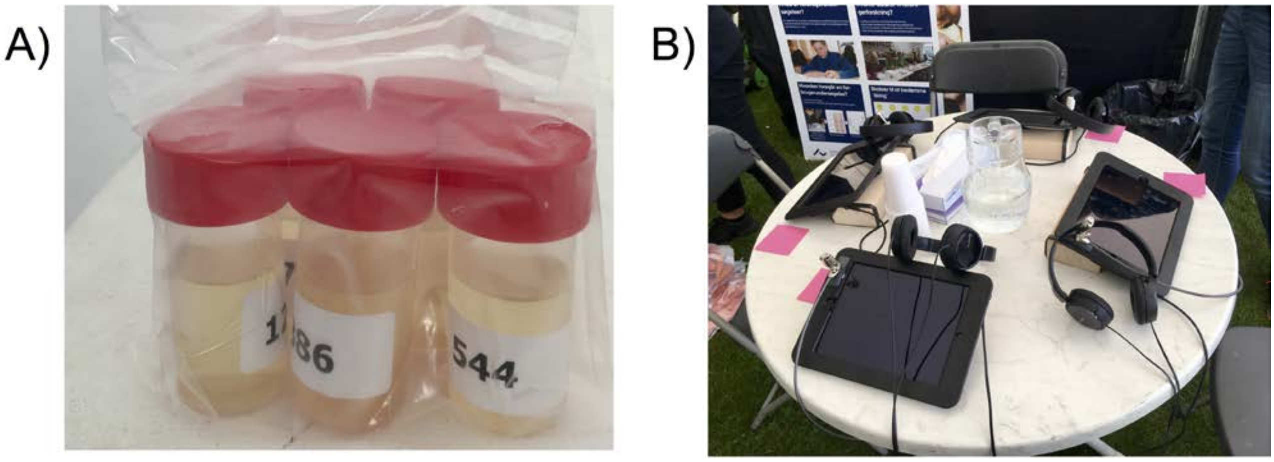
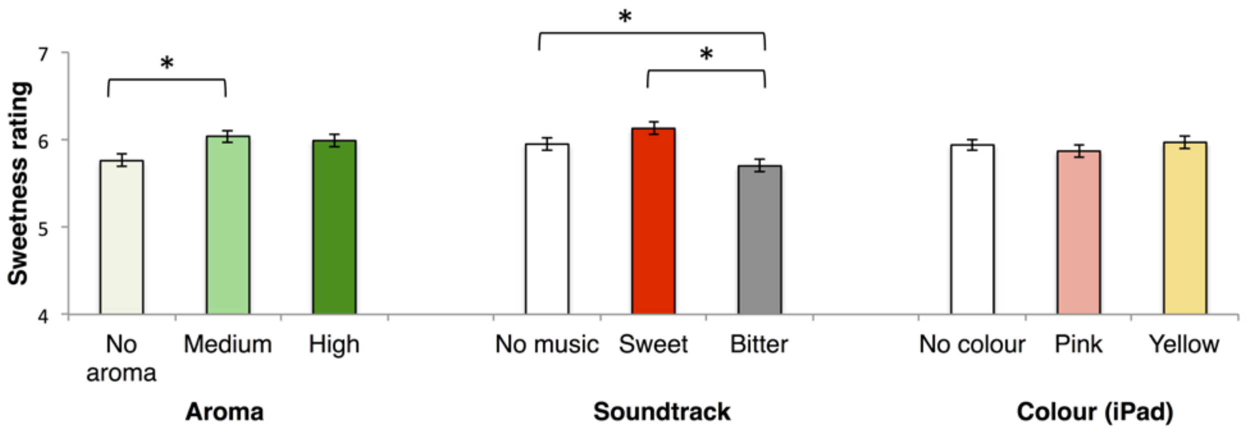
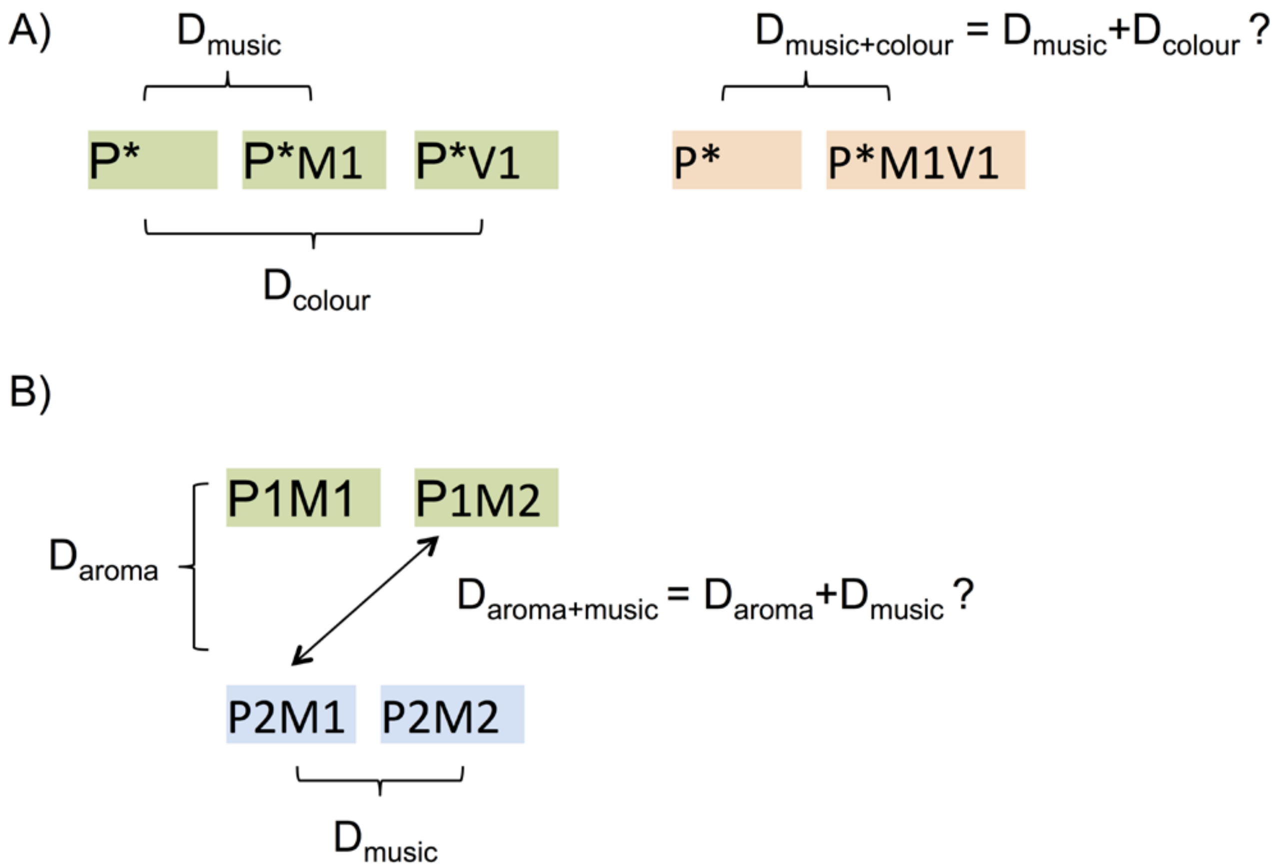


Figure 3


*
*
*
7
6
5
4
Sweetness rating
No aroma
Medium
High
No music
Sweet
Bitter
No colour
Pink
Yellow
Aroma
Soundtrack
Colour (iPad)

684 **Figure 4**

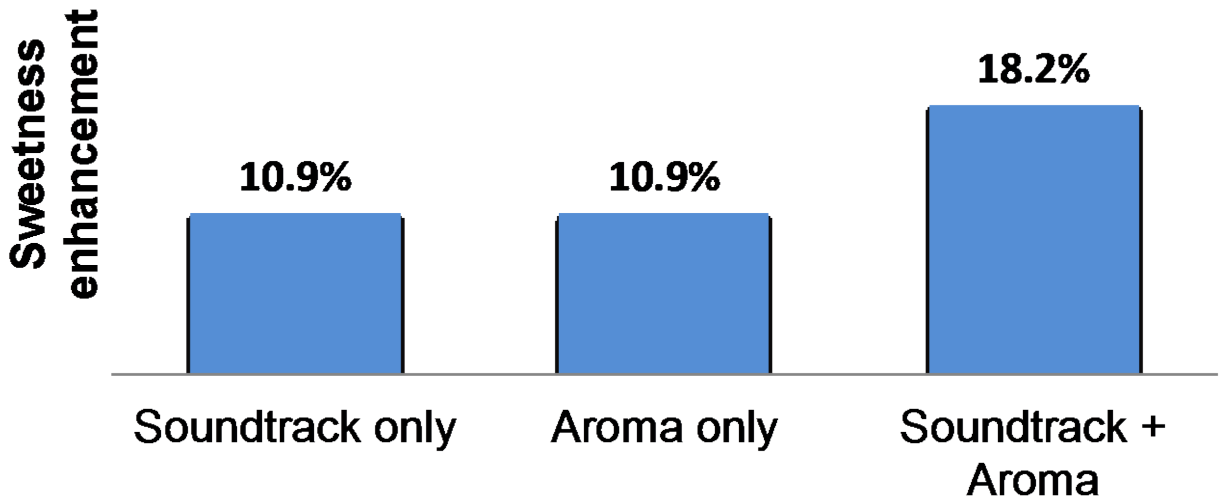


685

686

687

Figure 5


Sweetness enhancement
10.9%
10.9%
18.2%
Soundtrack only
Aroma only
Soundtrack + Aroma

Tables

Table 1. List of the contents of the beverages used in the experiment.

Content of base product	Nutritional content of base product (per 100 g)	Beverage stimuli	Aroma (μL/L)
Water, unfiltered apple juice (20%), sugar, unfiltered lemon juice (5%) from concentrate and elderflower extract (5%)	Energy 41 kcal, Fat 0.5 g, Carbohydrates 10 g (9.8 g sugars), protein 0.5 g	**P1**	0 (none)
		P2	250 (medium concentration)
		P3	500 (high concentration)

Table 2. Effects of aroma concentration and music for each rated attribute, in terms of degrees of freedom, error degrees of freedom, F value, p value, and effect size (partial eta squared). Significant effects (*p* < .05) are shown in bold.

	Effect	*Df*	*Error df*	*F*	*p*	η_p^2
Sweetness	**Aroma**	**2**	**1628**	**4.55**	**.011**	**.006**
	Music	**2**	**1628**	**9.38**	**< .0005**	**.011**
Bitterness	**Aroma**	**2**	**1628**	**6.33**	**.002**	**.008**
	Music	2	1628	1.53	.22	.002
Sourness	**Aroma**	**2**	**1628**	**5.00**	**.007**	**.006**
	Music	2	1628	1.99	.14	.002
Liking	Aroma	2	1628	0.18	.84	< .0005
	Music	2	1628	2.13	.12	.003

Table 3. Average ratings and standard deviation of samples per aroma condition (left side of table) and per sound condition (right side of table). Within each rated attribute (sweetness, bitterness, sourness, and liking), samples that do not share a letter are significantly different from each other ($p < .05$) in Bonferroni-corrected post-hoc tests.

	Aroma			**Music**		
	Aroma concentration	**Mean (SD)**	**Comparison**	**Sound condition**	**Mean (SD)**	**Comparison**
Sweetness	None	5.76 (1.60)	A	No music	5.95(1.56)	b
	Medium	6.04 (1.62)	B	Sweet	6.13 (1.59)	b
	High	5.99 (1.53)	AB	Bitter	5.70 (1.60)	a
Bitterness	None	3.56 (2.00)	B	No music	3.41 (2.06)	a
	Medium	3.13 (1.96)	A	Sweet	3.24 (1.94)	a
	High	3.42 (2.05)	AB	Bitter	3.46 (2.00)	a
Sourness	None	4.46 (1.87)	AB	No music	4.38 (1.98)	a
	Medium	4.20 (2.04)	A	Sweet	4.30 (1.93)	a
	High	4.57 (1.99)	B	Bitter	4.55 (1.99)	a
Liking	None	6.74 (1.49)	A	No music	6.82 (1.46)	a
	Medium	6.79 (1.50)	A	Sweet	6.83 (1.44)	a
	High	6.77 (1.40)	A	Bitter	6.66 (1.49)	a