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Timing is everything: Onset timing moderates the crossmodal influence of background sound on taste perception

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Abstract

Recent evidence demonstrates that the presentation of crossmodally corresponding auditory stimuli can modulate the taste and hedonic evaluation of various foods (an effect often called "sonic seasoning"). To further understand the mechanism underpinning such crossmodal effects, the time at which a soundtrack was presented relative to tasting was manipulated in a series of experiments. Participants heard two soundtracks corresponding to sweet and bitter tastes either exclusively during or after chocolate tasting (Experiment 1), or during and before chocolate tasting (Experiment 2). The results revealed that the soundtracks affected chocolate taste ratings only if they were presented before or during tasting, but not if they were heard after tasting. Moreover, participants' individual soundtrack-taste association mediated the strength of the sonic seasoning effect. These results therefore imply that the modulatory effect of sound on taste was not driven by retrospective interpretation of the taste experience, but by mechanisms such as priming and crossmodal association. Taken together, these studies demonstrate the complex interplay of cognitive mechanisms that likely underlie sonic seasoning effects.

Keywords: crossmodal correspondences; sonic seasoning; audition: taste; chocolate; expectations; hedonic mediation

Public Significance: This study elucidates the temporal conditions under which what we hear influences what we taste. Our findings have broad implications for those working in the food and hospitality sector pertaining to the design of auditory atmosphere to maximise eating pleasure.

Introduction

"Sonic seasoning", the idea that what we hear alters what we taste, is becoming an increasingly popular term both in academic literature (Spence, 2017; see Spence et al., 2019, for a recent review) and in mainstream media (e.g., Basu, 2016; Fleming, 2014; Knapton, 2014). Previous research has shown that certain basic sonic attributes (such as pitch or articulation) are generally associated with specific taste words (for a review, see Knöferle & Spence, 2012). Crisinel et al. (2012) first demonstrated that beyond merely associating sounds with taste words, participants made different food evaluations based on what they heard while tasting. More specifically, the participants in their study were given several samples of bittersweet cinder toffee to evaluate while listening to soundtracks that had been specifically composed to correspond to either sweet or bitter tastes. The participants rated the cinder toffee samples higher on the sweet-bitter scale (i.e., sweeter and less bitter) while listening to the sweet soundtrack than while listening to the bitter soundtrack. Since then, a number of studies have demonstrated the sonic seasoning effect with specially-designed soundscapes that altered the taste and even mouthfeel attributes of various foods and beverages (e.g., Reinoso Carvalho et al., 2015; Spence 2015; Wang et al., 2017a; Wang & Spence, 2016, 2018).

However, there has been no research published to date with the goal of delineating the possible mechanisms underlying such a sonic seasoning effect. As a case in point, one of the most fundamental questions is whether such effects really are perceptual, or whether instead they reflect biased self-reported ratings (Litt & Shiv, 2012). In other words, it is not clear whether the specially designed soundscapes actually modify participants' sensory experience, or whether participants are instead motivated to evaluate the food/beverages differently due to some other reason(s) unrelated to the nature of their actual perceptual experience, such as perhaps wishing to conform to what they perceive to be the experimenter's expectations. For example, Lee and colleagues (2006) set out to determine whether external conceptual information about a product only affects people's preferences, or whether it can alter their actual gustatory experiences. The authors demonstrated that the timing of information regarding the content of the "MIT Brew" — a beer adulterated with a few drops of balsamic vinegar — affected participants' liking for the beverage. Specifically, beer liking was decreased only when the disclosure of the secret ingredient preceded the tasting, but not if the disclosure took place after tasting. The authors inferred that the disclosure influenced the real-time experience of drinking itself, rather than altering the participants' retrospective interpretation of the experience. If the extrinsic information (the addition of balsamic vinegar) had acted to bias participants' responses ("balsamic vinegar in beer, gross!"), then participants' beer preference should have been similar regardless of when they were presented with the information (Lee et al., 2006). To translate their study to the context of sonic seasoning, if background sound really does influence the gustatory experience itself, then listening to a soundtrack after tasting should influence one's food evaluation less than when the soundtrack is played during tasting.

Another hypothesis behind sonic seasoning is that auditory stimuli corresponding to a specific taste/flavour might enhance the said taste/flavour by way of evoking sensory expectations. In other words, if hearing a specific soundscape could prime a specific taste, this could lead people to adjust their actual product perception in order to conform to a heightened expected value (Lange et al., 2018). Expectation effects have been widely demonstrated in the food-related area when it comes to visual food cues (Spence et al., 2016; Verasteigui-Tena et al., 2017), linguistic descriptions

(Piqueras-Fiszman & Spence, 2015; Spence, 2016), or even from the sound of opening of food/beverage packaging (Wang & Spence, 2019). In the context of sonic seasoning, then, hearing a specific soundtrack before tasting might well be expected to generate sensory expectations which would then go on to influence the actual tasting experience.

As the previous two examples have already alluded to, one way to examine the mechanisms underpinning sonic seasoning is by altering the onset timing of the sound stimuli. To this end, we set up three different timing conditions, with the different taste soundtracks presented exclusively either before tasting, during tasting, or after tasting (i.e., during food evaluation). If a sonic seasoning effect is observed when the soundtracks are played before the food is tasted, the effect is likely based on expectations (i.e., sound likely shapes the listener's expectations regarding how the food will taste). On the other hand, if a sonic seasoning effect is observed even when the soundtracks are played only after tasting, then the change in taste ratings is likely due to a retrospective interpretation of the taste experience rather than a perceptual effect. We tested these accounts in two experiments (see Figure 1).

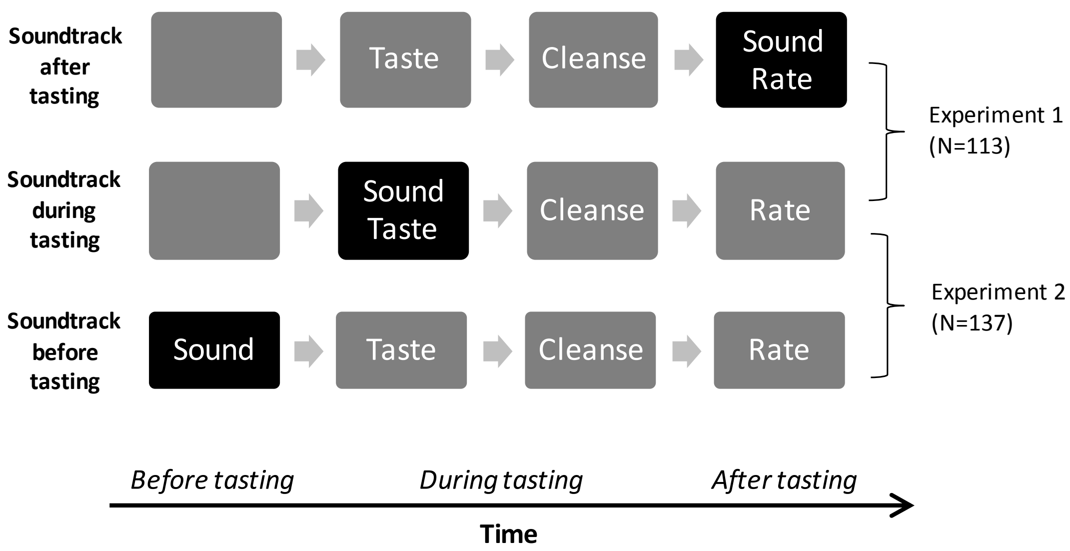

Figure 1. Overview schematic of both Experiments 1 and 2 investigating different sound-onset timings (before, during, or after tasting).

The goal of Experiment 1 was to uncover whether taste-congruent soundtracks can influence the perceptual experience of tasting. The soundtracks were presented either only during tasting or after tasting. If sound genuinely does change the tasting experience, then one would expect there to be a greater sonic seasoning effect when the soundtracks are presented while the participants are tasting the chocolate samples, as compared to when the soundtracks are presented after tasting. However, if sound only biases participants' self-report, then one should expect sonic seasoning effects in both timing conditions.

Experiment 1

Methods

Participants

A total of 113 participants (76 women, 35 men, 2 unreported) aged 18-51 years (M = 24.66, SD = 4.81) took part in Experiment 1. A between-participants design involved half of the participants tasting chocolate in the soundtrack-during-tasting condition while the other half tasted chocolate in the soundtrack-after-tasting condition. We aimed to recruit at least 55 participants per condition to achieve a statistical power of 0.90-0.95 using the Cohen's d calculation of 0.41, as found in our previous research involving the influence of bitter and sweet soundtracks on bitter-sweet rating scales (Reinoso Carvalho et al., 2016). It should be noted that our sample size calculation was only concerned with determining the number of participants within each timing condition. We could not do a power calculation based on the interaction effect between sound onset time and soundtrack type, since there were no prior studies of that type to provide a sensible effect size. We therefore used the effect size found in a previous sonic seasoning study to estimate the number of participants required in the soundtrack-during-tasting timing condition, and then recruited the same number of participants for the soundtrack-after-tasting timing condition to ensure that we had an equal number of participants in both groups.

Participants were recruited via BI Norwegian Business School's participant recruitment platform. All of the participants gave their informed consent to take part in the study. None of the participants reported a cold nor any other known impairment of their sense of smell, taste, or hearing at the time of the study. The study was approved by the Central University Research Ethics Committee of Oxford University (MSD-IDREC-C1-2014-205).

Auditory stimuli

Wang et al.'s (2015) study compared and ranked 24 different soundtracks that had previously been designed to be associated with taste attributes (comparison based on ratings made on basic tastes scales). For the experiments in the present study, the sweet and bitter soundtracks with the highest number of matches in Wang et al. (2015) were chosen. The sweet soundtrack (chosen by 89 out of 100 participants), was developed by Jialing Deng and Harlin Sun as a soundtrack for Synaesthetic Appetiser, part of Deng's Masters of Arts Thesis project (June, 2015). The bitter soundtrack (chosen by 42 out of 100 participants) was the one used by Crisinel et al. (2012) in their pioneering sonic seasoning study. Both soundtracks were matched higher than if the participants had matched the tastes to soundtracks by chance (25%). The soundtracks were edited to last for approximately 30 seconds each, root-mean-square (RMS) equalised to an internal reference and played over closed-ear headphones at 70 dB SPL. The soundtracks can be heard at the following link: https://soundcloud.com/janicewang09/sets/timing.

Gustatory stimuli

70% Lindt chocolate was used for the study for its fairly complex taste, ambiguous sweet-bitter balance, and commercial availability. Each sample consisted of approximately 3g of chocolate. All of the samples were served on a white Styrofoam plate with 3-digit labels. Unbeknownst to the participants, the same type of chocolate was served across all trials.

Design and Procedure

The study was designed with timing condition (sound presented only during or only after tasting) as a between-participants factor and soundtrack type (bitter or sweet) as a within-participants factor. Each participant was randomly assigned to one timing condition, completed four trials, and heard each soundtrack twice. The order of sample presentation and soundtracks were randomised.

The experimental sessions comprised of up to ten participants at a time. Each participant was seated in front of a computer screen in an experimental cubicle, isolated from other cubicles by opaque plastic separators. No two participants sat immediately adjacent to one another during the experimental sessions. The experiment was programmed on the Qualtrics online survey platform and participants responded by using the mouse to click or drag the indicator on the continuous rating scales. Sound was presented via headphones (Beyerdynamic DT770 Pro), which participants were instructed to put on at the beginning of the study. Each participant was given four chocolates on labelled plates (A-D) as well as tap water and crackers to cleanse their palates.

The participants were randomly assigned to either the during-tasting (N = 56) or after-tasting timing condition (N = 57). The participants in the during-tasting condition were instructed to start tasting the chocolate once they heard the soundtrack playing. They were then instructed to move onto the next page (which stopped the sound playback), where they cleansed their palate with water and crackers before moving onto the next page for sample evaluation. Participants in the after-tasting condition tasted the chocolate sample in silence, rinsed their mouths with water, then moved on to the evaluation page, where they were instructed to start the evaluation as soon as they heard a soundtrack playing. (Participants cleansed their palates right after tasting to minimise the possibility that the soundtracks heard during evaluation might act upon any residual flavours in the mouth.) All participants evaluated each chocolate sample using two visual analogue scales (VAS), one for liking (anchored by "dislike extremely" on one end and "like extremely" on the other end) and one for taste balance (anchored by "much more bitter than sweet" on one end and "much more sweet than bitter" on the other end). The scales were coded from 0-100, although numbers were not displayed to the participants. The order of the rating scales were randomised.

The experiment lasted for around 20 minutes and participants were paid 50 NOK for their time.

Data Analysis

Bittersweet and liking ratings were first averaged over the two identical soundtrack trials for each participant. Repeated measures analyses of variance (RM-ANOVA, SPSS 25) were conducted with 'soundtrack type' as the within-participant factor and 'timing' as the between-participant factor, for bittersweet and liking ratings.

Results

The mean values of the participants' ratings for the chocolates in both timing conditions are shown in Figures 2 and 3. For bitter-sweet ratings, there was a significant main effect of soundtrack (F(1,111) = 6.80, p = .010, η^2 = 0.06), where the chocolates experienced with the sweet soundtrack (either during or after tasting) were rated as sweeter than the chocolates experienced with the bitter soundtrack ($M_{bitter\_soundtrack}(SE)$ = 42.96(1.61), $M_{bitter\_soundtrack}(SE)$ = 39.45(1.66), p = .010). More importantly, there was a significant interaction between timing condition and soundtrack (F(1,111) = 5.51, p = .021, η^2 = 0.05). Specifically, those participants who heard a soundtrack while tasting evaluated the chocolates as tasting significantly sweeter when the sweet soundtrack was playing than when the bitter soundtrack was playing ($M_{bitter\_soundtrack}(SE)$ = 46.03(2.29), $M_{bitter\_soundtrack}(SE)$ = 39.37(2.35), p = .001). The taste-congruent soundtracks had no such effect on taste ratings for those participants who heard the soundtrack only after tasting, that is, during chocolate evaluation (p = .853). To evaluate evidence for the null hypothesis (i.e., no influence of sound on taste ratings) against the experimental hypothesis (i.e., influence of sound on taste ratings) in the soundtrack-after-tasting scenario, we calculated the Bayes factor using the Jeffreys-Zellner-Siow (Rouder et al., 2009) t-test (BayesFactor R package). The Bayes factor was 0.15, which gives moderate evidence in support of the null hypothesis compared to the experimental hypothesis (Wagenmakers, 2007). In comparison, in the soundtrack-during-tasting scenario, the Bayes factor is 15.72, giving strong evidence for the experimental hypothesis compared to the null hypothesis.

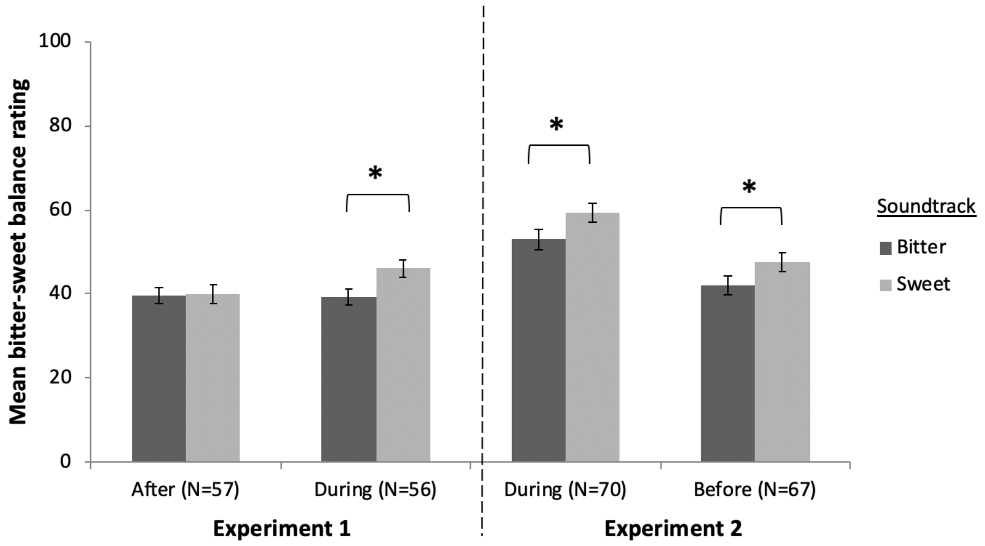

Figure 2. Overview of mean values of bitter-sweet ratings (0 indicating much more bitter than sweet, 100 indicating much more sweet than bitter) for chocolate samples, grouped by auditory stimulus timing, for both Experiments 1 and 2. Error bars indicate standard error. Asterisk '*', indicates statistical significance at *p* < .05 (Bonferroni-corrected paired testing).

In terms of chocolate liking, there was a significant main effect of timing condition ($F(1,111) = 5.71$, $p = .019$, $\eta^2 = 0.05$), where the chocolates were liked more when the soundtracks were played during, rather than after, tasting ($M_{during}(SE) = 53.46(2.43)$, $M_{after}(SE) = 45.29(2.41)$, $p = .019$). There were no other main or interaction effects.

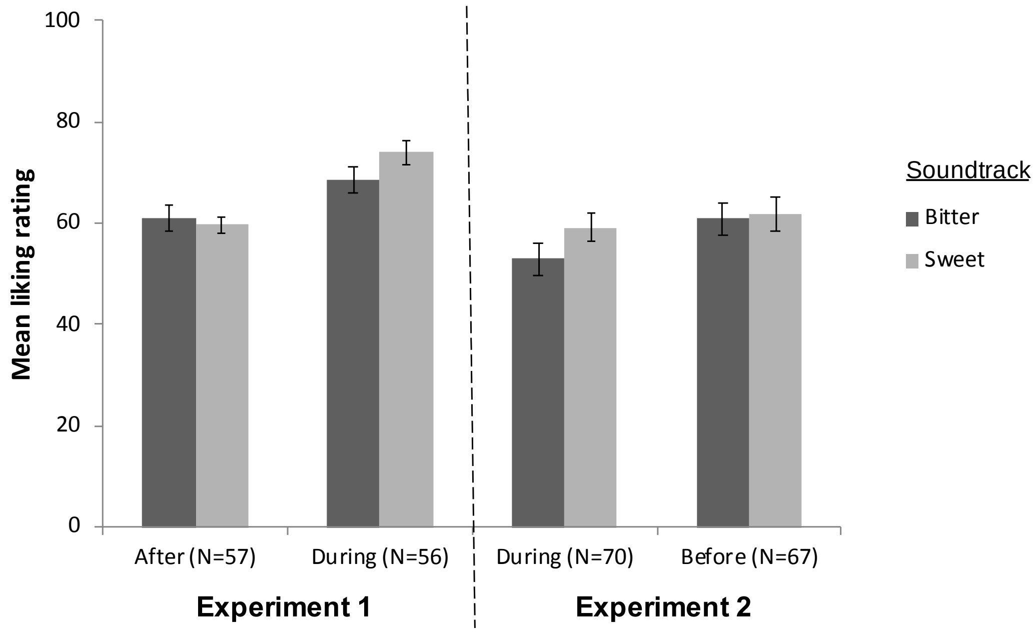

Figure 3. Overview of mean values of liking ratings (0 indicating not liked at all, 100 indicating extreme liking) for both Experiments 1 and 2, grouped by soundtrack timing condition. Error bars indicate standard error.

Discussion

The results of Experiment 1 clearly demonstrated that the timing of soundtrack presentation does indeed modulate the sonic seasoning effect. The sweet soundtrack enhanced the sweetness of chocolates as compared to the bitter soundtrack, but only when the soundtracks were presented *during* tasting. When the soundtracks were played only during food evaluation, no such modulatory effects were observed.

The results of Experiment 1 therefore provide evidence that the sonic seasoning effect, first reported by Crisinel and her colleagues (Crisinel et al., 2012), involves a genuine interaction between the soundtrack and the tasting experience that goes beyond simply altering people's retrospective interpretation of their own tasting experience. In the study reported by Crisinel et al., the soundtracks were presented while the participants tasted cinder toffee samples and, as such, the observed effect on taste ratings could have been perceptual and/or attributed to demand effects. From Experiment 1, the fact that the sonic seasoning effect was only observed when sound was heard during the tasting, and not after tasting, provides support for the view that the soundtracks influenced the real-time experience of eating. To further verify that the soundtracks had an effect on the actual perceptual experience, a plausible future study might involve running a functional Magnetic Resonance Imaging (fMRI) experiment where participants listen to a variety of soundtracks (taste congruent and otherwise) while lying inside the brain scanner. If the sweet soundtrack were found to enhance activity in the sweet gustatory field in the primary taste cortex (Chen et al., 2011; Peng et al., 2015; Reiter et al., 2015) relative to, say, silence, then that would support an interpretation in terms of a truly perceptual influence (see Spence, 2016; Woods et al., 2011).

A further question, then, is which mechanism(s) might explain the sonic seasoning effect observed in Experiment 1, in the case where sound was heard during tasting. One possibility here is that the listener might transfer their feelings about the sound to the taste stimuli (Cheskin, 1972); therefore, if participants find the soundtrack to be pleasant, they might also find the taste stimuli more pleasant than they would otherwise have done (cf. Reinoso-Carvalho et al., 2019). Support for this theory also comes from Wang and Spence (2018). The latter researchers demonstrated that positive-valence audiovisual stimuli (the image of a happy face or music with consonant harmonies) increased sweetness ratings for a fruit beverage, as compared to low valence audiovisual stimuli (image of a sad face or music with dissonant harmonies).

In summary, the results of Experiment 1 suggest that the auditory-taste modulation effect observed here and in previous research (e.g., Crisinel et al., 2012; Reinoso Carvalho et al., 2015, 2016; Wang & Spence, 2016) may involve the participants' actual perceptual experience. In Experiment 2, the timing of soundtrack onset was again varied to examine whether these soundtracks can modulate sensory expectations that, in turn, influence taste perception. Furthermore, additional data were collected regarding the emotion and taste associations with the two soundtracks, to better understand how sound-taste associations mediate the sonic seasoning effect.

Experiment 2

Methods

Participants

A total of 137 participants (78 women, 59 men) aged 18-38 years (M = 23.07, SD = 3.13) took part in the study. We aimed to recruit a comparable number of participants as in Experiment 1. The participants were recruited in the same way as in Experiment 1, via BI Norwegian Business School's participant recruitment platform.

Auditory and gustatory stimuli

The same auditory and gustatory stimuli were used as in Experiment 1.

Design and procedure

Experiment 2 was designed with timing condition (sound before or during tasting) as a between-participants factor and soundtrack (bitter or sweet) as a within-participants factor. The physical study set-up was the same as that of Experiment 1, except that the participants were seated in individual sound-attenuated booths. As in

Experiment 1, the participants were randomly assigned to either the sound before-tasting condition (N = 67) or the sound during tasting condition (N = 70).

Participants in the before-tasting condition first looked at the target chocolate sample for 30 seconds while listening to either the sweet or bitter soundtrack over headphones. Next, they tasted the chocolate sample in silence for 30 seconds. Participants in the during-tasting condition were first asked to look at the chocolate sample for 30 seconds in silence. Next, they tasted the chocolate sample for 30 seconds while listening to either the sweet or bitter soundtrack. The participants in both groups rinsed their mouths out with water before moving onto the evaluation page, where they rated the chocolate on the same bitter-sweet and liking scales as in Experiment 1. The participants cleansed their palates immediately after tasting to ensure that the soundtracks during the evaluation stage did not act on any residual tastes in the mouth (Lucak & Delwiche, 2009). The order of the soundtracks and the order of the rating scales were randomised.

Finally, the participants rated the soundtracks in terms of emotional association on two 7-point scales for valence (unpleasant-pleasant) and arousal (calm-exciting). The participants also rated how much each soundtrack matched each of four basic tastes (sweet, bitter, sour, and salty) on four 11-point VAS scales (anchored by “not at all” on one end and “very much” on the other end).

Data Analysis

A mixed RM-MANOVA conducted with ‘soundtrack type’ as the within-participants factor and ‘timing’ as the between-participants factor included bittersweet and liking ratings as measures. In addition, the emotional ratings of the soundtracks were used to conduct emotion mediation analyses between soundtrack type and chocolate ratings. Finally, soundtrack-taste matching scores were analysed to (1) verify that participants did indeed associate sweetness with the sweet soundtrack and bitterness with the bitter soundtrack, and (2) conduct mediation analysis between soundtrack type and taste rating. Multiple mediation analysis was conducted using the "lavaan" structural equation modelling package in R (Rosseel, 2012) with soundtrack type as the independent/exogenous variable, chocolate taste balance as the dependent/endogenous variable, and soundtrack valence and soundtrack-taste association as the two mediators. To compare differences in mediation between the timing conditions, multigroup analysis was conducted using the "piecewiseSEM" package in R (Lefcheck, 2015) with timing condition as the grouping variable.

Results

Influence of soundtrack and onset timing

The mean values of the participants' taste and liking ratings for the chocolates in both timing conditions are shown in Figures 2 and 3. An RM-MANOVA revealed a significant main effect of soundtrack ($F(2,134) = 12.58$, $p < .001$, *Wilk's Lambda* = 0.84). There was neither a significant main effect of timing condition ($F(2,134) = 1.23$, $p = .295$), nor a significant interaction effect between timing condition and soundtrack type ($F(2,134) = 2.92$, $p = .057$, *Wilk's Lambda* = 0.96).

In terms of taste ratings, there was a significant main effect of soundtrack ($F(1,135) = 23.46$, $p < .001$, $\eta^2 = 0.15$), such that participants rated the chocolates as tasting sweeter when they had listened to the sweet soundtrack – either before or during tasting – as compared to the bitter soundtrack ($M_{sweet\_soundtrack}(SE) = 47.90(1.52)$, $M_{bitter\_soundtrack}(SE) = 39.99(1.37)$, $p < .001$).

In terms of liking ratings, there was a significant main effect of soundtrack ($F(1,135) = 8.77$, $p = .004$, $\eta^2 = 0.06$), where the chocolates tasted during the sweet soundtrack were also liked more than during the bitter soundtrack ($M_{sweet\_soundtrack}(SE) = 60.49(1.79)$, $M_{bitter\_soundtrack}(SE) = 57.99(1.73)$, $p = .004$).

Mediation analysis

We assessed soundtrack-emotion ratings and soundtrack-taste associations as potential mediators. In terms of participants' soundtrack-taste association ratings for each soundtrack (see Figure 4), the bitter soundtrack was rated as matching bitterness significantly better than the other tastes ($p < .001$ for all comparisons), and the sweet soundtrack was rated as matching with sweetness significantly better than with the other tastes ($p < .001$ for all comparisons). To facilitate mediation analysis, a total soundtrack-taste association score was calculated that took into account both participant's sweetness and bitterness ratings for a particular soundtrack (total score = sweet association score – bitter association score). The total score was calculated to mirror the bitter-sweet rating scale used for taste evaluation: a soundtrack with more bitter than sweet associations results in a low total score, whereas a soundtrack with more sweet than bitter associations results in a high total score.

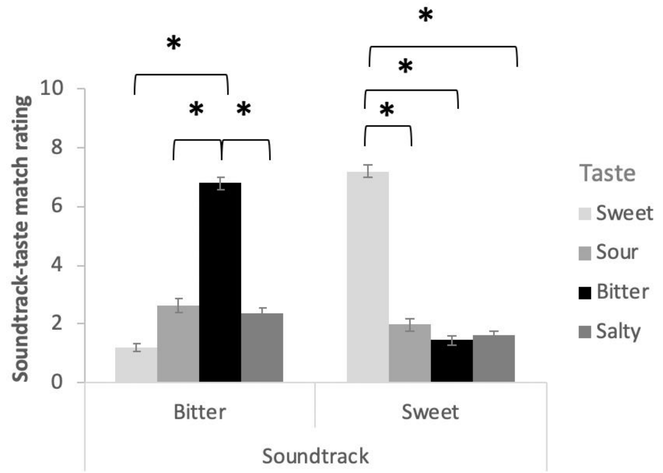

Figure 4. Mean values of soundtrack-taste match ratings for the sweet and bitter soundtracks used in Studies 1 and 2. Participants rated how well each soundtrack matched each of four basic tastes (sweet, sour, bitter, salty) on a scale of 0-10. Error bars indicate standard error. Asterisk '*', indicates statistical significance at $p < .05$.

In terms of the soundtrack emotion ratings, participants rated the sweet soundtrack as significantly more pleasant than the bitter soundtrack ($M_{bitter\_soundtrack}(SE)$ = 2.56(0.11), $M_{sweet\_soundtrack}(SE)$ = 5.84(0.11), $p < .001$). However, the two soundtracks were not significantly different in terms of arousal ($M_{bitter\_soundtrack}(SE)$ = 3.57(0.14), $M_{sweet\_soundtrack}(SE)$ = 3.69(0.18), $p = .673$). Therefore, soundtrack valence, and not arousal, was included in the multiple mediation model (see Figure 5).

As part of the mediation analysis, we first conducted multigroup analysis to determine whether there were any group differences between those participants who listened to the soundtracks before tasting and those who listened to the soundtracks during tasting. As the results revealed no significant interaction effects between model and group ($p > .05$ for all paths), all regression coefficient calculations were constrained to the estimate from the global model which included data from both timing conditions. As Figure 5 illustrates, while the regression coefficients between soundtrack type and both mediators were significant, only the regression coefficient between soundtrack-taste association and taste rating was significant. The standardised indirect effect of soundtrack-taste association on chocolate taste ratings was significant (b = 0.26, p = .010), while the indirect effect of soundtrack valence on chocolate taste ratings was not (b = 0.04, p = .575). Furthermore, there was no significant direct effect of soundtrack type on chocolate taste rating (b = -0.07, p = .628) once the mediation effects had been accounted for, indicating a complete mediation effect of soundtrack-taste association on taste ratings.

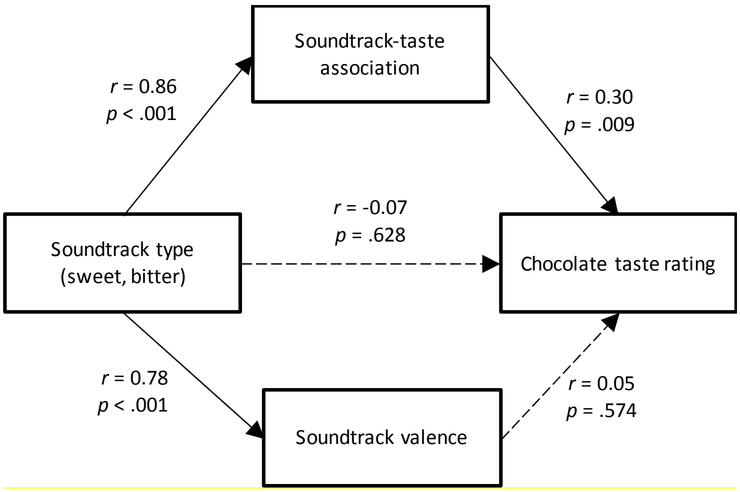

Figure 5. Diagram of multiple mediation model in Experiment 2 with soundtrack type as independent variable, taste rating as dependent variable, and soundtrack valence as well as soundtrack-taste association as mediators. Arrows represent unidirectional relationships among variables. Paths are shown with standardised regression coefficient and p values. Dashed lines indicate no significant correlation.

Discussion

In Experiment 2, we did not find any differences in the timing of the auditory stimuli – whether before or during chocolate tasting – on the modulatory effects of crossmodally congruent soundtracks on taste evaluation. There was an overall effect of soundtrack type, where the sweet soundtrack enhanced the sweetness of chocolates as compared to the bitter soundtrack. Not only did we replicate the sonic seasoning effect for the soundtrack during tasting condition as observed in Experiment 1, we also showed that sounds heard before tasting can influence the subsequent taste experience. This result is in line with previous studies (Wang et al., 2017), where a spicy-congruent soundtrack was shown to alter participants' expectations about the spiciness of the food. In this case, the timing condition where the sweet/bitter soundtracks were heard before the tasting phase presumably influenced the participants' expectations about the chocolate they were about to consume.

Furthermore, mediation analysis supported the sensation transfer hypothesis, whereby participants liked the chocolate more when the sweet soundtrack was played because they likely transferred their positive feelings about the soundtracks to the taste stimuli. Interestingly, while hearing the soundtracks before tasting generated sensory expectations, it did not bias participants chocolate liking (i.e., the so-called halo/horns effect, Lavin & Lawless, 1998). It is possible that this was because the two soundtracks – which were composed to reflect basic taste attributes, not emotional states – were simply not liked or disliked enough to influence the participants' emotional state after the soundtrack had finished. However, as we did not measure the participants' emotional state during the study, future studies would be needed to verify this possibility.

Mediation analysis also revealed that the participants' chocolate ratings were indirectly influenced by their soundtrack-taste associations but not by how pleasant they found the soundtracks. This supports the sensory priming theory, whereby taste soundtracks evoke sensory expectations in the listener, and these expectations then shape the subsequent tasting experience (see Piqueras-Fiszman & Spence, 2015, for a review). That said, our results do not exclude the possibility that may be even be additional mechanisms at play, for instance, a direct physiological effect, whereby sound triggers a food-related physiological response such as salivation (Wang et al., 2017b).

General Discussion

Overall, the two experiments reported here provide evidence on how crossmodally congruent soundtracks give rise to the sonic seasoning effect. Not only did soundtracks heard during tasting alter the sweet-bitter balance of the chocolates, soundtracks heard before eating could also influence people's sensory expectations about the food they are about to consume (perhaps under the assumption that the sounds and the food are somewhat related). We found no evidence that sounds heard during evaluation influenced the recalled tasting experience, with moderately strong support for the null hypothesis. This leads to the idea that there is a genuine perceptual effect, although neuroscientific evidence on this score is currently still scarce (Callan, Callan, & Ando, 2018).

Taken together, we presented an overall analysis on the influence of background sound on taste evaluation and food liking when played before, during, or after tasting (see Table 1). Not surprisingly, sound appears to have the greatest influence on the eating experience when it is played during tasting. After all, temporal congruency is a key constraint of multisensory integration (Spence, 2011). However, it should also be noted that background sound can alter tasting evaluations even when it is heard before eating, presumably via the setting of sensory expectations. Our results can be contrasted with the results of Shankar and her colleagues (Shankar et al., 2010), where colour cues were shown to participants before, during/after, or after exposure to olfactory cues. In that study, colour was shown to influence olfactory identification when it was presented during or after smelling, but not before. The differences observed in the timing patterns in the Shankar et al. (2010) study, when compared to the present paper, might be attributable to the fact that olfactory identification is a cognitive rather than perceptual task (as in the experiments presented here). In other words, colour influenced odour identification even when presented after smelling, potentially because it modified retrospective interpretation of the olfactory experience.

Table 1. Overview of results across Experiments 1 and 2, in terms of auditory influences on chocolate taste balance and liking ratings.

	Sound before tasting	**Sound during tasting**	**Sound after tasting**
Taste difference	Yes	Yes	No
Liking difference	No	Yes	No

In Experiment 2, the soundtrack-before-tasting timing condition was designed such that the participants were instructed to taste the food immediately after the 30 second soundtrack had finished playing. Presumably, we observed a priming effect of soundtrack on taste evaluation because the time between listening and tasting was comparatively short. However, it should be kept in mind that participants could have continued to hum or playback the soundtrack in their mind while tasting the chocolate. After all, auditory mental imagery has been shown to activate the same neural substrates as auditory perception (see Zatorre & Halpern, 2005, for a review). Keeping in mind the potential use of sounds and music for food advertising in a restaurant setting, it would be worthwhile for future studies to investigate the plausible window of time between hearing a sound and tasting food.

The present studies have several limitations stemming from the fact that we recruited university students from a business school. While the students came from many different countries, they still represent a fairly narrow demographic in terms of age and socioeconomic status. Moreover, the participant sample was predominately female. In addition, as the experiments were conducted in sensory booths, ecological validity was sacrificed in return for controlled laboratory conditions. For instance, the participants wore headphones during the study to ensure sound isolation across booths. Not only is it unusual for people to eat while wearing headphones, the headphones might have inadvertently drawn people's attention to the fact that sound was a part of the study. Moreover, soundtrack type (bitter or sweet) was manipulated as a within-participants factor in both experiments, which may have heightened the relative aspects of the two soundtracks but is hardly reflective of a real-world listening situation.

In terms of the evaluation procedure, our choice of a bitter-sweet balance scale may be especially problematic, since, as claimed by Höchenberger and Ohla's (2018) partial replication, the sonic seasoning effect may be an artifact of using aggregated taste scales. However, given that sonic seasoning effects have been demonstrated in many different studies even when using single taste scales (e.g., Reinoso Carvalho et al., 2016; Wang & Spence, 2015; Wang et al., 2017a, 2019), Höchenberger and Ohla's claim is unlikely to be true (see Spence et al., 2019, for a more detailed critique).

Furthermore, the generalisability of the current set of experiments is limited by the fact that we only used one version of each sound and one type of food. Therefore, future studies involving different types of soundtracks and foods are needed to show that the timing effects observed here can be extended beyond the specific experimental stimuli used here. That said, there is a body of prior studies using different variations of sweet- and bitter- congruent soundtracks (Reinoso et al., 2017; Kantono et al., 2019) as well as different foods beyond chocolate (toffee candy: Crisinel et al., 2012; beer: Reinoso et al., 2016; gelato: Kantono et al., 2019; juice: Wang et al., 2019) showing similar sonic seasoning effects, at least in the soundtrack-during-tasting condition.

Finally, it should be noted that in the present studies, the participants made subjective ratings of liking and taste on VAS scales. Our experimental methodology can be supported by the inclusion of implicit methods, such as biometric recordings and neuroimaging, to assess the degree to which background sound can truly influence one's perceptual experience. Encouragingly, there is evidence linking music-evoked emotions with electrophysiological measurements and flavour ratings (Kantono et al., 2019; Xu et al., 2019), which can be extended in future studies to disentangle the affective from taste-associative effects of music. Furthermore, the influence of sweet- and salty-congruent soundtracks have been documented both in terms of visual attention and food choice in a recent eye-tracking study (Peng-Li et al., in press). Turning to traditional psychophysics methods, signal detection theory offers another way to separate bias from genuine effect, at least in terms of discrimination. However, there are theoretical and practical limitations to this suggestion. First, it is unclear whether sonic seasoning would influence sweetness discrimination. An attentional theory of sonic seasoning posits that sound-taste associations would draw the taster's attention to the associated taste in a mixture. By contrast, the emotion mediation theory suggests that sound changes the taster's emotional state, which then may heighten the perception of related tastes (for instance, more positive valence with sweetness). While different, both theories have the implication that the same soundtrack may have a uniform effect on samples where sweetness is varied at JND levels (as is common in signal detection studies). In other words, hearing a single soundtrack may not necessarily alter sensory discrimination, but rather, alter perceived taste intensity when different pieces of music are presented. Therefore, a signal detection study would ideally involve comparisons of foods at different sweetness levels as well as with different background music. While not impossible, such a study would need to be carefully conducted in order to take into account the role of music.

While it is true that the current studies may still reflect responses biases, what we can also conclude is that the auditory environment we are immersed in plays an important role in our eating experience. Our results demonstrating the impact of background sound timing on food taste as well as preference therefore have practical implications for those professionals working in advertising and food-retail spaces, not to mention those in the healthcare industry looking for ways to mitigate malnutrition in patients with smell/taste loss.

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Figure1

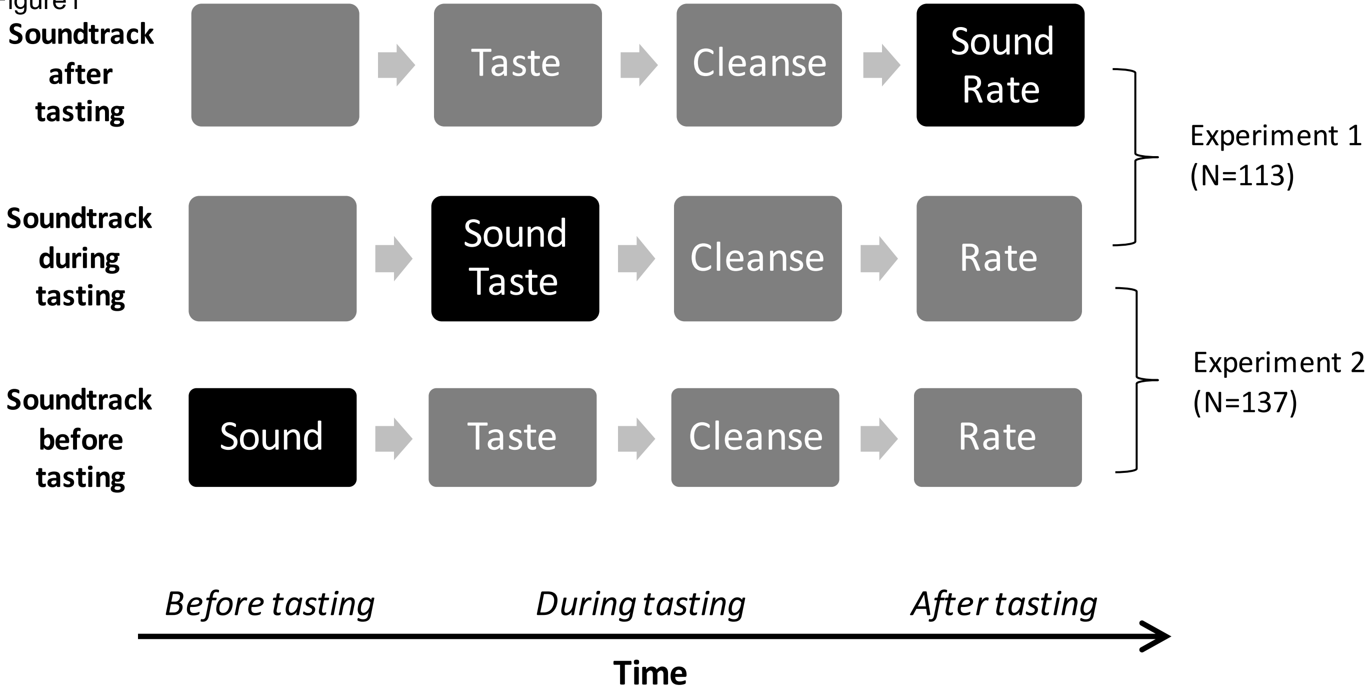

Soundtrack after tasting
Taste
Cleanse
Sound Rate
Soundtrack during tasting
Sound Taste
Cleanse
Rate
Soundtrack before tasting
Sound
Taste
Cleanse
Rate
Experiment 1 (N=113)
Experiment 2 (N=137)
Before tasting
During tasting
After tasting
Time

Figure2

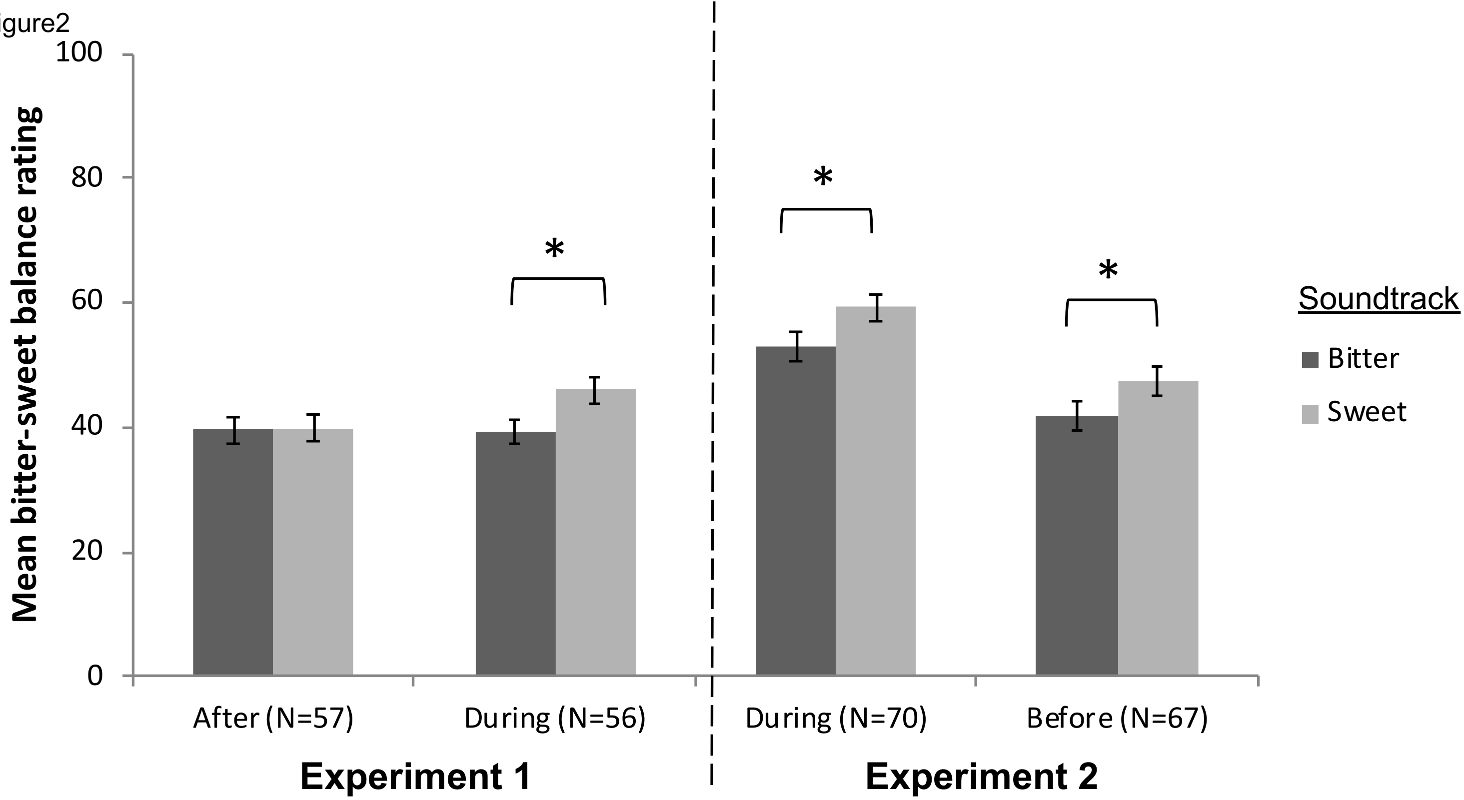

100
80
60
40
20
0
Mean bitter-sweet balance rating
*
*
*
Soundtrack
Bitter
Sweet
After (N=57)
During (N=56)
During (N=70)
Before (N=67)
Experiment 1
Experiment 2

Figure3

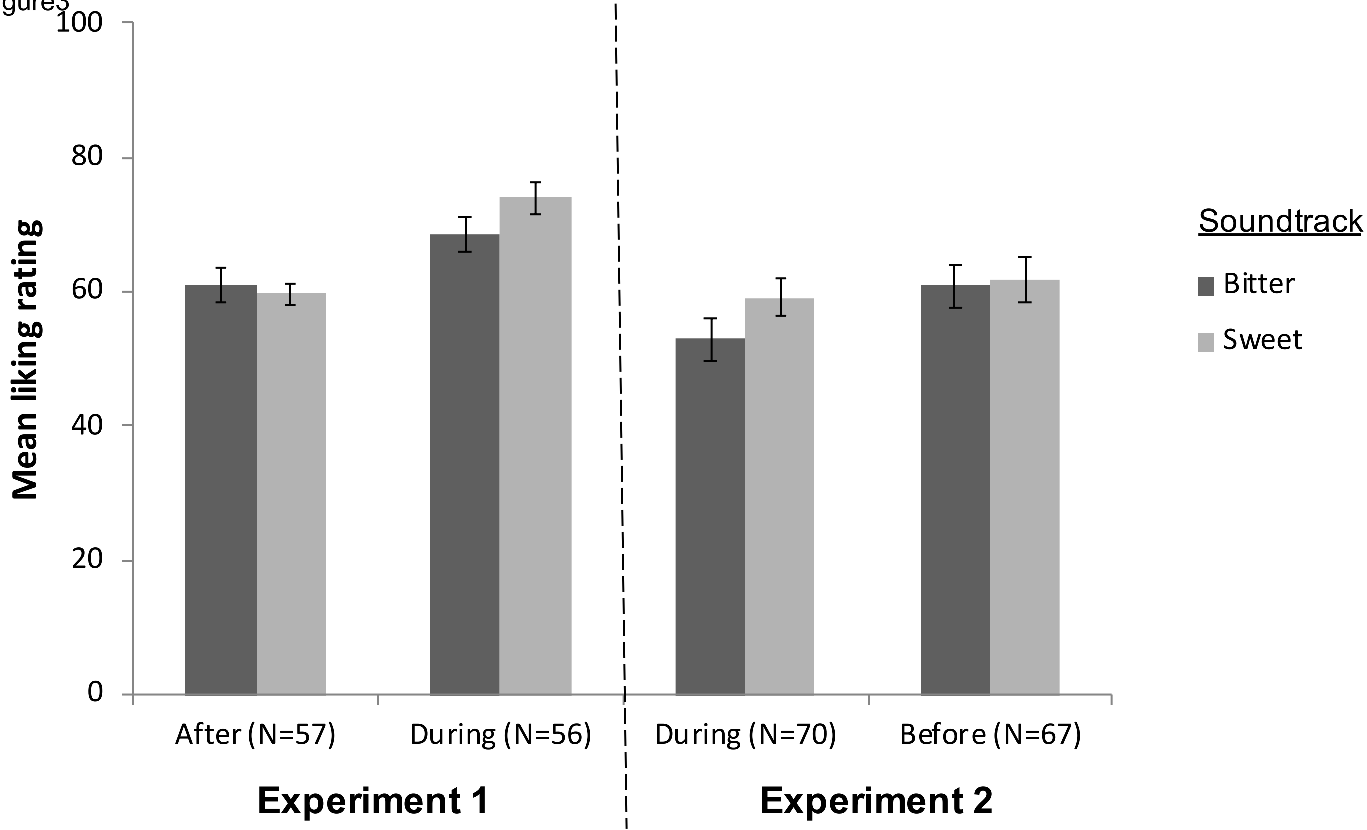
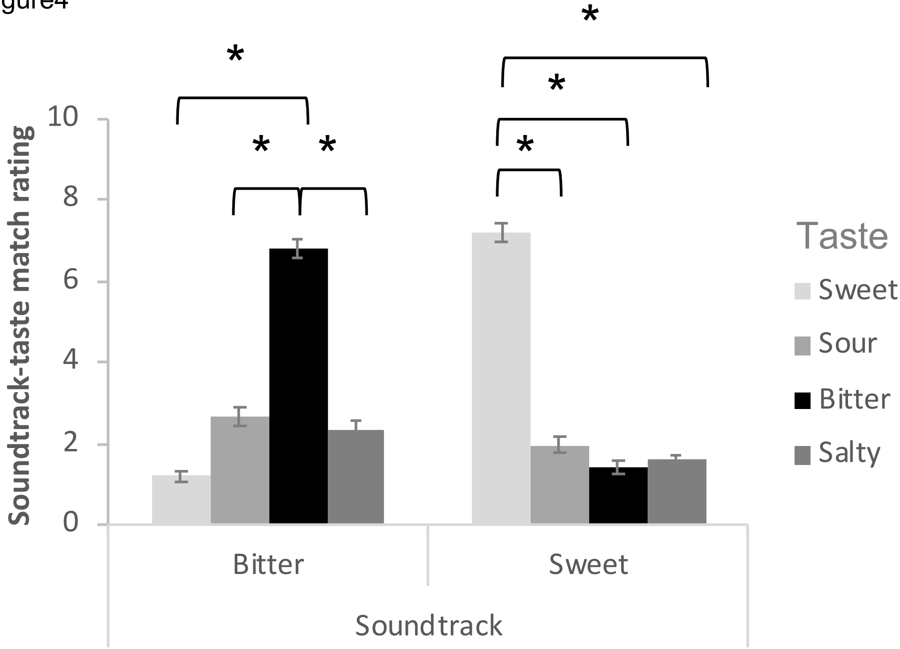
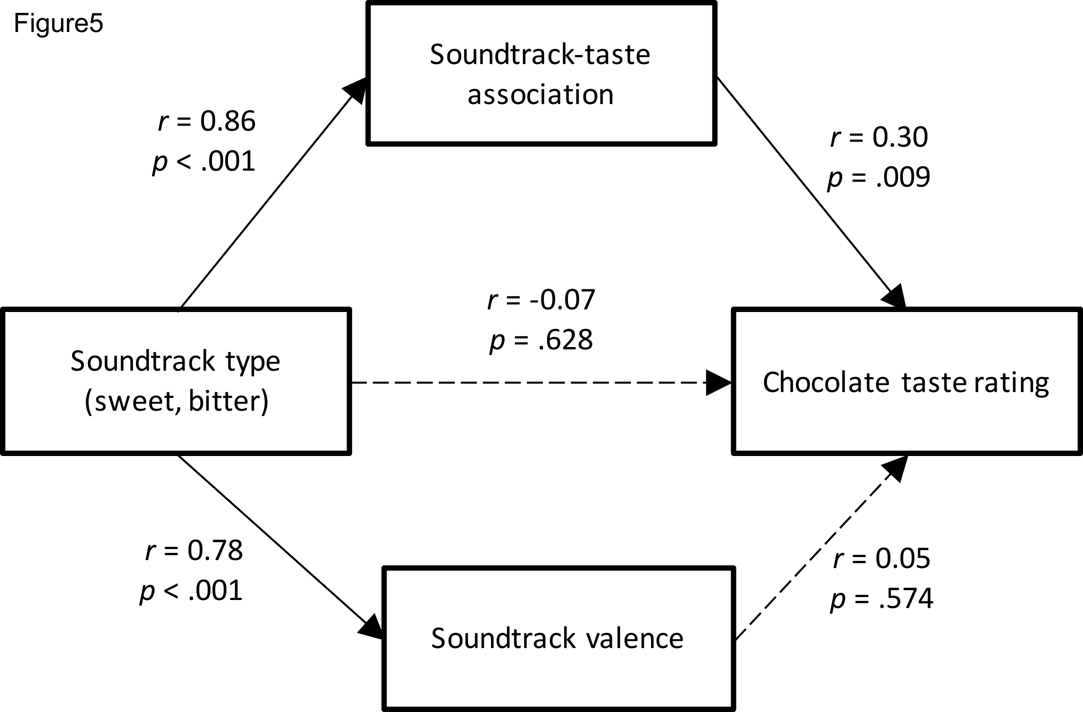

100
80
60
40
20
0
Mean liking rating
After (N=57)
During (N=56)
During (N=70)
Before (N=67)
Experiment 1
Experiment 2
Soundtrack
Bitter
Sweet

Figure4



*
*
*
*
*
*
10
8
6
4
2
0
Soundtrack-taste match rating
Taste
Sweet
Sour
Bitter
Salty
Bitter
Sweet
Soundtrack

Figure5



Soundtrack-taste association
r = 0.86
p < .001
r = 0.30
p = .009
r = -0.07
p = .628
Soundtrack type (sweet, bitter)
Chocolate taste rating
r = 0.78
p < .001
r = 0.05
p = .574
Soundtrack valence