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Disentangling cross-modality and affect in "sonic seasoning": The effect of music associated with different degrees of sweetness and valence on food perception

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ABSTRACT

The presence of music while eating can influence how foods are perceived. One line of inquiry has focused on the potential of music to evoke taste-related associations (such as perceiving a song as "sweet") to enhance the perception of congruent taste/flavor attributes in foods. However, music is also an expression of emotion, and its influence on mood has been put forward as an alternative explanation to why music changes taste perception. Disentangling both effects remains a challenge since taste and affective dimensions (e.g., valence) are usually highly correlated. This work examines the effectiveness of two pairs of soundtracks with different degrees of association with the sweet taste (Experiment 1a) or varying valence (Experiment 1b) in shaping food perception. In the two experiments, participants tasted foods differing in sugar content (i.e., cucumber, croissant, banana, and chocolate) while listening to the soundtracks and evaluated each sample on sweetness, liking, valence, and probability of future consumption. The results show that the higher (vs. lower) sweetness soundtrack significantly increased ratings in all dimensions. In contrast, no differences were observed in any of the dependent measures when listening to the higher valence (more positive) versus the lower valence (less positive) soundtrack. These findings seem to support the hypothesis that taste correspondences can contribute to modulating the multisensory eating experience. In contrast, it appears that when controlling for sweet taste correspondences, differences in the valence of music stimuli have a less salient impact on food evaluation. The theoretical implications of these findings and their potential applications to promoting healthier eating are discussed.

1. Introduction

Sound is an important element of meal settings. Places like restaurants, cafés, or food courts have long integrated music into their atmosphere, for instance, to promote a more pleasant ambiance or subtly nudge customers' behavior (Karapetsa et al., 2015). While music selections in these contexts may sometimes be haphazard, some researchers and practitioners have aimed to understand how aspects like musical style or specific acoustic attributes (e.g., loudness, tempo) may be deliberately engineered to improve consumer experience (Garlin and Owen, 2006; Spence et al., 2019). Music tempo, for instance, has been studied as a contributing variable to customer rotation and satisfaction, given its association with eating pace (Mathiesen et al., 2020, 2022), food enjoyment (Alamir and Hansen, 2021), as well as the time customers spend in a restaurant (Caldwell and Hibbert, 2002). The volume level of background music is yet another relevant acoustic attribute with important implications for how much customers drink (Guéguen et al., 2008; McCarron and Tierney, 1989).

If not appropriately managed, some of these aspects of sonic environments might easily contribute to undesirable consumption patterns (e.g., excessive eating/drinking). However, in recent years, the potential role of music in fostering healthier eating has also been a subject of interest. For instance, soundtracks with lower volume (Biswas et al., 2019) or higher pitch (Huang and Labroo, 2020) have been shown to contribute to healthier eating choices. In a similar vein, music genre has been linked with a preference for healthy (vs. indulgent) foods. Across two experiments, Motoki et al. (2022) found that listening to jazz and classical music increased the preference for healthy savory foods,

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compared with rock/metal and hip-hop. One alternative pathway to healthier eating promotion is through the impact of music on taste perception. The field of "sonic seasoning" has produced compelling evidence that music (and other sound stimuli alike) may be deliberately selected to enhance specific taste/flavor attributes in foods and drinks (Spence, 2021; for a review, see Guedes et al., 2023c). Recent research suggests that enhancing the perceived intensity of certain tastes (e.g., sweet, salty) through sound may improve the acceptance of products with lower sugar or salt contents with minimal compromises to consumers' satisfaction (e.g., Guedes et al., 2023b; Swahn and Nilsen, 2023). While compensation for sugar reduction through multisensory enhancement has been acknowledged as a feasible strategy for other sensory modalities (e.g., adding vanilla flavor in low-sugar products; Alcaire et al., 2017), we are only now beginning to understand the potential of extrinsic auditory stimuli for this purpose.

In what concerns sugar consumption, one recent experiment found that music was able not only to improve the perceived sweetness of products with low sugar contents (e.g., vegetables and 0% sugar cookies) but also their acceptance (Guedes et al., 2023b). Similar to other studies in the field, music pieces were selected based on their crossmodal associations with basic tastes. In this case, the two soundtracks were evaluated by participants as having different levels of association with the sweet taste. Other studies have shown that the associations people make between these two seemingly unrelated modalities (audition and taste) may have relevant perceptual implications (Guedes et al., 2023a,b; Spence, 2016, 2020; Wang and Spence, 2015). Yet, the processes underlying these effects have remained elusive.

One likely hypothesis is that the crossmodal associations between sounds and tastes (e.g., perceiving a song as sweet) somehow shift the attention toward the congruent attributes in the oral modality, thus making it more salient in the flavor matrix (Wang et al., 2019a). It has also been proposed that music may set up taste expectations that, in turn, influence the subsequent taste evaluation. This hypothesis seems consistent with recent findings, where delivering a soundtrack before tasting a chocolate had comparable effects on taste ratings to when music was presented during the tasting (Wang et al., 2020). What is less clear to date is whether crossmodal associations are necessary and/or sufficient to explain why such differences occur or whether these would be better explained by the influence of music on emotions and/or feeling states. For instance, Kantono et al. (2016b) found that listening to liked music emphasized the sweet taste of gelati, whereas disliked music seemed to highlight its bitterness. Recently, it has also been argued that emotional (i.e., positive vs. negative) music may originate more prominent effects on the tasting experience than music selected based on crossmodal correspondences (in this case, "soft" vs. "hard" music; Reinoso-Carvalho et al., 2020a,b).

One enduring challenge for understanding what drives sonic seasoning effects is that affective dimensions and crossmodal correspondences tend to be strongly associated. For instance, sweetness correspondences are usually highly correlated with positive emotions and affective dimensions, whereas the opposite pattern is commonly found for bitterness correspondences (Guedes et al., 2023d). Considering the close link between affective evaluations and basic taste correspondences, there is still considerable uncertainty regarding the individual contributions of both variables to the multisensory perception of foods.

1.1. Current work and hypotheses

Notwithstanding the technical constraints of disentangling taste correspondences and affect, advancing research on this topic has important future implications. If affective dimensions, such as valence, prove to be the primary determinant of changes in taste perception in response to music, perhaps the field should move beyond mapping the taste correspondences of auditory stimuli and focus on emotions instead. In contrast, should taste correspondences be the main drivers of sonic seasoning, more attention should be devoted to unraveling how to convey gustatory attributes through sound. A third possibility could be that a thoughtful conjugation of both attributes results in better outcomes than any of the two alone.

To disentangle the influence of affect and cross-modality on taste perception, we conducted two experiments examining the influence of soundtracks varying in sweet taste correspondences and valence on the perception of different foods. In the first experiment, we investigated the effects of two soundtracks rated higher versus lower in sweetness (controlling for valence - Experiment 1a) and higher (i.e., more positive) versus lower (i.e., more negative) in valence (controlling for sweetness - Experiment 1b) on the taste perception (sweetness), hedonic (liking, valence) evaluation, and probability of future consumption of foods varying in sugar content.

Overall, we expected the soundtracks evaluated as higher (vs. lower) in sweetness and higher (vs. lower) in valence to increase ratings of sweetness (H1a) and hedonic dimensions (H1b). Still, if individuals directly transfer the attributes of the stimuli from the auditory to the gustatory modality, then we could expect the crossmodal attributes of music to have a more robust effect on taste than hedonic ratings, while the music's valence would be expected to impact more significantly hedonic rather than taste ratings (H2).

2. Pilot study

A Pilot Study was conducted to select the most suitable auditory and gustatory stimuli for the main experiments.

2.1. Participants

Forty-three participants were recruited on Clickworker. The sample (M_{age} = 36.2, *SD* = 12.9 years) included 26 participants who identified as female and 17 as male. Participants received monetary compensation for completing the study.

2.2. Materials and methods

Eight soundtracks were selected from the Taste & Affect Music Database (Guedes et al., 2023d) based on sweetness and valence ratings. Two soundtracks were chosen for each category of higher sweetness (moderate valence), lower sweetness (moderate valence), higher valence (moderate sweetness), and lower valence (moderate sweetness) stimuli.

The food stimuli were 24 pictures selected from the Food-Pics (Blechert et al., 2019). All images were in the medium range of valence ratings (mean ± 1 SD) and were chosen to reflect different sweetness and healthfulness attributes. The full auditory and visual stimuli description is available as supplemental material (Supplementary Tables 1 and 2).

A survey was programmed in Qualtrics and distributed online via the Clickworker platform. Participants were asked to evaluate the soundtracks (presented in random order) in sweetness (1 = *not sweet at all* to 9 = *very sweet*), valence (1 = *very negative* to 9 = *very positive*), and arousal (1 = *not arousing at all* to 9 = *very arousing*). The food pictures (presented in random order) were evaluated in the same dimensions, as well as *healthiness* (1 = *very unhealthy* to 9 = *very healthy*).

2.3. Results

The two soundtracks that differed more strongly in sweetness than valence were selected as the high sweetness (HS) and low sweetness (LS) soundtracks. The HS soundtrack was evaluated as significantly sweeter ($M = 7.09$, $SD = 1.97$), than the LS soundtrack ($M = 5.19$, $SD = 2.57$), $t(42) = 4.49$, $p < .001$, $d = 0.69$. The HS soundtrack was also evaluated as more positive ($M = 6.81$, $SD = 2.12$) than the LS soundtrack ($M = 5.86$, $SD = 2.33$), although to a lesser extent, $t(42) = 2.16$, $p = .037$, $d = 0.33$.

The two soundtracks differing more strongly from one another in valence than in the sweetness dimension were selected as the high valence (HV) and low valence (LV) soundtracks. The HV soundtrack was evaluated as significantly more positive ($M = 6.56$, $SD = 2.05$) than the LV soundtrack ($M = 5.37$, $SD = 2.24$), $t(42) = 3.56$, $p < .001$, $d = 0.54$. The HV soundtrack was also evaluated as sweeter ($M = 5.72$, $SD = 2.11$) than the LV soundtrack ($M = 4.98$, $SD = 2.43$), although with a less pronounced difference, $t(42) = 2.16$, $p = .036$, $d = 0.33$.

Four food items were selected based on perceived healthiness and sweetness ratings. Banana was selected as a healthy ($M = 8.00$, $SD = 1.41$) and sweet ($M = 6.74$, $SD = 1.59$) product, whereas cucumber was selected as a healthy food ($M = 7.60$, $SD = 1.73$) but lower in sweetness ($M = 4.21$, $SD = 2.43$). Likewise, a chocolate-caramel bar was selected as a less healthy ($M = 5.07$, $SD = 2.63$), sweet ($M = 7.53$, $SD = 1.83$) product, whereas croissant was selected as a lower healthiness ($M = 5.86$, $SD = 1.77$) product with lower sweetness ($M = 5.33$, $SD = 2.02$).

The two sweeter products (banana and chocolate) were rated significantly higher in sweetness ($M = 7.14$, $SE = 0.22$) than the two less sweet products ($M = 4.77$, $SE = 0.29$), $F(1,42) = 38.13$, $p < .001$, $\eta_p^2 = 0.48$. Likewise, the two healthier products (cucumber and banana) were rated significantly higher in the healthiness dimension ($M = 7.80$, $SE = 0.20$) than the two less healthy products ($M = 5.47$, $SE = 0.28$), $F(1,42) = 52.80$, $p < .001$, $\eta_p^2 = 0.56$.

Soundtracks' and food items' ratings are presented as supplemental material (see Supplementary Tables 3-4).

3. Experiments 1a and 1b: the influence of music on taste perception

To examine how the affective and crossmodal attributes of music affect food perception, we conducted two parallel experiments where participants were exposed to two pieces of music differing in their correspondences with the sweet taste (higher vs. lower - Experiment 1a) or in their valence levels (higher vs. lower; Experiment 1b). In both experiments, participants tasted samples of the four products selected based on the Pilot Study (in counterbalanced order) across two trials (each trial with a different soundtrack, also presented in counterbalanced order).

3.1. Participants

Two hundred and fourteen university students volunteered to participate in the two experiments. All participants received course credits as compensation for taking part in this study.

Experiment 1a had a sample of 107 participants ($M_{age} = 21.9$, $SD = 4.9$ years), with 74 participants who identified as women, 32 as men, and one as non-binary. Based on self-reported anthropometric measures, most participants (72%) were classified as normoponderal (18.5 < BMI <24.9 kg/m^2), 9% as underweight (<18.5 kg/m^2), and 19% as overweight or obese (>25 kg/m^2).

Experiment 1b had a sample of 107 participants ($M_{age} = 23.1$, $SD = 7.4$ years), with 96 participants who identified as women and 11 as men. Based on self-reported height and weight, most participants (73%) were classified as normoponderal, 9% as underweight, and 18% as overweight or obese.

3.2. Materials and methods

3.2.1. Gustatory stimuli

Four food products were selected based on the results of the Pilot Study. Objective average sugar contents were checked based on the information provided by the USDA FoodData Central (fdc.nal.usda.gov) for the unprocessed products and the nutritional information provided by the manufacturer in the case of processed foods. These data supported the choice of banana as the sweeter healthy sample with an average sugar content of 15.8% and baby cucumber as the less sweet healthy sample with 1.38% sugar. To obtain comparable organoleptic properties (e.g., sweetness, astringency), bananas were served at similar ripening stages.[1] Among the less healthy products, commercially available versions of chocolate-caramel bars and croissants were selected. The chocolate bar (brand: Mister Choc®, variety: choco & caramel) had a 60% reported sugar content and consisted of a soft nougat topped with caramel and coated in milk chocolate. The croissant samples (brand: La Cestera®) were packed plain croissants with a 17.2% reported sugar content. The samples were served on white disposable paper plates and identified with randomly generated three-digit codes (unrelated to the samples' identity).

3.2.2. Auditory stimuli

Four soundtracks were selected based on the results of the Pilot Study. For the crossmodal (sweet) pair, we chose two soundtracks that differed more strongly in sweetness than valence levels. Based on this criterion, soundtrack #58 ("Fruity Juice" by Jerry Lacey) was selected as the higher sweetness (HS) soundtrack, whereas soundtrack #11 ("What we used to know" by Farrell Wooten) was chosen as the lower sweetness (LS) soundtrack.

The affective music pair included soundtracks that differed more strongly in valence than sweetness levels. Soundtrack #88 of the database ("Balkan Wishes" by Trabant 33) was selected as the higher valence (HV) soundtrack, whereas soundtrack #27 ("Destiny Rising" by ForMantX) was selected as the lower valence (LV) soundtrack. All soundtracks are available as supplemental material in the original paper (Guedes et al., 2023d).

3.3. Procedure

The experiments were approved by the ethics committee of Iscte - Instituto Universitário de Lisboa (Approval #117/2020). A prescreening for food allergies and intolerances was conducted. Participants were informed in advance that the study involved food consumption, and this information was presented again in the informed consent before beginning the experiment. Participants were also instructed to refrain from eating, drinking coffee, brushing their teeth, or smoking the hour prior to participation.

Data were collected at the university lab in individual soundproof booths equipped with computers and headphones. All devices were kept at a comfortable sound volume level. Participants were told they would be asked to evaluate different food samples while listening to music. All instructions and measures were integrated into a web survey (Qualtrics). The background music played automatically with sound controls invisible to participants.

Participants were randomly allocated to one of the two experiments. Depending on the experiment, participants completed the taste evaluation task with either the crossmodal (HS vs. LS) soundtracks or the affective (HV vs. LV) soundtracks. See Fig. 1 for an overview of the survey flow.

After providing informed consent, participants were asked to fill out their sociodemographic information (e.g., age, gender) along with self-report measures of anthropometric (height, weight) and hunger/satiety levels. Two blocks of sample evaluations followed.

In the first block, participants tasted the four food samples in counterbalanced order while listening to one of the two soundtracks. After evaluating each food, participants were asked to drink water and wait 30 s before proceeding to the following sample. In the second block, participants tasted the same products again (in counterbalanced order) while listening to the second soundtrack. The order by which soundtracks were presented was also counterbalanced across participants.

[1] Ripeness level was evaluated based on visual inspection of peel color and samples were preferred at around grade 5 (yellow with green tip) of von Loesecke's (1950) maturation scale.

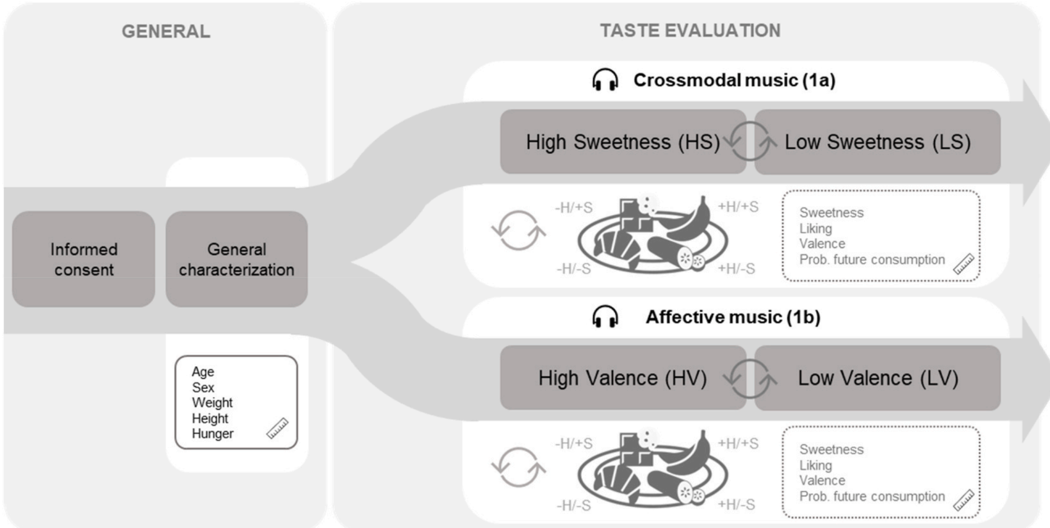

Fig. 1. Overview of the survey flow in experiments 1a and 1b. *Note.* + = High, - = Low, H = healthiness; S = sweetness.

3.4. Measures

The food samples were evaluated using 9-point rating scales anchored by bipolar labels ("Please rate this food using the following rating scales"). The stimuli were assessed in sweetness (1 = *Not sweet at all* to 9 = *Very sweet*), liking (1 = *I don't like it at all* to 9 = *I like it very much*), and valence (1 = *Very negative* to 9 = *Very positive*). Additionally, participants were asked to rate the probability of choosing to consume each product again in the future using a continuous probability scale ranging from 1% to 100%.

3.5. Data analyses

All hypotheses and analytic plan were specified before data collection. Data were analyzed in IBM SPSS Statistics 28. Separate 2 (music) x 2 (sugar content) x 2 (healthiness) repeated-measures ANOVA tested the effect of music condition on each dependent variable: sweetness, liking, valence, and probability of future consumption. The independent variable "music condition" consisted of the two crossmodal soundtracks (HS and LS) in Experiment 1a and the two affective soundtracks (HV and LV) in Experiment 1b. Besides music, the model included the independent variables of foods' sugar content (higher: chocolate, banana vs. lower: cucumber, croissant) and healthiness (higher: banana, cucumber vs. lower: chocolate, croissant).

All main effects are reported in Tables 1 and 2. Interactions with the music condition were analyzed and reported when significant (p < .050). Participants' soundtrack evaluations were compared with Paired Samples *t*-tests.

3.6. Results

3.6.1. Experiment 1a: The influence of sweet music on the perception of taste and hedonic attributes

The original data is publicly available at osf.io/znadf. Two participants refused to taste one of the food samples and, thus, were excluded from the analyses of variance.

The results of the ANOVA showed that music significantly influenced all dependent measures. The food samples were evaluated as significantly sweeter when listening to the HS soundtrack (M = 5.75, SE = 0.08) than the LS soundtrack (M = 5.60, SE = 0.08), F(1,104) = 4.28, p = .041, η^2_p = 0.04. The products were also liked more, rated more positively, and evoked higher intentions of future consumption (all p < .043) in the HS (vs. LS) condition.

Table 1
Descriptives (M, SE) and main effects of soundtrack condition (A), sugar level (B), and healthiness (C) across the dependent measures in Experiment 1a.

(A) Soundtrack condition	**HS**		**LS**		***F* (1,104)**	***p***	η^2_p
	M	***SE***	***M***	***SE***			
Sweetness	5.75	0.08	5.60	0.08	4.28	.041	0.04
Liking	6.76	0.09	6.58	0.10	8.40	.005	0.08
Valence	6.74	0.10	6.48	0.10	11.37	.001	0.10
Future consumption	73.05	1.44	71.60	1.44	4.21	.043	0.04
(B) Sugar content	**High**		**Low**		***F* (1,104)**	***p***	η^2_p
	M	***SE***	***M***	***SE***			
Sweetness	7.49	0.08	3.86	0.10	959.57	<.001	0.90
Liking	7.51	0.12	5.82	0.13	90.37	<.001	0.47
Valence	7.39	0.12	5.83	0.13	82.57	<.001	0.44
Future consumption	82.83	1.56	61.82	2.11	73.16	<.001	0.41
(C) Healthiness	**High**		**Low**		***F* (1,104)**	***p***	η^2_p
	M	***SE***	***M***	***SE***			
Sweetness	4.39	0.10	6.96	0.08	461.39	<.001	0.82
Liking	6.20	0.15	7.13	0.11	23.90	<.001	0.19
Valence	6.18	0.15	7.04	0.11	22.51	<.001	0.18
Future consumption	69.78	2.02	74.87	1.80	3.76	.055	0.04

Note. HS = Higher sweetness; LS = Lower sweetness.

Additionally, the food samples' sugar content and healthiness also affected the dependent measures significantly (all p < .001), except for healthiness in the probability of future consumption (p = .055). Notably, participants provided higher ratings in all dependent variables for higher (vs. lower) sugar content and lower (vs. higher) healthiness. No significant interactions with music condition were observed. The descriptive statistics and main effects are reported in Table 1.

3.6.2. Experiment 1b: The influence of affective music on the perception of taste and hedonic attributes

The original data is publicly available at osf.io/znadf. Three participants refused to taste one of the food samples and, thus, were excluded from the analyses of variance.

The results of the ANOVA did not show a significant main effect of music on any of the dependent measures (see Table 2).

Once again, the food samples' sugar content significantly affected all

Table 2
Descriptives (M, SE) and main effects of soundtrack condition (A), sugar level (B), and healthiness (C) across the dependent measures in Experiment 1b.

(A) Soundtrack condition	**HV**		**LV**		***F* (1,103)**	***p***	η_p^2
	M	***SE***	***M***	***SE***			
Sweetness	5.73	0.09	5.72	0.09	0.01	.929	0.00
Liking	6.67	0.11	6.63	0.11	0.30	.586	0.00
Valence	6.64	0.11	6.55	0.11	1.10	.298	0.01
Future consumption	71.11	1.72	70.77	1.73	0.16	.694	0.00
(B) Sugar content	**High**		**Low**		***F* (1,103)**	***p***	η_p^2
	M	***SE***	***M***	***SE***			
Sweetness	7.50	0.09	3.94	0.11	828.80	<.001	0.89
Liking	7.59	0.12	5.71	0.16	99.30	<.001	0.49
Valence	7.48	0.11	5.71	0.15	106.81	<.001	0.51
Future consumption	81.96	1.75	59.92	2.38	77.61	<.001	0.43
(C) Healthiness	**High**		**Low**		***F* (1,103)**	***p***	η_p^2
	M	***SE***	***M***	***SE***			
Sweetness	4.47	0.10	6.97	0.10	436.21	<.001	0.81
Liking	6.17	0.14	7.13	0.14	25.38	<.001	0.20
Valence	6.11	0.14	7.08	0.13	29.75	<.001	0.22
Future consumption	67.27	2.07	74.61	2.03	9.50	.003	0.08

Note. HV = Higher valence; LV = Lower valence.

dependent variables (all $p < .001$), and so did healthiness (all $p < .003$) in the same direction as Experiment 1a. A significant interaction between music condition and sugar content was observed on the valence ratings, $F(1,103) = 6.25$, $p = .014$, $\eta_p^2 = 0.06$ (not shown in tables). In the sweeter samples, participants provided higher valence ratings with the more positive music ($M = 7.60$, $SE = 0.12$) than with the less positive music ($M = 7.36$, $SE = 0.13$), $p = .016$. The opposite pattern was observed in the less sweet samples, where participants provided lower valence ratings with the more positive ($M = 5.68$, $SE = 0.16$) than with the less positive music ($M = 5.75$, $SE = 0.15$), although the difference was not significant ($p = .582$).

4. Discussion

The empirical evidence accumulated thus far seems increasingly convergent in showing that music can modulate sweet taste perception (Guedes et al., 2023c; Spence et al., 2019). While originally these effects were thought to be a by-product of the implicit associations between attributes on the gustatory and auditory modalities, subsequent research has increasingly emphasized the role of emotional/affective factors in shaping the multisensory perception of foods (e.g., Reinoso-Carvalho et al., 2020a,b). The current paper reports the results of two experiments where participants tasted products varying in sugar content and healthiness while listening to one of two pairs of soundtracks chosen to reflect contrasting crossmodal (higher vs. lower sweetness) or affective (higher vs. lower valence) attributes. The findings suggested that listening to higher (vs. lower) sweetness music increased the perceived intensity of the corresponding sweet taste, independently of the samples' healthiness or sugar content. Participants also reported liking the samples more, found them more positive, and showed higher intentions to consume them again in the future. Contrary to our expectations, this effect was larger on the hedonic (liking, valence) variables than on taste ratings. Also, in disagreement with the initial hypotheses, higher (vs. lower) valence music did not significantly affect any of the variables under analysis.

Previously, it has been suggested that emotions may affect not only the perception of taste/flavor attributes but also the hedonic experience with foods (Wang and Spence, 2018). According to an emotion mediation hypothesis, sounds may change individuals' affective states, and these, in turn, may highlight certain taste attributes (Kantono et al., 2019; Lin et al., 2019; Xu et al., 2019). Indeed, it is often the case that the taste attributes enhanced by music are those that are more associated with pleasure and affect. Most notably, pleasant music usually enhances the sweet taste, whereas unpleasant music more often intensifies bitter sensations (Kantono et al., 2016b, 2019; Lin et al., 2022; Reinoso-Carvalho et al., 2019, 2020a,b; Wang and Spence, 2016). This pattern is commonly thought to reflect the implicit preferences of evolutionary origin, where sweetness is equated with pleasant subjective experience and bitterness with aversive reactions (Beauchamp, 2016; Ventura and Mennella, 2011).

The concept of "sensation transference" has also been called upon to explain the influence of emotional music on food perception. Originally put forward by Cheskin (1972), the concept has further been elaborated to refer to how the feelings elicited by music may transfer to the hedonic and sensory perception of foods and drinks (Reinoso-Carvalho et al., 2016). The basic tenet is that positive or negative feelings toward music would not only transfer to the hedonic evaluation of a product being tasted but also likely to its taste in a congruent fashion. Again, the idea of congruence here implicates the implicit associations mentioned above between emotions and tastes, such as that between sweetness and positive affect. Some studies have favored this hypothesis, showing, for instance, an effect of pleasant music both on taste and hedonic attributes, whereas crossmodal music seemed to impact the first but not the latter (Reinoso-Carvalho et al., 2016, 2017; Wang and Spence, 2016, 2018). This view has since been challenged in more recent experiments where crossmodal music has impacted hedonic measures too (Guedes et al., 2023b; Reinoso-Carvalho et al., 2020a,b).

While these findings might seem puzzling, it is important to note that studies have differed in the attributes they manipulate, as well as in the hedonic measures they intend to capture. To complicate matters further, it is yet virtually impossible to fully disentangle cross-modality and affect to the extent that taste correspondences and affective ratings are strongly and positively correlated, even when these variables are studied across large stimulus sets (Guedes et al., 2023d). In the experiments presented here, we aimed at extricating sweetness associations from the affective dimensions of valence since this seems to be one of the main confounding variables in the sonic seasoning literature. Based on a Pilot Study, we selected two soundtracks that differed more strongly in sweetness than in valence (crossmodal pair) and two that differed more strongly in valence than in sweetness (affective pair). Although the results of the main experiments support the choice of soundtracks to some extent (e.g., by identifying a modulatory effect of the HS and LS soundtracks on sweet taste perception), fully disentangling cross-modality and affect remains a challenge. As the results from the Pilot Study suggest, the two dimensions (sweetness and valence) still appear to be positively correlated. Thus, instead of searching for fully controlling alternative variables, one may look at the attribute that is more dominant in each soundtrack.

While it might be tempting to interpret the current findings as suggesting a primacy of cross-modality over affect, it remains unclear whether these results are entirely attributable to differences in the subjective dimensions examined here or the characteristics of the stimuli used in these experiments. As with other studies in this field of inquiry, it is uncertain whether the effects obtained with a given stimulus are generalizable to others within the same class of stimuli (e.g., from a particular sweet music piece to other sweet music). Additionally, the fact that the affective music was perceived as more arousing could have contributed to it being considered less suitable to accompany food tasting. Indeed, the perceived fitness between music and food could be a measure of interest in future studies, as an adequate pairing between the senses may be key to the quality of the multisensory experience (Vandenberghe-Descamps et al., 2022). Pairing principles are particularly relevant in real-world settings where individuals seem to prefer to listen to music that is deemed adequate or appropriate to the eating situation (Wilson, 2003). In other words, music should blend and harmonize with the food rather than overshadow it. In effect, there have been efforts to achieve such harmonious effects by selectively pairing music with wine, similar to what is done unimodally (e.g., pairing wines with foods; Wang and Spence, 2015). While it seems apparent that a thoughtful selection of sounds in collective meal settings would result in a better dining experience, musical background choice seems generally unsystematic. More commonly, music is seen as a tool to build an atmosphere that matches a desired mood (Kontukoski et al., 2016) or alludes to a specific cuisine (Feinstein et al., 2002; Zellner et al., 2017). In what concerns crossmodal correspondences, it might be relevant to question how many unintended effects could be taking place in restaurants, cafés, or even in domestic contexts.

In sonic seasoning experiments, it has been common practice to test the effects of bespoke soundtracks deliberately composed to evoke taste associations. However, numerous studies to date have shown that different styles of music may also lead to changes in gustatory perception (e.g., Kantono et al., 2016b, 2019; Spence and Deroy, 2013). That also appears to be the case of the Taste & Affect Music Database stimuli on which this study was based (Guedes et al., 2023d). This stimulus set comprises 100 music excerpts retrieved from a music catalog designed to cover different moods and music genres. Still, despite the lack of intentions of composers to evoke taste associations, this stimulus set includes various soundtracks that were matched to basic tastes with above-chance agreement rates.

In addition to the effects in taste (sweetness) and hedonic (liking) measures, we also found that music influenced participants' reported intentions of consuming the food products again in the future. While this was beyond the scope of this study, future experiments might wish to examine how pairing less liked foods (e.g., bitter vegetables) with music with the right crossmodal characteristics could contribute to increase food acceptance and, potentially also food selection, for example, in addition to repeated exposure (Corsini et al., 2013). That might result not only in reduced sugar intake but possibly also in higher consumption of healthier alternatives.

The samples used in the study varied in visual (color, shape) and textural (hardness) characteristics that might also suggest taste associations (e.g., color-taste, Spence and Levitan, 2021; shape-taste, Spence, 2023b; texture-taste, Barbosa Escobar et al., 2022). In future studies, it might be interesting to test whether the congruency between auditory and other sensory cues (e.g., color and shape of products) might lead to more robust effects than manipulating auditory stimuli alone (Wang et al., 2019b). This investigation would be particularly relevant from an applied perspective, considering the multisensory nature of meal settings. Unlike controlled laboratory environments, real-world settings might include myriad sensory cues with potential interactive effects. Therefore, it becomes particularly challenging to ascertain whether a statistically significant effect obtained in the lab will result in meaningful changes in realistic environments.

Another limitation that should be mentioned regards how affective dimensions are to be interpreted. Indeed, there seems to be a lack of consensus regarding how valence should be measured (e.g., as a positive-negative continuum or a pleasantness dimension), and the difference between objective and subjective foci may also contribute to the mixed results. While "felt" (what the individual feels in response to music) and "perceived" (what the individual believes that music is intended to portray) affective dimensions tend to be correlated, they do not necessarily overlap (Guedes et al., 2023d; Schubert, 2013; Song et al., 2016). Thus, guiding stimulus selection on felt instead of perceived valence could lead to different results. What is more, some studies have relied on subjective music preferences (i.e., liked music) rather than pleasantness or valence dimensions (e.g., Kantono et al., 2019; Kantono et al., 2016a,b). Concerning the crossmodal pair of music, these findings support the idea that lay individuals are capable of associating tastes with sounds in a non-arbitrary fashion. Previously, it was shown that individual differences in musical skills had a negligible impact on the ability to match sounds to tastes (Guedes et al., 2023d) and that individuals with no musical training are able to decode the tastes that inspired musical improvisations by expert musicians with above-change accuracy (Mesz et al., 2011). Still, it remains unknown whether sonic seasoning effects might depend on participants' level of musical sophistication or, specifically, their knowledge of music-taste associations. In the present study, we did not formally evaluate participants' prior knowledge of crossmodal correspondences. However, future studies might wish to address, for example, how familiarity with crossmodal correspondences might contribute to the results.

While disentangling cross-modality and affect remains a relevant theoretical endeavor, there are also important consequences from an applied standpoint. Whether one wishes to restructure environmental sounds to promote healthier eating or simply to foster a better multisensory experience, it is worth questioning what attributes to look for in music. Although we may still be far from determining precisely what sounds work best for what foods, environments, and attributes, the current research may provide relevant insights for this future transition. Importantly, the current findings reinforce the potential of music as a sensory cue to promote the acceptance of healthier foods. The sonic seasoning effect observed across foods with different sugar content further suggests that music may serve as a multisensory trick to allow for an improved balance regarding the sugar contents of individual food products or meals.

Translating this knowledge into practical applications and creative solutions is an open challenge for scientists, chefs, baristas, gastronomists, nutritionists, and other professionals. Present and future technological advances, such as artificial intelligence and virtual/augmented reality, are also prone to offer new possibilities for selecting and delivering novel multisensory experiences involving sound (Spence, 2023a). Importantly, future developments in this area should not ignore the potential of multisensory interventions to respond to current public health challenges, namely by promoting healthier eating (Guedes et al., 2023b; Hutchings et al., 2019; World Health Organization, 2015).

5. Conclusions and implications

Disentangling cross-modality and affect in the context of sonic seasoning is an important step toward using music as a multisensory "sweetening" strategy. The findings presented here suggest that music selected based on sweet taste correspondences may effectively modulate the eating experience, not only by increasing sweet intensity ratings but also by fostering a more favorable hedonic evaluation and higher intentions of future consumption of the samples under analysis. Importantly, these results add to previous findings showing that music can improve the acceptance of products with varying sugar content (Guedes et al., 2023b). From that standpoint, it appears that the potential of music stimuli reaches beyond simply delivering engaging multisensory experiences, as it may also contribute to promoting healthier eating habits.

Collective meal contexts, such as restaurants or cafeterias, are multisensory environments where music is often a key part of the ambiance. While some features of the auditory environment (e.g., loud noise) may deteriorate some aspects of taste perception (Woods et al., 2011), the growing body of literature on sonic seasoning may, in the future, allow practitioners to start developing smarter sonic spaces that can assist people in engaging in better eating behaviors.

Ethical statement

The experiments were approved by the ethical review board of Iscte – Instituto Universitário de Lisboa (Approval #117/2020).

Implications for gastronomy

In recent years, we have witnessed an increasing interest in the contributions of audition for multisensory taste perception. A growing body of literature now suggests that sounds may be deliberately picked to enhance specific gustatory sensations, such as basic tastes. The current paper shows that music selected based on crossmodal attributes (i.e., association to sweetness) can effectively shape the perception of foods with varying sugar levels, not only in taste intensity but also in the hedonic evaluation of products. These findings may offer relevant insights for understanding taste perception and its underlying psychological mechanisms and inform future multisensory applications targeting sweet taste. Having shown the positive impact of music across products with different sugar levels, we suggest that future developments in this area should consider the potential of multisensory interventions involving sound to allow a better adjustment of ingredients (e.g., sugar) in food products and meals to more favorable hedonic and health outcomes. This goal will likely require collaborative efforts from scientists and practitioners from the food and gastronomy fields to imagine new and creative solutions to promote better health, considering the challenges posed by real-world environments. Some practical applications may include conceiving novel gastronomical experiences involving the auditory modality, designing smarter multisensory eating environments (e.g., restaurants, canteens), creating custom soundscapes/playlists for hospitality contexts, or developing new products (e.g., digital apps) to support better eating.

CRediT authorship contribution statement

David Guedes: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft. **Margarida V. Garrido:** Conceptualization, Methodology, Writing – review & editing. **Elsa Lamy:** Conceptualization, Methodology, Writing – review & editing. **Marília Prada:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is available at a data repository (OSF)

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Appendix A. Supplementary data

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