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Emotional and electrophysiological measures correlate to flavour perception in the presence of music

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ABSTRACT

Research into the influence of auditory cues upon food perception has increased in the past decade. Mechanisms evoked to explain crossmodal interactions between the auditory and gustatory senses include attentional, emotional, and affective mediators. In this study, the Temporal Dominance of Sensations (TDS) method was utilised to document the changes in taste and flavour of chocolate gelato while participants listened to music. After each TDS trial, the participants rated their emotions using intensity scales. Additionally, electrophysiological measures including heart rate, respiration rate, and skin conductance were obtained. As anticipated, listening to liked music evoked positive emotions (*enjoyment, happiness, love,* and *satisfaction*), while disliked music elicited negative emotions (*disappointment, and disgust*). No significant difference in terms of respiration parameters were observed while listening to music differing in liking. When compared to neutral and liked music, listening to disliked music exhibited the greatest change in skin conductance. Additionally, neutrally liked music significantly decreased blood volume pulse amplitude, while listening to liked music significantly increased heart rate. Partial Least Square Regression (PLSR) analysis was employed to explore associations between electrophysiological and sensory measures. Skin conductance and cardiovascular measures were both linked to the perception of gelato. Partial Least Square Path Modelling (PLS-PM) was also utilised to investigate the relationships between the electrophysiological measures, subjective ratings of emotion, and perception. The PLS-PM model showed that changes in cardiac and skin conductance measures were correlated with subjectively-rated emotions. Furthermore, these self-reported emotions evoked by music were significantly correlated with flavour.

1. Introduction

Research into the crossmodal interactions between the auditory and gustatory systems has increased in recent years. Studies have reliably demonstrated that different musical styles can influence the perception of chocolate gelati in terms of pleasantness [31,33] taste dynamics [34], and flavour [30]. Other studies have attempted to understand the influence of music on the taste of beer [9], chocolate [10], and the temporal intensity of wine [58]. In addition, soundscapes have been shown to influence perceptions of beer [11] and toffee samples [13]. These studies support the veracity of the mood mechanism/emotion transference theory whereby the stimulus provided by the environment (i.e. auditory cues) may be transferred to the food itself, which in turn influences perceptual processes [53,61]. However, these studies only measured subjective ratings of emotion using simple line scales, possibly effecting internal validity, and analysed their data in terms of the relationship between food perceptions and the rudimentary physical parameters of the music (e.g. pitch, mode, tempo). By utilising electrophysiological measurements, further verification work in documenting the relationship between food perceptions and emotions evoked by music is a central aim of the current study.

There is evidence emerging in the crossmodal sensory literature indicating that emotions can influence not only food selection, but also food perception. A review by Macht [40] documented how emotions affected consumers' eating behaviours, emphasising the importance of emotional states on food choice and consumption. Desmet and Schifferstein [18] further demonstrated that participants' emotions can be influenced by the food's valence (i.e., pleasantness). Torres and Nowson [56] reported that participants exposed to intense stressors were inclined to select fatty foods. Platte, Herbert, Pauli, and Breslin [48] also found that viewing a sad movie resulted in higher ratings of perceived fat in dairy solutions, and lower ratings of sweetness of sucrose solutions. Other studies demonstrated that mildly stressed participants showed higher bitterness ratings when judging saccharin solution [19], and lowered sweetness ratings of sucrose solution [1].

Arguably, emotions are defined at two levels of description (i.e.,

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experiential or electrophysiological), and are typically described as the variations in both psychological and physiological states that accompany exposure to an object or an internal event. According to the emotion circumplex model, emotions are conceptualised along arousal (low-high) and valence (pleasant-unpleasant) dimensions. In the context of the affective responses elicited by stimuli, valence is the perceived attractiveness or repulsiveness of an object or event, while arousal represents a stimulus's ability to activate (high arousal) or deactivate (low arousal) an individual's cognitive state. Note that both arousal and valence do not necessarily predict approachability towards a stimulus. Of relevance to the current study, music can evoke positive emotional states such as *goodness* and *friendliness* [21], or negative emotions such as *bad feelings* and *unpleasantness* [4]. Listening to liked music (i.e., high valence and high arousal) activates those brain areas thought to underlie positive emotions [7]. On the other hand, listening to disliked music (i.e., low valance and low arousal) suppresses activity in the brain areas associated with reward [46].

Mechanism mediating crossmodal interactions between the auditory and gustatory systems have hitherto focused on their direct effects on mood and emotion. Firstly, a mechanism proposed by Woods et al. [61] described the heightened emotional states experienced by the stimulation of one sensory system (e.g., auditory) influencing the processes involving another modality (e.g., gustatory). Data supporting this model was reported by Heath, Melichar, Nutt, and Donaldson [27], who demonstrated that a heightened mood state increased sweetness and decreased bitterness perceptions. Furthermore, Platte et al. [48] reported that sweetness of sucrose solution increased after watching an emotionally positive movie clip, while watching a sad movie clip increased the bitterness of a quinine solution. Evidence supporting the model of Woods et al. [61] was further marshalled by Wang and Spence [59], who investigated the emotional associations between music and wine [59,60]. In a related study, participants were exposed to music varying in valence while providing subjective ratings of taste and emotional responses to chocolate gelato [31]. It was shown that the positive emotions evoked by liked music were linked to gelato sweetness, while negative emotions evoked by disliked music were correlated with bitterness, supporting the emotional mechanism proposed by Woods et al., [61]. To further validate self-report emotional measures, which are predisposed to response biases, more objective physiology measures known to covary with emotional states (i.e., cardiovascular, respiratory, and skin conductance responses) can be used. Supplementing subjective ratings of emotion with adjunct electrophysiological measures can arguably offer a more holistic perspective of how individual emotions may vary in response to auditory stimuli while consuming food.

Broadly, across the domain of psychology, the measurement of emotion is problematic [36]. However, subjective measures of emotion can be complemented by measures of autonomic nervous system (ANS) activity, where emotions elicited by high arousal/negative valence stimuli are associated with the activation of the sympathetic nervous system [44]. The ANS is responsible for regulating organ function, which it achieves through its sympathetic (activation) and parasympathetic (relaxation) branches. Pertinently, the afferent feedback from the body's organ systems are intrinsic to emotional response (e.g., experiencing the ‘butterflies’ when nervous), and the autonomic specificity hypothesis argues that specific subjective emotions evoke specific ANS responses [8]. Measures of ANS activity include skin conductance, cardiovascular, and respiratory responses, all of which are widely reported in the literature and have been found to correlate with specific positive and negative emotions [36]. Each of these measures reflect either sympathetic activity (e.g., skin conductance response), parasympathetic activity (e.g., respiration rate), or both (e.g., heart rate). Of note, cardiovascular states such as high heart rate (i.e., tachycardia) reflects sympathetic dominance, while greater Blood Volume Pulse amplitude is correlated with the activation of the parasympathetic system.

Electrophysiological responses to sound and music have been reported in literature, and a review [38] detailing optimal methods to induce emotions suggests that some ‘induction methods’ (e.g., film or music) have a much more reliable influence on ANS measures than others (e.g., picture slides). For example. Listening to pleasant sounds (i.e. bird sounds) was found to significantly lower heart rate [63]. An increase in heart rate (HR) has been associated with *anger* [42], and is commonly associated with a high arousal response [12,20]. Blood volume pulse (BVP) amplitude, a measure of vascular resistance, has been shown to increase with calm states and decrease with stressed or aroused states [26]. BVP amplitude has also been reported to be amplified while listening to neutral music and attenuated for unpleasant music [70]. BVP amplitude was also positively correlated with pleasure ratings while listening to music [52]. In one study [37], music that elicited negative emotions (e.g., fear) significantly increased skin conductance response compared to happy music. Interestingly, respiration rate measures have been shown to increase while listening to either happy or fear-inducing music, but not to sad music [22].

Research into autonomic activity while consuming food and beverages is lacking. To date, studies have investigated autonomic responses to the five basic tastant solutions [51], and ANS measures have been linked to perceptions of food varying in liking [17]. Furthermore, ANS response was reported to predict the liking of both breakfast drinks [16], and fruit juices [15]. Rousmans et al. [51] showed that sweet solutions elicited weaker sympathetic autonomic responses, while bitter solutions evoked stronger autonomic responses. These changes in autonomic response were probably due to the innate acceptance (i.e., high valence and arousal) of sweetness and rejection (i.e., low valance and arousal) of bitterness [54,55]. de Wijk et al. [16] demonstrated that foods high in valence increased finger temperature and HR, and significantly decreased skin conductance response when compared to disliked foods [17]. Similarly, Danner et al. [15] found a negative correlation between skin conductance response and food liking, indicating that liked food may have a calming effect.

This research aims to explore how emotions (measured both subjectively and electrophysiologically) covary with perceptions of chocolate gelato while listening to music differing in liking. We hypothesise that electrophysiological responses will correlate with subjectively reported emotions, and that both measures will be robust predictors of changes of perceptions while listening to music. As such, this study attempts to understand the underlying associations between emotion and subjective reports of sensations and flavours over time. To this end, this study will be the first to augment self-report emotion measures with objective measures of ANS response in an attempt to explain the crossmodal interactions occurring while participants concurrently listen to music and consume food.

2. Materials and methods

2.1. Ethics statement

Ethical approval was granted by the Auckland University of Technology Ethics Committee. Written consent was provided by participants prior to the commencement of data collection.

2.2. Participants

Ninety panellists (35 males, 55 females) aged between 21 and 52 years old ($M_{age} = 22.3$; $SD = 8.1$) participated in the study. Participants were recruited online through an advertisement posted on social media networks (i.e., Facebook and Instagram). Participants were excluded if they were smokers, or reported any hearing loss, eating disorders, or other health problems that may interfere with hearing or gustation. All data was collected between the hours of 11:00 am and 1:00 pm, and participants were directed not to eat two hours prior to the study.

Table 1
Frequencies of liked, neutral, and disliked music genres. Chi square analyses were carried out on the ratio of each genres for liked, neutral, and disliked music selection as carried out by [31].

Genre	Song	Artist	Liked	Neutral	Disliked
Classical	Für Elise	Alfred Brendel	3	3	10
Folk	Sigh No More	Mumford and Sons	8	10	11
Alternative	Narcissus	Alanis Morissette	9	10	5
Rock	Somebody That I Used To Know	Gotye Ft. Kimbra	9	7	5
Country	A Woman Like You	Lee Brice	6	7	4
Pop	Glad You Came	The Wanted	9	5	9
Soul	All of The Lights	Kanye West	5	3	1
Blues	I Got A Woman	Ray Charles	6	7	11
Jazz	La Vie En Rose	Louis Armstrong	4	5	3
Heavy Metal	Thunder Struck	AC/DC	9	6	11
Religious	Dream On	Larnelle Harris	9	6	10
Funk	Living in America	James Brown	6	8	4
Hip Hop	Can't Get Enough	Black Eyed Peas	5	6	3
Electronica	Wild One Two	Jack Back ft. David Guetta	2	7	3
p-value			0.59	0.631	0.46

2.3. Music liking

Fourteen music genres were selected in this study [64]. A 45-s segment of each genre was played. Our previous study showed that listening to music for 45 s was the optimum time for rating pleasantness intensity of ice cream [32]. As with Kantono et al. [32], music was played through a Sennheiser headset (Series HD 518: Sennheiser Electronics GmbH and Co. KG), and participants rated their liking of each genre (Table 1) using a 100 mm unstructured line scale anchored with *extremely dislike* and *extremely like* at each end of the scale. The least and highest liking scores were classed as disliked and liked music respectively. The piece of music with a rating closest to the mid-range liking score (i.e., 50 mm) was classed as the neutrally liked music. Hence the music set (liked, disliked, and neutrally liked music) used in this study accounted for individual variation in music preference as it was played for each individual as they consumed gelato.

2.4. Gelati preparation and presentation

The bittersweet gelato samples were produced using an ice cream maker (Cuisinart ICE-100). Gelato samples (10.0 ± 0.8 g) were placed in individual white plastic containers (45 mm diameter) and stored in a commercial-grade freezer (Fisher and Paykel, NZ) at −18 °C for at least 24 h prior to testing and tempered (−12 ± 2 °C) prior to serving. Samples were marked with a three digit random code, with presentation randomized and counterbalanced across panellists [6]. Participants consumed one mouthful (approx. ~10 g) of gelato in each experimental trial.

2.5. Temporal dominance of sensations

In this study, the Temporal Dominance of Sensation (TDS) method as described by [29] was used. For this study the intensity scales were replaced with buttons that corresponded to the presence of sensory attributes (e.g., sweet, bitter, cocoa, milky, creamy, vanilla, roasted). TDS data was subsequently binary coded across time (0 for an unselected attribute and 1 for selected attribute). If one button representing a single sensory attribute was selected, then the other buttons would become automatically deselected in order to adhere to the concept of dominance. The sensory attributes used in this study followed Kantono et al. [33], being sweetness, bitterness, cocoaness, milkiness, and creaminess, but with the addition of *vanilla* and *roasted* flavour attributes [24,43]. In addition, TDS-related best-practice was also implemented, this being: 1) short product evaluation time (between 20 and 40 s); 2) consistent order of attributes, and; 3) diverse range of sensory attributes [47].

This study also adopted the protocol reported by Jager et al. [29] to train participants without prior experience of the TDS procedure or sensory analysis generally. The training regime described by Kantono et al. [33] was used in the current study, where participants were exposed to both demonstration videos showing how TDS is carried out, as-well-as familiarisation with the TDS method through participation in dummy trials. During training the panel leader actively asks participants whether they understood the procedure and assists them when necessary. Fig. 1 presents the TDS assessment screen. All sensory data acquisition was done using FIZZ Acquisition 2.46b (Biosystemes, France).

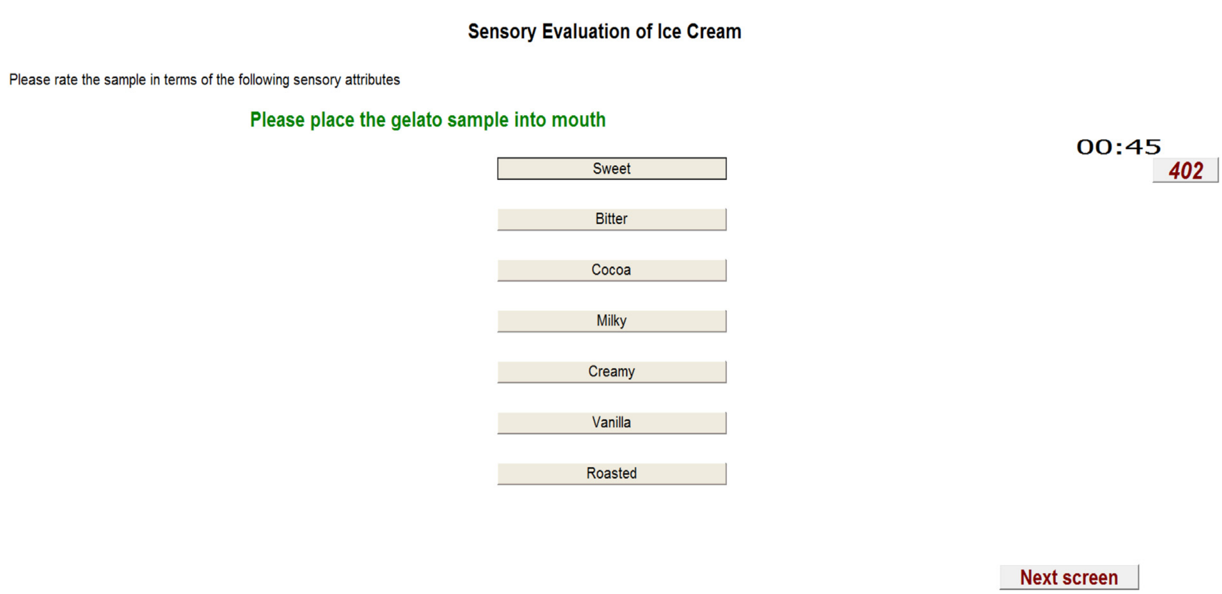

Fig. 1. Representation of the TDS screen.

Table 2
Emotion attributes, classification, and descriptions used in the current study.

Sensory attributes	Valence	Description
Anger	–	Annoyance, displeasure, hostility
Contempt	–	Feeling of negative-ness, mean, vile, dishonoured
Disappointment	–	Sadness due to lack of fulfilment of expectations
Amusement	+	Enjoyment from an entertainment, or surrounding context and environment
Disgust	+	Disapproval of something unpleasant and offensive
Happiness	+	Feeling of pleasure and contentment
Enjoyment	+	Positive pleasure of having something good
Love	+	Intense affection
Satisfaction	o	Peaceful, happiness, calm, feeling when an outcome is above expectations

The symbols '-', '+' and 'o' indicates negative, positive, and neutral valence respectively.

2.6. Emotional responses to music

Self-report emotional responses to music were measured according to Kantono et al. [34] using unstructured intensity line scales (100 mm) anchored by *none* and *extreme* at each end. Based on the work by [50], nine emotions were measured: *Amusement, Happiness, Enjoyment, Anger, Contempt, Disgust, Love, Disappointment,* and *Satisfaction* (see Table 2). These emotions were chosen to capture the feelings experienced by participants as they consumed food while listening to music. Definitions of these emotions were provided to the participants prior to testing, which only commenced when the panel leader was satisfied that the emotions were understood by all the participants. All emotional data acquisition was performed using FIZZ Acquisition 2.46b (Biosystemes, France).

2.7. Physiological measures

The physiological measures in this study were obtained using medical-grade hardware (NeXus 10) and software (Mind Media, Netherlands). Electrodes (gelled Ag/AgCl) were used to measure the participant's cardiac and skin conductance activity. The standard three-lead electrode configuration was used to obtain the electrocardiogram, while skin conductance response was measured from the 3rd and 4th digits (middle phalanx) of the non-dominant hand. Blood volume pulse signal was also recorded with Nexus-10-Blood Volume Pulse sensor attached the left index finger using a photoplethysmograph. In addition, respiration rate was recorded using a transducer belt that generated an electrical signal based on changes in tension.

Electrophysiological measurements started with a ten minute baseline during which participants were encouraged to sit in an upright and relaxed comfortable position, and were told not to move their non-dominant hand throughout the duration of the experiment. In the second phase of the trial, a headset (Series HD 518, Sennheiser Electronics GmbH and Co. KG) was provided and participants listened to their three individualised pieces of music that varied in liking. All music conditions were randomized and counter-balanced across participants and trials. In the third and final phase of the trial, participants consumed chocolate gelato (8.0 ± 0.4 g) either in silence or while listening to their three songs, each which lasted 45 s. This was chosen as phasic electrodermal measures in our laboratory typically peaks around 2–5 s with recovery occurring after 30 s. The rate of recovery is dependent upon the emotions hence an average of 45 s was calculated. All electrodermal signals were recorded at a data sampling rate of 32 data samples/s.

2.8. Experimental procedure

The measures in this study were obtained at three different stages during a single experimental session that typically lasted ninety minutes (Fig. 2). First, participants made subjective ratings of the 14 music genres using 100 mm line scales. Participants were instructed to play each music file and listened to the whole piece of music before rating the liking of each music genre. Participants then had a five minute break before proceeding with the next task.

Second, electrophysiological recordings were made with the participants at rest (i.e., the ten minute baseline), when consuming gelato in the silent condition, and when listening to 45 s of music with and without gelato consumption. Electrodes were attached to the appropriate sites (e.g. the three-lead electrode configuration for the electrocardiogram). Participants were instructed to relax while electrophysiology measurements were obtained for the ten minute baseline condition. Participants were then given a five minute break. Subsequently. ANS measurements were recorded when participants listened to liked, neutral and disliked music (this was unique for each participant with the order of music presentation counterbalanced). ANS measurements were also recorded when participants consumed gelato in the presence of music (45 s excerpts) varying in liking. Participants then had a five minute break before proceeding with the next task.

Third, TDS measurements and subjective emotional ratings were obtained. Participants were again provided with the food and music stimuli. A single TDS trial lasted for 45 s to measure the flavour dynamics of gelato. On-screen instructions were also provided in-order to minimise eating variation. Once participants were ready, they were then instructed to place the sample in their mouth and started TDS ratings. When participants pressed a TDS button the music started and on-screen instructions on how to consume the gelato samples was presented to the participants. Pertinently, the music was automatically

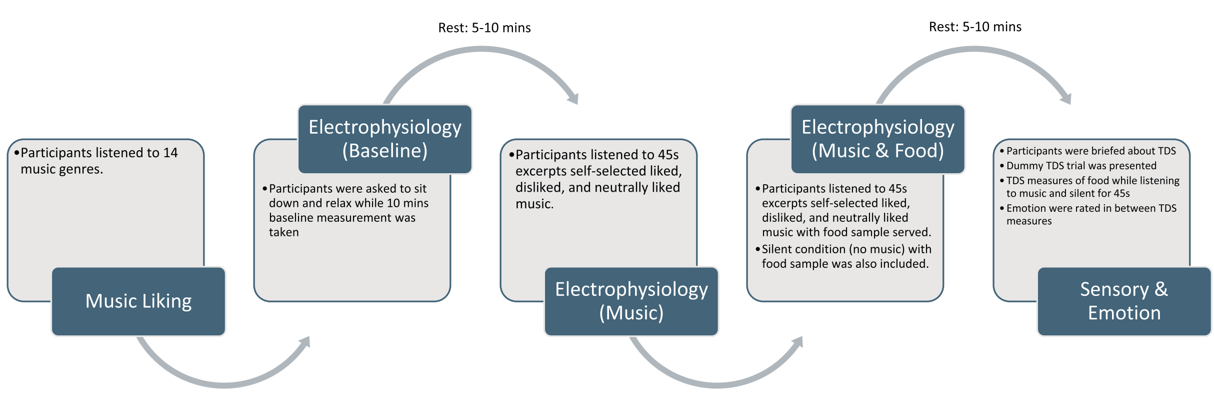

Fig. 2. Experimental protocol for the major experimental components in this study.

played when participants first clicked the TDS button on screen. After each TDS trial, participants subjectively rated their emotions using an intensity scale. Prior to moving from one stage of the study to the next, participants took a momentary 5–10 min break to prevent fatigue. Furthermore, 45 s punctuated the presentation of successive food samples within the final stage of the study.

2.9. Data analysis

2.9.1. TDS curves

The dominance rating of each attribute was plotted as a function of time using FIZZ's in-built spline-based smoothing algorithm [39]. Aggregation of TDS data was undertaken, followed by calculations of chance (P_0) and significance levels (P_s) [65].

$$P_0 = {}^{1}\!/_{p}$$

$$P_s = P_0 + 1.645\sqrt{\frac{P_0\,(1 - P_0)}{n}}$$

Where.

P_0: Chance level

p: Number of attributes

P_s: Significance level

n: Number of TDS observations (*number of subject x replication*)

TDS time was presented as standardized time [57], and data was converted to percentages (0% to 100%).

2.9.2. Canonical variate analysis

Canonical Variate Analysis (CVA) was carried out to explore differences between perceptions of samples while listening to different music using XLSTAT (Addinsoft, U.S.A). CVA was carried out on TDS sensory durations in this study as it can maximize the distances between products, while minimizing residual variability [66]. In addition, Hotelling-Lawley Multivariate Analysis of Variance (MANOVA) tests were carried out to determine significant differences (α = 0.05) between each product (i.e. different music). CVA has been used in numerous TDS-based studies due to its robustness in discriminating samples [2,29,47].

2.9.3. Emotional response to music

One-way repeated measures ANOVA (RM-ANOVA) was applied to explore significant differences (α = 0.05) in emotions elicited by music varying with liking. Tukey's multiple comparison tests were carried out for analyses that reached statistical significance. RM-ANOVA was carried out using XLSTAT (Addinsoft, U.S.A).

2.9.4. Electrophysiological measures

Average values of physiological parameters measured (i.e. RESP Rate, SC, BVP Amplitude, and HR) were extracted. The 10 min baseline was used as reference. The percentage change from the baseline was calculated according to the equation below:

$$\text{Percentage change (\%)} = \left({}^{(raw\ value\ -\ mean\ baseline\ value)}\!\Big/_{mean\ baseline\ value} \right) \times 100$$

Repeated measures ANOVA was applied to the modified data with music condition and participants taken into account as factors. Tukey *post-hoc* comparisons were applied when significance was encountered.

2.9.5. Partial least square regression (PLSR) and path modelling (PLS-PM)

PLSR was performed using PLS (Unscrambler, CAMO ASA, Oslo, Norway). PLSR analyses are widely used to illustrate relationships between two datasets, in this case sensory ratings and physiological measures. The contribution of each factor (sensory, physiological) to the overall regression model was then drawn using regression coefficients. TDS datasets was derived from the dominance durations of each attributes selected by the participants. This was done by adding all the time periods during which the attribute is perceived to be dominant regardless the moment of perception [23]. while the electrophysiological data was converted to the % change (*re*: baseline). This was done in order to be consistent with the previous analyses carried out in this study. PLS-PM was performed with the XLSTAT PLSPM module of the XLSTAT software (Addinsoft, U.S.A). PLS-PM is mainly used to construct cause-and-effect models. As used in this study, PLS-PM summarized the relationships between physiological measurements, and self-reported emotions, and sensory measurements. PLS-PM was used in this study as it: 1) generates latent models with non-normality, 2) is suitable for small to medium samples, and 3) is robust to multicollinearity. To assess whether the model was reliable, Goodness of Fit (GoF) statistics, Cronbach's α, and Dillon-Goldstein's rho were obtained for each manifest variable. Additionally, the R^2 value of the latent variable was also calculated. A value greater than $R^2 = 0.7$ for all three statistics indicates sufficient reliability [45].

3. Results

3.1. Emotion responses

Table 3 revealed that positive emotions (*enjoyment*, *happiness*, *love,* and *satisfaction*) were rated significantly higher while listening to liked music compared to the silent, neutral music, and disliked music conditions. Negative emotions such as *disappointment* and *disgust* were significantly higher under the disliked music condition compared to other conditions (silent, neutral, and liked music). High arousal negative emotions of *anger,* and *contempt*, and the positive emotion of *amusement* showed no significant differences.

3.2. Temporal dominance of sensations

Fig. 3 displayed the spline smoothed TDS curves for each music condition. The calculated chance and significance levels were found to be between 15% and 20% respectively. Attributes below 20% (*re*: significance level) will not be discussed further.

During the silent condition, sweetness was the first dominant attribute, subsequently decreasing from a maximum dominance rate of 47% between 0 and 10% standardized time (ST). Creaminess was observed with sweetness and increased between 15 and 19% ST, reaching a maximum dominance rate of 42% at 15% ST. Creaminess later decreased to 28% ST. Finally, bitterness was dominant from 57% ST until the end of the evaluation, reaching a maximum dominance rate of 36% at 87% ST.

Table 3
Self-rated emotions following the consumption of gelato while listening to music varying in liking.

	Music condition				
Emotions	Silent	Liked	Neutral	Disliked	*F*-value
Anger $^-$	6.43	10.12	6.53	8.49	2.0
Contempt $^-$	17.48	18.73	17.29	21.54	0.7
Disappointment	7.59^b	6.59^b	6.34^b	20.96^a	8.0$_*$
Disgust	9.54^b	8.51^b	8.32^b	49.79^a	40.2$_*$
Amusement $^-$	31.69	35.85	32.13	39.66	1.2
Enjoyment	20.57^d	67.29^a	59.54^b	42.32^c	10.4$_*$
Happiness	32.80^d	77.92^a	52.52^b	41.58^c	10.0$_*$
Love	31.43^d	57.18^a	49.02^b	41.80^c	10.8$_*$
Satisfaction	13.62^d	68.44^a	56.41^b	47.66^c	12.6$_*$

The superscripts [a,b,c,d] denote mean values of emotional ratings that are significantly different ($p < .05$) across music conditions for each emotion

* represents significance observed for the emotion terms across the four sound conditions.

Fig. 3. Panel dominance rates (%) of the seven sensory attributes presented in the TDS sessions expressed in standardized time (%). TDS curves are for the four music conditions: Silent condition (or reference) (a), neutral music condition (b), liked music condition (c), and disliked (d).

When a neutral song was played, cocoa exhibited a higher dominance rate and longer duration time from 0 to 40% ST, reaching a maximum dominance rate of 40% at 9% ST and 11% ST. Milkiness was significantly dominant between 22 and 48% ST, reaching 44% dominance rate at 32% ST. Finally, bitterness was dominant from 50 to 100% of ST, reaching a maximum rate of 36% on 100% ST.

For liked music, sweetness was the main dominant attribute selected by panellists. Indeed, a longer duration of sweetness was observed from 0 to 23% ST, then from 40 to 100% ST with a maximum dominance rate of 55% at 0% ST. Bitterness increased significantly at the late period of mastication (from 70 to 100% ST) reaching a maximum dominance rate of 40% at 92% ST.

Finally, in the disliked music condition, sweetness was perceived as a dominant attribute at several points of evaluation. It was significant between 0 and 28% ST, with a maximum dominance rate of 47% at 2% ST. It was again dominant between 42 and 80% ST. Creaminess was dominant between 5 and 20% ST reaching a dominance rate of 37% at 17% ST. Bitterness was significantly perceived by the panel from 60 to 100% ST, reaching a maximum dominance rate of 42% at 100% ST.

Fig. 4 shows a CVA plot of TDS sensory durations as a function of different music liking. 90% confidence ellipses indicate that the means differ significantly. The first two canonical variates explained 99.60% of the data. Hotelling-Lawley MANOVA analysis was significant for the sensory data indicating that significant differences exist between the three music and silent condition in terms of sensory attributes. Liked music was shown to evoke sweetness and milkiness, while disliked music evoked bitterness, creaminess, and vanilla. Neutral and silent music were associated with milkiness, roasted, and cocoaness.

3.3. Electrophysiological responses

One-way repeated measures ANOVA was significant for the effect of music on SC ($F_{(2,119)} = 141.291$, $p < .01$), BVP Amplitude ($F_{(2,119)} = 25{,}073.053$, $p < .01$), and HR ($F_{(2,119)} = 24.01$, $p < .01$) measures only (Fig. 5). No significance was observed for the RESP measures ($F_{(2,119)} = 0.018$, $p > .05$). In terms of cardiovascular measures, HR while listening to liked music was significantly higher than

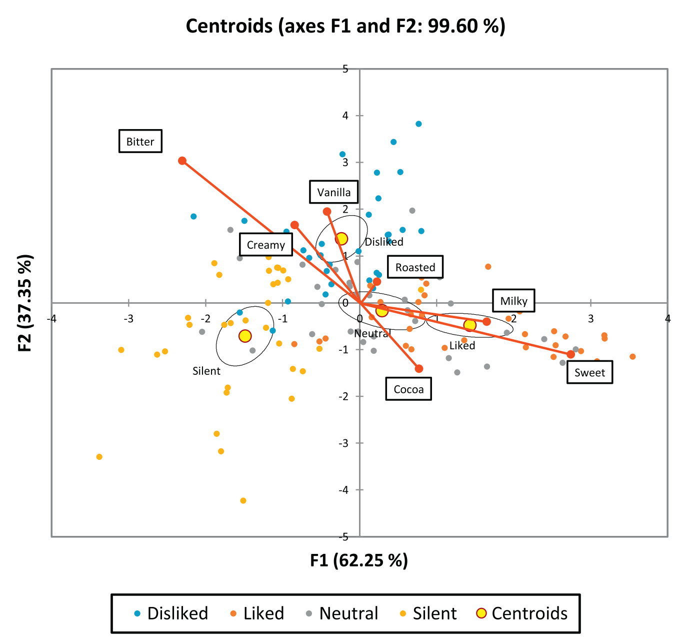

Fig. 4. Canonical Variate Analysis bi-plot of dominance durations of sensations. Hotelling-Lawley MANOVA test showed significant product differences ($F_{(21,240)} = 10.17$; $p < .05$) based on sensory attributes.

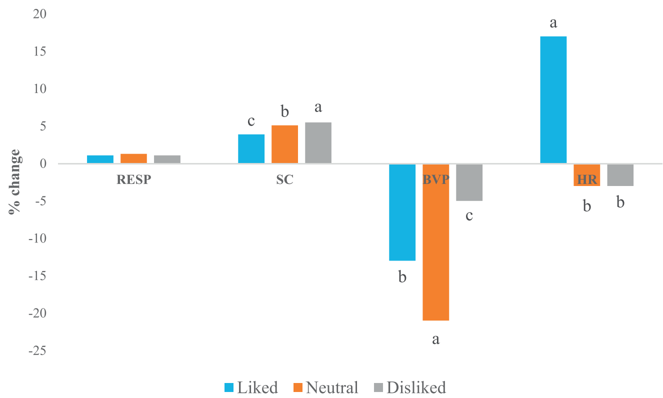

Fig. 5. Physiological measure values using Respiratory Rate (RESP), Skin conductance response (SC), Blood Volume Pulse (BVP), and Heart Rate (HR). Values were calculated based on the changes in baseline (silent condition) compared to three music conditions (liked, neutral, and disliked). [a,b,c,d] indicate changes in physiological measure readings with different superscripts indicating significance ($p < .05$).

the other three music conditions. BVP amplitude resulted in the highest changes while listening to neutral music, followed by liked, and disliked music. SC was the highest while listening to disliked music, followed by neutral, and liked music subsequently. However, RESP rate showed no significant relationships in this study.

3.4. Relationship between electrophysiology measures, perception, and emotional response

Fig. 6 illustrates the relationship between electrophysiological measures and perception using PLS regression coefficient values. In terms of sensory attributes, cardiovascular measures such as HR were

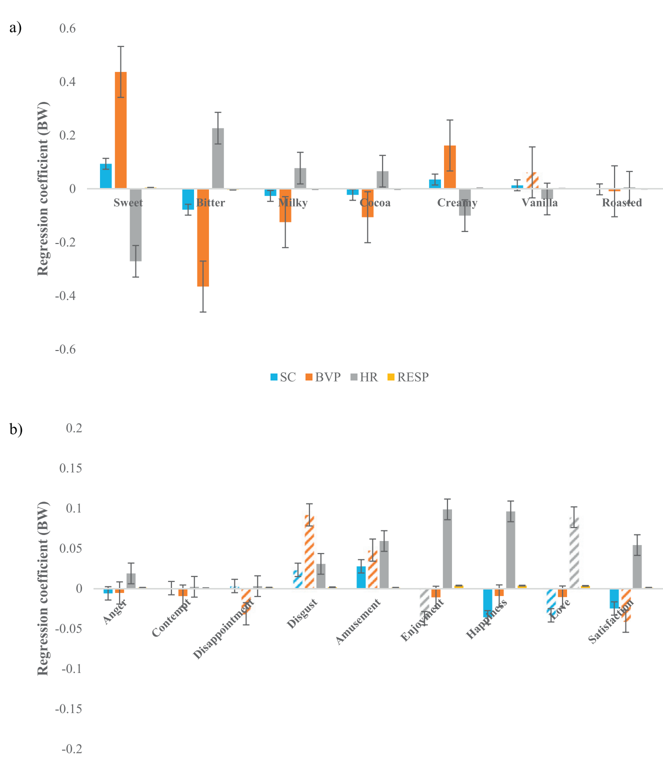

Fig. 6. Calculated regression coefficients using PLSR between: a) physiological measures and sensory measures, and b) physiological measures and emotional measures. Filled bars indicate significant regression coefficient (BW).

found to be positively associated with sweetness, and to a lesser extent with milkiness, and cocoaness sensations. In contrast, it was correlated negatively with bitterness and somewhat correlated with perceptions of vanilla and creaminess. Skin conductance (SC) and BVP responses were positively associated with bitterness and to some degree with creaminess and vanilla. These responses were negatively associated with sweetness and to some degree to milkiness and cocoaness sensations. Respiration (RESP) did not correlate to any sensory and emotional attributes.

Autonomic responses were found to correlate with positive emotions (*amusement, enjoyment, happiness, love, and satisfaction*) and one negative emotion (*disgust*). Particularly, HR showed a positive correlation with positive emotions (*amusement, enjoyment, happiness, love, and satisfaction*) and to a lesser degree to negative emotions (*anger, and disgust*). BVP amplitude exhibited a positive correlation with *disgust*, and *amusement*, and a negative correlation with *satisfaction* and *disappointment*. SC was shown to positively correlate with *disgust* and *amusement*, while having a negative correlation with *enjoyment*, *happiness*, *love*, and *satisfaction*.

3.5. Overall relationship between electrophysiological and emotion measures, and perception

PLS-PM was employed in this study to explain the relationships between physiological changes, subjective-rated emotion, and perceptions (see Fig. 7). Cronbach's α, Dillon-Goldstein's *rho*, and R^2 values of each variable was > 0.7, indicating overall reliability of the measured variables [45]. GoF measured value was similar to the GoF of bootstrapping model (GoF = 0.583). In this study the GoF can be considered as the geometric mean of the average communality and the average R^2 [67]. Fig. 7 shows that physiological measures such as SC, BVP amplitude, and HR could be linked to the subjective measures of emotions by participants. However, RESP rate showed a no significant correlations with self-rated emotions.

Negative emotions were positively correlated with SC and BVP amplitude, while negatively correlated with HR. Positive emotions were positively correlated with HR, and negatively correlated with SC and BVP amplitude. Negative emotions showed a significant positive correlation with bitterness and creaminess, and a negative correlation for sweetness. Positive emotions showed a significant positive correlation for sweetness and milkiness, while showing a negative correlation for bitterness.

4. Discussion

The results of the present study demonstrate that electrophysiological measures can covary sensory changes while listening to music. Pertinently, this study is the first to utilise electrophysiological measures to quantify emotional changes within the domain of cross-modal correspondence between music and flavours. Electrophysiological measures allow an alternative approach to measuring emotions, and unlike subjective ratings are not prone to the so-called *introspection illusion* [68]. This illusion, which may bias self-reported emotions to extremes on the measurement continuum, does not affect electrophysiology measures. As such, the findings of the current study offers evidence to support the findings by [31], who showed that ratings of positive of emotions were associated with sweetness perception, while ratings of negative emotions with bitterness perception.

4.1. Influence of music and food on electrophysiological measures

Further to the above electrophysiological findings, our estimates of Heart Rate (HR) obtained with liked music were the highest, followed by neutral, and then disliked music. Yanagihashi, Ohira, Kimura, and Fujiwara [62] demonstrated that listening to sounds varying in pleasantness affects heart rate variability, particularly the High-Frequency

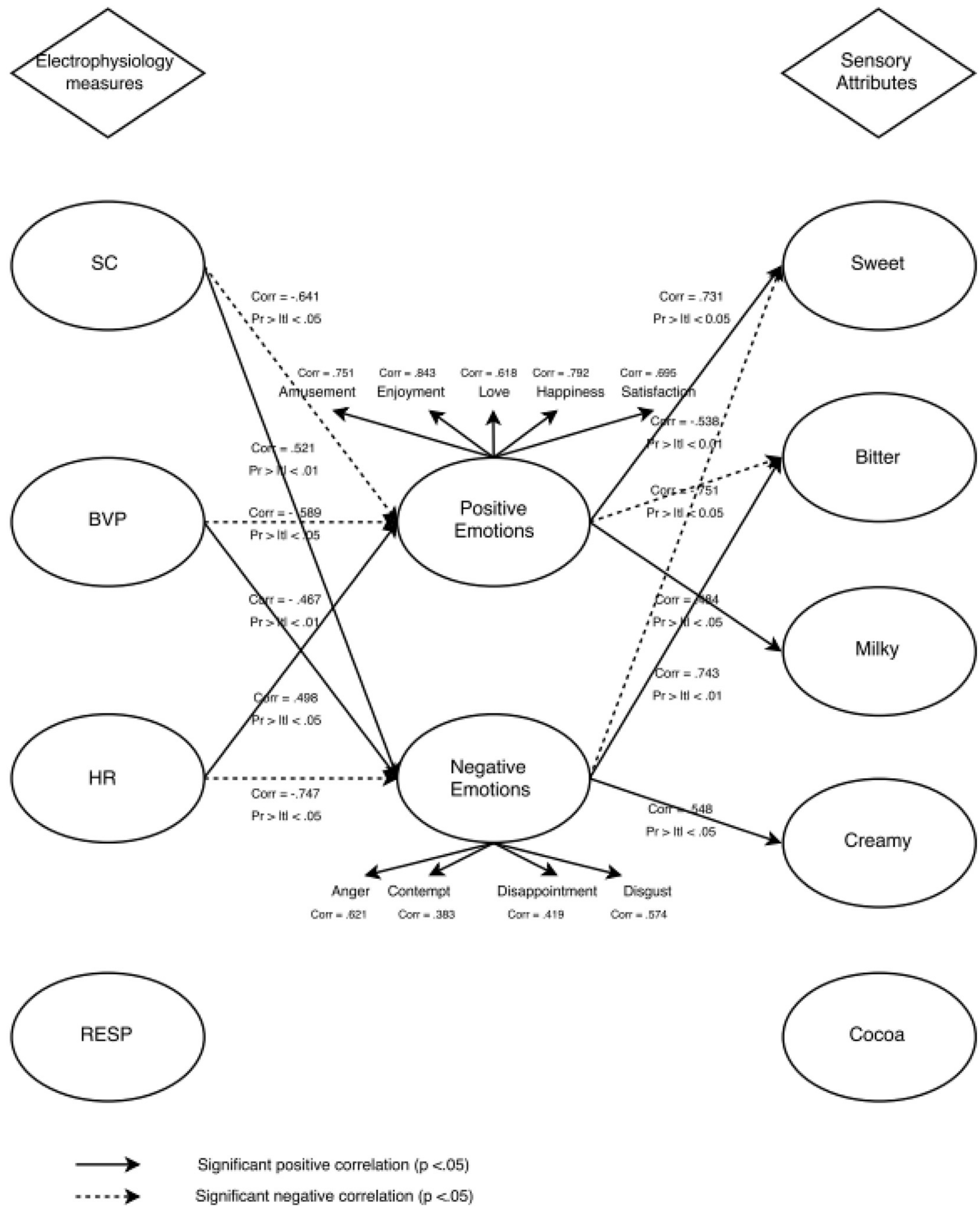

Fig. 7. PLS-PM showing the significant correlations between physiological measures, self-rated emotion measures, and perception. Significant correlations are indicated by the lines added. Absence of lines between the latent variables indicates no significant correlation.

(HF) component indexing parasympathetic dominance. Listening to unpleasant mechanical sounds had the lowest HF value, significantly lower than pleasant bird twitters or music synthesizer sounds. The authors proposed that listening to mechanical sounds inhibited the parasympathetic nervous system and amplified unpleasant feelings of hypervigilance. Higher heart rate is associated with lower heart rate variability, and so in relation to the current study, participants listening to liked music were more highly aroused, possibly as they selectively attended to the music.

In our study, Blood Volume Pulse (BVP) amplitude was influenced the most while listening to neutral music, followed by liked and disliked music. Participants in Salimpoor et al. [52] study were provided with a limited range of music genres and self-selected their most liked (high pleasure), most disliked (low pleasure), and neutral genres. They found that BVP amplitude for neutral music was the highest, followed by small changes of low pleasure and high pleasure music. Based on converging evidence from other electrophysiological indicators (i.e. HR), they explained that these changes were due to emotional arousal. Speculatively, neutral music may be filtered out during early cognitive processing, allowing participants to focus on events and objects that are more arousing.

Skin conductance response (SCR) was the highest while listening to disliked music, followed by neutral, and liked music (Fig. 5). Skin conductance activity reflects sweat gland activity, which in turn is mediated exclusively by the sympathetic nervous system. These results are consistent with Krumhansl [37] who investigated the correlation between emotions induced by music and SCR. In his study, two musical excerpts that elicited feelings of *sadness*, *fear*, and *happiness* were selected, with the most changes in SCR occurring while listening to *sad* music. As sadness is not generally considered a desirable emotional state, it can be argued that sad music is typically disliked music, and the sympathetic activity noted by Krumhansl [37] can be considered consistent with our own findings.

When investigating emotional responses to musical excerpts, Etzel et al. [22] demonstrated that increases in respiration rate were associated with positive emotions (*happiness*), while decreases were linked to negative emotions (*fear and sadness*). Their results differ from the findings we report, as we found no differences in respiration rate. A possible explanation for this might be that in their study the researchers had pre-selected the musical excerpts to evoke a specific singular emotion (i.e. *happiness*, *fear*, or *sadness*). Participants in our current study listened to three music pieces varying in liking which were self-selected, and as such music may not have differed across all emotional dimensions. In our study the individualised music will carry personal meaning and some degree of familiarity to the participant, which in turn may influence the emotions evoked by the music [5]. In addition, our study showed that the emotions evoked by the individualised music pieces were multifactorial in nature (*re*: Table 3). For example, listening to liked music does not only evoke high valence/high arousal emotions (e.g., *happiness*), but also high valence/low arousal emotions (e.g., *enjoyment*). Hence, the emotions evoked by the self-selected music used in this study may not differentiate across the arousal dimension, and this may explain the lack of significance in our respiration measure. Pertinently, respiration measures have been identified as an indicator of the parasympathetic nervous system activity [49], which can be linked to the sedative/relaxing effects of music [28].

We found that sweetness was positively correlated with SC and BVP amplitude, but negatively associated with HR. In contrast, an inverse relationship was observed between these measures and bitterness. In Rousmans et al. [51] study, participants were provided with sweet, salty, sour and bitter solutions while both cardiovascular and SC responses were obtained. Their results demonstrated that sweetness was correlated to weaker sympathetic response, while bitter tastes induced a more arousing sympathetic response. According to the authors, a possible explanation for this might be due to evolutionary factors, where sweetness is innately accepted and bitterness is distinctively rejected [54,55]. Their results were in agreement to ours, where sweetness ratings correlated with the activation of parasympathetic response which corresponds to low arousal, while bitterness was correlated with the activation of sympathetic response which corresponds to high arousal.

In our study, milkiness and cocoaness were negatively correlated with SC and BVP amplitude. A significant negative correlation between SC and food liking was demonstrated by Danner et al. [15], and a significant positive correlation between HR and food liking has also been reported [16]. Interestingly, in our study creaminess was shown to correlate positively with SC and BVP amplitude, and negatively with HR. It has been reported that an increase in SC has been associated with negative emotions of *fear* [37], and *displeasure* [52], while increase in BVP amplitude and a decrease in HR were associated with the activation of parasympathetic ANS [42]. Our indirect ANS responses show that negative emotions were likely evoked. Platte et al. [48] reported that participants who were induced into negative states provided higher creaminess ratings in milk fat dairy solutions.

Concurring with the literature, our findings suggest that liked and disliked music evoked positive and negative emotions respectively (Table 3). Music has been widely used in psychology as an affect modulator, evoking positive emotions [21], and negative emotions (*bad feeling*, and *unpleasantness*), both of which influenced consumers' attitudes towards a product [4]. Brown et al. [7] reported that listening to liked music activated the nucleus accumbens, orbitofrontal cortex, and ventromedial prefrontal cortex, all linked in the processing of positive emotions. Pereira et al. [46] showed no evidence of brain activations related to affective or cognitive processing. Interestingly, we found that emotions associated with high levels of arousal (e.g., *anger*, *contempt*, and *amusement*) were equally intense during consumption of gelato while listening to disliked music.

4.2. Influence of music on temporal flavour perception

In the silent (reference) condition, bittersweet chocolate gelato was initially perceived to be sweet and creamy but turned bitter at the end of the mastication period. The TDS profile in our study for this silent condition was similar to the changes in the chocolate dairy dessert sensory profile described by Morais et al. [69], where the dominant attributes of sweetness and creaminess evolved in the early mastication period, while bitterness evolved at the end of mastication. The effect of listening to liked music on the TDS profile resulted in a longer dominance of sweetness and a reduced dominance of bitterness. In contrast, listening to disliked music produced resulted in longer dominance in bitterness and shorter dominance in sweetness. Similarly, [31] established that music influenced the TDS profile of bittersweet chocolate gelati.

Neutral music was found to increase temporal changes in dominance of cocoaness, and milkiness. [32] reported that listening to neutral music increased the pleasantness of chocolate gelati In their study, they speculated that the neutral music may have been unattended or phased out of awareness, thus increasing the cognitive capacity for food evaluation [41]. Hence, panellists were able to free-up cognitive resources to focus directly upon the cocoaness and milkiness attributes of gelato. Disliked music evoked creaminess in the early mastication period and prolonged the dominance of bitterness. In this case, listening to disliked music evoked negative emotions that might have acted as a mild stressor. Torres and Nowson [56] reported that consumers exposed to stressful situations may crave high-fat food, explaining the increase in creaminess perception noted in our study, which is linked with fat perception in ice cream [25].

4.3. Relationships between electrophysiology, emotion, and perception

In our study, negative emotions were positively associated with SC and BVP amplitude. Salimpoor et al. [52] found that an BVP amplitude is negatively correlated with feelings of pleasure. Increase in BVP measures can be due to the overall increase in autonomic sympathetic activation [44]. In our study, the fact that SC ratings increased when listening to music that evoked negative emotions is as expected. This can be explained by the effect of arousal on top-down cognitive processes [35], by which music activates the sympathetic nervous system [14]. On the other hand, negative emotions were found to be negatively associated with HR. Marci et al. [42] showed that negative emotions (*sadness*) evoked using 'emotion scripts' were associated with decreases in HR. They explained that negative emotions (e.g., *anger*, *disgust*, *fear*, and *sadness*) generated high levels of arousal, which is known to correlate with increases in sympathetic activity and decreases in parasympathetic activity [12].

Positive mood states have been shown to decrease taste thresholds (Heath et al. [27]. In their study, serotonin was used to induce positive mood states in participants and was associated with lower sugar thresholds. Negative emotions positively correlated with perceptions of bitterness, while positive emotions positively correlated with sweetness. Using music to evoke emotions, [31] also showed a positive association between positive emotions (*satisfaction*, *happiness*, and *amusement*) and perceived sweetness of gelato, and between negative emotions (*contempt*, *disappointment*, and *disgust*) and bitterness. A related study by Jager et al. [29] with different chocolates (mint, fruit, and dark chocolate) demonstrated that negative emotions (*bored*, *aggressive*, and *guilty*) were associated with dryness and bitterness of dark chocolate. Fruity chocolates on the other hand were associated with positive emotions such as *happiness*, *loving*, and *interested,* as-well-as the perception of sweetness.

Interestingly, positive emotions also correlated significantly with milkiness, while negative emotions were associated with creaminess.

Studies have demonstrated that positive emotions evoked by neutral/ liked music increase the perception of milkiness in food. In ice cream, creaminess is related to fat content [25]. Torres and Nowson [56] demonstrated that consumers are inclined to consume food higher in fat under stressful conditions. Using sad and uplifting movies, Platte et al. [48] further showed that negatively induced emotions increased fat ratings of milk-cream mixes compared to a positively induced emotions. Our study framework adapted the Mehrabian-Russel (M-R) model, where it expands the idea of how environmental stimuli may affect affective states (valence, arousal, and dominance), which then promote the approach/avoidance behaviour [50]. This study explored how the valence dimension (i.e. liked/disliked music) can affect mood that in turn influences perception. However, other affective dimensions such as arousal can influence consumer consumption behaviour. For example, a study [3] demonstrated that positive arousal showed positive association with pleasure and satisfaction in a theme park experience. Therefore, future studies should also include other affect dimensions (e.g. arousal, dominance) in creating such framework.

5. Conclusion

We measured music-induced emotions both subjectively (i.e., self-report) and objectively (i.e., electrophysiologically). Findings from this study showed that an affective (or 'emotion') mechanism may mediate the relationship between music valence and the perception of food. Our study also demonstrated the use of electrophysiology to augment subjective measurements of emotion in order to explain the temporal changes in perceptions of chocolate gelato while listening to music varying in valence. Arousal and dominance should be measured as the part of the affective response to stimuli to further elucidate the influence of affect upon crossmodal interactions. In addition, the psychoacoustical attributes of music (i.e. pitch, tempo, roughness) should also be measured, as previous studies have demonstrated specific influence of these attributes on food perception. Finally, measures of brain activity (i.e. electroencephalography, fMRI) could be utilised to further understand the changes in the brain's reward system linked to emotion, and to observe the correlational effect towards flavour perception while listening to music in the context of food consumption.

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