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Harmonising flavours: How arousing music and sound influence food perception and emotional responses

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ABSTRACT

This study aims to provide a novel understanding of how music and sound varying in arousal can affect temporal changes in food perception and the corresponding emotional responses, measured through both subjective and objective (i.e., electrophysiological) methods. Exciting conditions are associated with low valence and high arousal, whereas calm conditions are associated with high valence and low arousal. Calm music (CM), calm sound (CS), and a combination of calm music and sound (CMCS) evoked emotions such as joy, relaxation, calmness, pleasantness, and at ease, and were correlated with the perception of sweetness and creaminess. Conversely, exciting music (EM) increased arousal, evoked emotions such as, activity, enthusiasm, energy, and excitement, and amplified the perception of roasted and bitter flavours. Exciting sounds (ES) and combined exciting music and exciting sound (EMES) conditions were positively correlated with anxiety, fatigue, unease, unhappiness, difficulty concentrating, irritation, and restlessness, as well as enhancing the perception of roasted and bitter flavours. Furthermore, the EM and EMES conditions gave rise to significantly higher skin conductance and respiration rate, with corresponding correlations with the perception of roasted and bitter flavours. The ES and EMES conditions demonstrated significantly higher heart rate and respiration rate. The CM condition showed significantly higher heart rate and emotional responses while the CS condition showed significantly higher skin conductance. The findings of this study indicate that sensory attributes are closely associated with the emotions and physiological responses evoked when consuming ice cream under different music and sound conditions.

1. Introduction

Understanding the complex interplay between valence, arousal, and dominance in affective responses is crucial, as they shape our emotional experiences. The impact of environmental stimuli on emotional responses and consumer behaviours is a critical area of research that integrates findings from environmental psychology and cognitive science. Mehrabian and Russell (1974) developed the Stimulus-Organism-Response (SOR) model that examines how environmental stimuli (S) influence behavioural responses. It suggests that people's internal evaluations (O) of different cues in the environment lead to either approach or avoidance behaviours. The emotional dimensions of pleasure, arousal, and dominance play a role in mediating approach-avoidance behaviours. Valence refers to the pleasant or unpleasant reaction to a stimulus, arousal represents the level of affective activation, and dominance reflects the degree of control over the emotional state. Arousal serves as a measure of the emotions evoked, ranging from calm to excited (Warriner et al., 2013).

Music tempo and acoustic manipulations can influence arousal. McConnell and Shore (2011) found that participants reported significantly higher arousal when listening to fast-tempo Mozart Sonata music compared to slow-tempo music. Similarly, Blumstein et al. (2012) observed that arousal significantly increased, and valence significantly decreased, after participants listened to music containing noise or upward/downward pitch shifts as compared to a control condition. Tempo-induced arousal can influence various aspects of cognitive performance. Chebat et al. (2001) found that slow tempo background music, which has low arousal, significantly increased cognitive

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indicators. Day et al. (2009) demonstrated that fast music tempo, which is high in arousal, enhanced decision-making accuracy. Carr and Rickard (2016) reported that emotionally arousing music enhanced memory recall, while Asutay and Västfjäll (2017) found that higher auditory-induced arousal improved visual attention. However, to date no studies have investigated the effects of music and sounds varying in arousal on sensory perception of foods.

The interaction between auditory stimuli and flavour perception has been the focus of recent research. The concept of sensory dominance, as described by Spence and Shankar (2010) and further elaborated by Spence (2015), emphasises that certain senses can exert more influence over our overall sensory experience than others. Spence et al. (2019) further reported the phenomenon of "sensation transference," that may explain the impact of auditory cues on how individuals perceive flavour. These auditory stimuli, including music and environmental sounds, have been found to significantly affect the perception of flavour and the pleasantness of chocolate ice cream (Kantono et al., 2018, 2019; Kantono et al., 2016; Lin et al., 2019, 2022a; Xu et al., 2019). This highlights the substantial contribution of auditory stimuli in shaping consumers' perception of taste and flavour.

The impact of auditory stimuli on physiological and psychological responses has been investigated to better understand how sound influences our food perceptions and behaviours. Spence and Shankar (2010) attempted to explain the mechanisms through which auditory stimuli influence food perceptions and behaviours. Physiological measurements such as heart rate, skin conductance, and respiration rate, provide objective data on the body's reaction to sensory stimuli. Sounds eliciting varying levels of arousal have been found to influence physiological responses. Bradley and Lang (2000) discovered that highly arousing unpleasant sounds led to a significant decrease in heart rate compared to highly arousing pleasant and neutral sounds. Carr and Rickard (2016) found higher skin conductance levels in emotionally arousing music with high valence and arousal. Other studies examined the effects of unfamiliar relaxing and arousing classical music on physiological indicators (Kuan et al., 2017, 2018). The authors observed decreases in skin conductance for relaxing music compared to arousing music during sport imagery sessions. Yamamoto et al. (2007) further found that listening to music after engaging in high- or low-arousal stressful tasks led to reductions in heart rate, skin conductance, and respiratory rate.

The influence of music and sounds on food perception, and physiological and psychological responses has also been examined. Several theoretical perspectives have been formulated to explain the interplay between physiological measures, self-report measures of emotions, and sensory ratings (Barker et al., 2021; Gunaratne, Fuentes et al., 2019; Kantono et al., 2016a, 2016b; Lin et al., 2019; Xu et al., 2019b; Tanz and McClintock, 2017). At the core of these theories is the suggestion that the brain integrates sensory inputs from various sensory modalities, and that the auditory modality can influence the overall sensory experience of eating by interacting with visual, olfactory, gustatory processes, and with cognitive factors such as the memories and past associations evoked by soundscapes. Kantono et al. (2019) found that listening to liked music while consuming chocolate ice cream increased heart rate and positively correlated with enhanced perceptions of sweetness and milkiness. Conversely, disliked music correlated with increased skin conductance levels and intensified perceptions of bitterness, creaminess, and vanilla. In addition, Xu et al. (2019) investigated café soundscapes and found that a machine soundscape induced negative emotions and heightened physiological responses, while a forest soundscape elicited positive emotions and enhanced sweetness perception. These studies highlight the impact of music on emotional responses and sensory perceptions while consuming chocolate ice cream, emphasizing the crucial role played by valence. Nevertheless, the role of arousal has been overlooked in these investigations.

Studies have shown that music and sounds varying in valence can regulate positive and negative emotions which, in turn, influence the multisensory perceptions of chocolate ice cream (Kantono et al., 2018, 2019; Kantono et al., 2016; Lin et al., 2022a; Xu et al., 2019b). The Temporal Check-All-That-Apply (TCATA) method developed by Castura et al. (2016) provides detailed profiles of how various sensory attributes are perceived over time. TCATA has been used to examine how environmental sounds and music influence the multisensory perception of gelato and chocolate gelati, demonstrating its versatility in capturing dynamic sensory experiences across different contexts (Kantono et al., 2018; Lin et al., 2019). Emotional measurements, such as self-reports and psychophysiological indices, capture the affective impact of auditory stimuli. The Check-All-That-Apply (CATA) method is suitable to evaluate emotional responses in sensory studies, such as music or sound and food perception. This method has been used to examine emotional responses to musical and non-musical sounds (Lin et al., 2022a), and sound pleasantness (Lin et al., 2022b) while consuming ice cream. The novelty of the current study lies in its investigation of how a combination of musical and non-musical sounds varying in arousal can influence temporal changes in food perception. This is a unique approach that considers the emotional and physiological responses evoked by these sounds as we often hear music and sound together in real life. Therefore, this study aims to examine how music and sounds varying in the arousal they induce can alter perceptions of chocolate ice cream using TCATA and emotions, the latter measured both subjectively using CATA and with electrophysiological methods. The hypothesis is that music and sounds varying in arousal will change the flavour perception of chocolate ice cream, and that this relationship is mediated by changes in emotion.

2. Material and methods

2.1. Ethics statement

Ethical approval by the Auckland University of Technology Ethics Committee (AUTEC 17/202) was obtained for this study. Participants were provided with informed consent forms prior to the commencement of the study and were rewarded with supermarket vouchers for their participation in the experiment.

2.2. Participants

Participants were recruited online through advertisements posted on social networking services like Facebook (Cambridge, MA, Meta Platforms, Inc.) and Instagram (San Francisco, Meta Platforms). None of the participants was a smoker, and none reported hearing loss or allergies to chocolate ice cream. Sixty-nine participants (32 males, 37 females) aged between 20 and 40 years old were recruited (Mean age = 27.64 years; SD = 4.50 years). The number of participants was determined using a Cohen's d value of 0.8, giving a statistical power of 0.90–0.95 (Kenny, 1987). The sensory testing of chocolate ice cream was conducted at the Auckland University of Technology sensory laboratory. The laboratory is equipped with controlled lighting, temperature, and noise levels, creating an optimal environment for sensory evaluation. Each panellist participated in the testing within an individual booth, ensuring privacy and focus during the evaluation process.

2.3. Experiment procedure

The experimental protocol in this study consisted of four sessions, as illustrated in Fig. 1. Sessions 1, 2, and 4 were carried out on separate days, lasting 40 min, 1 h, and 40 min, respectively. Session 3 spanned over two days, with approximately 1–1.5 h on each day. In the first session, the participants were instructed to listen to musical excerpts from different genres in a random order. Each genre was played for a duration of 45 s, during which time the participants were required to rate the level of arousal they experienced. Following each genre, there was a 15-s break before the next excerpt began. After the music segment,

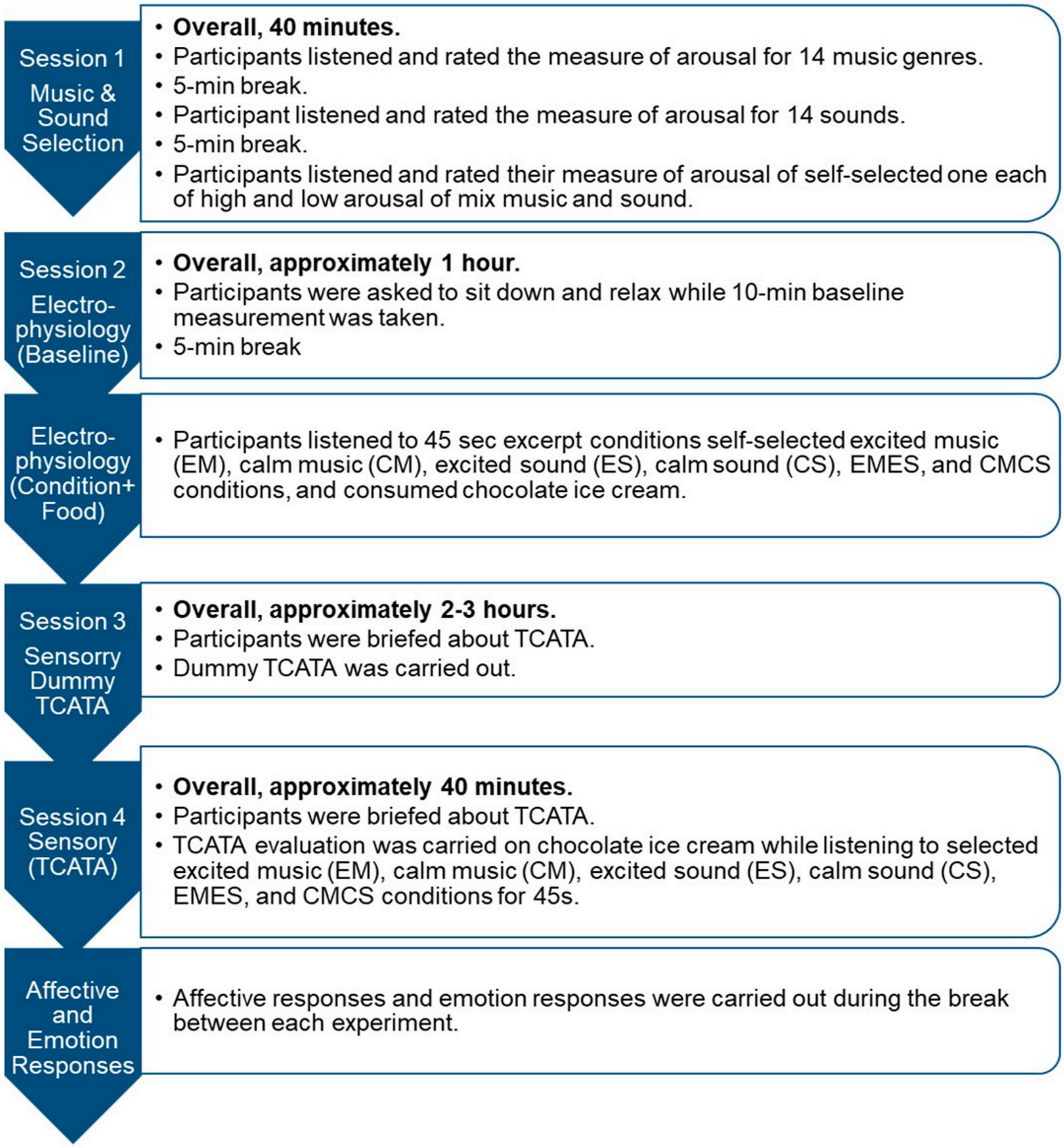


Fig. 1. The experimental protocol in this study comprised four sessions. Each session was carried out on a different day except for session 3, which was carried out over two days.

the participants were advised to take a 5-min interval before rating 14 different sounds. The participants were instructed to listen to the 14 sounds in a random order, with each sound playing for 45 s. After listening to each sound, they were asked to rate the level of arousal they experienced. A 15-s interval was given between each sound. Following the selection of the most exciting music (EM), the most calming music (CM), the most exciting sound (ES), and the most calming sound (CS) for each participant, combinations of the most exciting music and most exciting sound (EMES) and the most calming music and most calming sound (CMCS) were created for each participant. Participants were then instructed to listen to their own EMES and CMCS and rate their level of arousal. Ice cream was not consumed by the participants throughout this session.

In the second session of the study, participants were given an explanation of electrophysiological measures and were equipped with sensors to measure skin conductance (SC), heart rate (HR), and blood volume pulse (BVP). They were then asked to relax for 10 min while their electrophysiological responses were recorded. After a 5-min break, participants listened to 45-s self-selected music and/or sounds while consuming chocolate ice cream, prepared according to the method described in Appendix A.8. The participants experienced a total of six music and sound conditions (EM, CM, ES, CS, EMES, and CMCS) while consuming ice cream. Each auditory stimulus played for 45 s, followed by a 120-s break before the next stimulus. Participants were instructed to assess their level of arousal after experiencing each condition. The conditions were randomly assigned.

During the third session, a TCATA dummy trial was conducted over 2 days, with each day lasting approximately 1–1.5 h. This trial was aimed at familiarising the participants with the TCATA method and ensuring their understanding of the sensory evaluation process. This was designed to help reduce the likelihood of misinterpretation during the actual evaluations, leading to more accurate and consistent data. Participants were given a detailed explanation of the TCATA approach for evaluating sensory attributes. They evaluated the ice cream in terms of its sweetness, bitterness, creaminess, milkiness, cocoa flavour, vanilla, and roasted notes while listening to a specific music condition.

In the final session, the participants conducted TCATA evaluation of the chocolate ice cream. Each participant evaluated the sensory attributes while consuming chocolate ice cream over a 45-s period under the different auditory conditions (EM, CM, ES, CS, EMES, and CMCS). The order of auditory conditions was randomised. During a 60-s break period, the participants were directed to rate their affective responses (valence, arousal, and dominance) using an unstructured line scale. They were also asked to select the emotions they experienced using the check-all-that-apply (CATA) approach.

2.4. Rating of music and sounds in terms of arousal

We conducted a preliminary study using an online questionnaire platform (Qualtrics) that featured music spanning various genres and a range of sounds. A total of 242 participants (111 males and 131 females) aged between 20 and 40 years took part in the study. Each participant was required to evaluate their level of arousal on a 100-mm line scale after listening to each auditory stimulus played for 45 s. The scale allowed participants to rate their arousal level from "extremely calm" on the left to "extremely excited" on the right. During the preliminary study, we incorporated 14 music genres, including classical, folk, alternative, rock, country, pop, soul, blues, jazz, heavy metal, religious, funk, hip hop, and electronica. For each genre, three music selections were presented, resulting in a total of 42 musical pieces that participants assessed in terms of their arousal levels. Additionally, participants were exposed to a total of 42 sounds, comprised of 21 calm sounds and 21 excited sounds, and asked to rate them based on their arousal levels. From these evaluations, the seven music and sound pieces with the highest and lowest arousal scores were chosen as stimuli for the subsequent experiment.

In the evaluation phase, 69 participants rated the arousal level of fourteen different music genres (Rentfrow and Gosling, 2003) using a 45 s segment of each genre as shown in Appendix A.1. Music for each genre was categorised according to the Apple iTune's music classification system. Fourteen soundscapes that best represented excited and calm sounds (refer to Appendix A.2.) were selected from Soundsnap (https://www.soundsnap.com/, accessed on April 28, 2019) and downloaded from SoundCloud (https://soundcloud.com/). Participants rated the arousal of both music and sounds using a 100 mm unstructured line scale anchored with 'extremely calm and 'extremely excited at each end of the scale. The highest arousal scores were used to classify exciting music (EM) and exciting sound (ES), while the low arousal scores were used to classify calm music (CM) and calm sound (CS). To account for individual differences in music and sound preferences, unique mixtures of excited music and sound (EMES) and calm music and sound (CMCS) for each participant were produced (refer to appendix A.1 and A.2). During the experiment, each audio file for music, sound, or a mixture of both was played to each participant through a pair of Sennheiser Series HD 518 headphones (Sennheiser Electronics GmbH and Co. KG, Wademark, Germany), driven by a standard PC sound card. The order in which the various auditory stimuli were delivered was randomized and counterbalanced to minimize any order effects. All soundscapes were high pass filtered using Adobe Audition CC version 11.1.1.3 (Adobe, California, USA) to ensure balanced audio pressure levels across all samples. The Root Mean Square amplitudes of the audio samples were standardized to an internal reference and scaled to 70 dB of sound pressure level (SPL), using a Brüel and Kjær sound meter (Brüel & Kjær, Nærum, Denmark).

In this study, a silent control condition was not used as it may not be preferable or achievable in urban and suburban environments where the participants were likely to have been recruited from (Shepherd et al., 2024). Given that the research likely involved participants from such settings, it would have been impractical to implement a true silent condition. Furthermore, studies have suggested that silence might induce negative thoughts and increase cognitive arousal, potentially affecting the participants' stress levels and emotional regulation (Lui and Grunberg, 2017; Shepherd et al., 2023). Instead, the researchers opted to explore the effects of music and other sound conditions as potential alternatives for stress reduction and emotional regulation.

2.5. Temporal check-all-that-apply (TCATA)

The effects of music and/or sound on the temporal aspects of multisensory flavour perception of chocolate ice cream was investigated, using the temporal check-all-that-apply (TCATA) method (Castura et al., 2016). This dynamic method extends the Check-All-That-Apply (CATA) method, which involves the selection and deselection of attributes, by allowing participants to determine the temporal changes in sensory perception of products. The method has been widely used with consumers because it provides a detailed characterisation of the dynamic sensory characteristics of products throughout consumption (Ares et al., 2015).

The TCATA procedure used in this study was adapted from the protocol reported by Boinbaser et al. (2015). In accordance with Kantono et al. (2018) and Lin et al. (2019), the modification involved the use of buttons corresponding to the sensory attributes used in this study. The TCATA data was coded as binary values over time, with 0 indicating unchecked attributes and 1 indicating checked attributes. The participants continuously updated the attributes of the sample throughout the session by checking the attributes at times when applicable and unchecking them when not applicable.

The sensory attributes of the ice cream being measured in the study were sweet, bitter, cocoa, creamy, milky, roasted, and vanilla. A summary of the description and reference standards for these attributes is provided in Appendix A.3 (Kantono et al., 2018, 2019; Lin et al., 2019, 2022a; Xu et al., 2019; Xu et al., 2019). Each TCATA session lasted 45 s, which coincided with the participants listening to the different music and/or sound conditions. A mandatory 45 s silent break was given between each auditory condition that the participants were exposed to.

2.5.1. Panel familiarisation and evaluation of samples using TCATA

The TCATA method was introduced to participants during a familiarisation session. The seven attributes in Appendix A.3 were presented to participants on computers using the FIZZ sensory data acquisition software (FIZZ Network v2.46b, Biosystemes). Attributes were presented in a column on the screen, and the attribute order was kept consistent for each participant throughout the product evaluations (Meyners and Castura, 2016). Prior to the actual evaluation, participants practiced the TCATA evaluation protocol using chocolate ice cream.

Individual servings of ice cream (5.00 ± 0.80 g) were provided in 25 mL plastic portion cup labelled with a unique three-digit random number. Upon placing the first scoop or bite of ice cream in their mouth ($t = 0$ s), participants clicked the start button and began selecting or deselecting the attributes on the screen. At 20 s, participants were prompted to swallow the sample. They continued to select the relevant attributes until the end of the 45 s epoch.

After the familiarisation session, participants evaluated chocolate ice cream (-12 ± 2 °C) under the different music and sound conditions in a 2-h session, following the previously described protocol. Participants were given a practice sample immediately prior to data collection to eliminate potential first order effects. Participants were given a forced 5-min break between each condition and instructed to cleanse their palate with filtered water to minimize carryover effects. All product evaluations were conducted in sensory booths at 21 ± 1 °C under white light condition. The participants were provided with the attribute definitions in Appendix A.3 at the beginning of their evaluation session and had the opportunity to ask any questions and seek clarification on the attribute definitions before proceeding with the actual product evaluations.

2.6. Emotional responses

In this study, the emotions aligned with the Valence-Arousal-Dominance (VAD) model, as introduced by Russell and Mehrabian (1977), were used. The authors stated that emotions in this model can be represented in terms of three fundamental dimensions: valence that expresses the pleasantness or unpleasantness of a feeling, arousal that describes the level of affective activation, and dominance that reflects the level of control over the emotional state. In addition, CATA questions were used to obtain verbal self-report measures (i.e., emotion words) to evaluate participants' emotional responses. This method has been found to provide a comprehensive and balanced list of positive and negative emotions, which can effectively discriminate between products (Ng et al., 2013).

2.6.1. Affective responses

The study measured the affective responses of participants after consuming ice cream while being exposed to different music or sound conditions. To assess these responses, an unstructured line scale (40 cm) was used for the attributes of valence (ranging from unpleasant to pleasant), arousal (ranging from excited to calm), and dominance (ranging from controlling to not controlling attention). This measurement approach was adopted from Kantono et al. (2016) and Kantono et al. (2018).

2.6.2. Measurement of emotions

A preliminary study was conducted using a focus group consisting of 36 participants (16 males, 20 females) aged between 21 and 34 years. The objective was to capture the emotions experienced after the consumption of chocolate ice cream under various music and sound conditions that varied in the levels of arousal that they elicited. For this study, emotional terms that were not specific to food or sound were selected from various sources, including the Profile of Mood States (McNair et al., 1971), Multiple Affect Adjective Check List Revised (Lubin and Zuckerman, 1999), Positive and Negative Affect Scale (Watson et al., 1988), and the Geneva Affect Label Coder (Scherer, 2005). Initially, 150 emotion terms were considered, but based on participant feedback, the twenty most relevant and easily understood terms were retained for further analysis.

The Check-All-That-Apply (CATA) approach was used, which involved a list of 20 emotional attributes (refer to Appendix A.4). The participants were instructed to check all the terms from the list that they believed accurately characterised their emotional responses during the consumption of chocolate ice cream under different music and sound conditions. The presentation order of the CATA terms was balanced between and within participants, following a Williams' Latin square experimental design. Participants used the Fizz Software (Biosystèmes, France) to select the appropriate emotion terms that described their emotions when evaluating the ice cream samples under different music and sound conditions.

2.7. Electrophysiological measures

The electrophysiological measures of skin conductance level (SCL), electrocardiogram (ECG) for heart rate (HR), and respiration rate (RSP) in this study were obtained using a NeXus 10 MK-II multimodal signal acquisition device manufactured by Mind Media BV (Herten, The Netherlands). To process the data, BioTrace + software version V2018A provided by Mind Media BV was used (Van der Zwaag et al., 2011).

For both the SCL and ECG sensors, pre-gelled silver-silver chloride (Ag-AgCl) electrodes were used. The area of skin for electrode placement was exfoliated and cleaned with isopropyl alcohol prior to attaching the electrodes. SCL was measured by placing an electrode on the middle finger and another on the fourth finger of the non-dominant hand, positioned on the volar surface of the medial phalanges. The ECG was obtained using a conventional three-lead set-up, specifically standard lead II placement, and HR was derived from inter-beat intervals. The RSP sensor was recorded using a respiration belt sensor, which was placed over the abdomen to measure breathing rate and relative depth of abdominal of thoracic breathing.

Electrophysiological measurements began with a 10-min baseline period during which participants were instructed to sit in an upright and comfortable position. They were specifically asked not to move their non-dominant hand throughout the duration of the study. In the second phase of the trial, participants were provided with a headset (Series HD 518, Sennheiser Electronics GmbH and Co. KG) and were asked to listen to their selected music and sounds, which varied in the levels of arousal they elicit. The order of the music and sound conditions was randomised and counterbalanced across participants and trials. In the third and final phase of the trial, participants consumed chocolate ice cream (7.0 $\pm$ 0.5g) either in silence or while listening to their selected music and sounds. Each phase lasted for 45 s. HR, SC, and RSP data were recorded at a sampling rate of 128 samples/second.

2.8. Data analysis

2.8.1. Temporal check-all-that-apply (TCATA) curves

TCATA curves were generated using the FIZZ software (Fizz 2.61.1, Biosystemes, Bourgogne, France). These temporal curves depict the proportion of participants who cited a specific attribute at a given time. A higher citation rate for an attribute indicates a higher agreement amongst the participants in terms of attribute frequency. Spline-based smoothing was applied on each curve in order to aid visualisation of the TCATA curves (Lenfant et al., 2009).

The analysis of TCATA curves was carried out as described by (Castura et al., 2016). The proportions of citations were calculated as the percentage of panellists who clicked on an attribute at a given moment during the evaluation period. The TCATA time in this study was presented as standardized time (ST) to provide better understanding of perception and increase consensus across the pool of participants. Each participant's time data was standardized on a scale from 1 to 100, with 0 representing the initial click on the line scale and 100 indicating when the recording automatically stopped.

2.8.2. Correspondence analysis (CA)

CA was applied to the TCATA data to visualise the sum durations of selected sensory attributes. The sum duration of attributes was obtained by adding up the total CATA counts of each attribute for each product across all participants, as a function of time. CA enables the projection of sensory attributes onto a simplified oral trajectory and a visual map, aiding interpretation (Castura et al., 2016). In addition, chi-square tests of independence were performed to examine the linkage between sensory attributes and the different music and sound conditions.

2.8.3. Measure of affective states (valence, arousal, and dominance; VAD)

A one-way ANOVA was performed on the V-A-D measures to assess the impact of different auditory conditions. *Post hoc* comparison using Tukey's (HSD) test was applied if statistical significance was observed (i.e., $p < 0.05$).

2.8.4. Multidimensional alignment (MDA)

MDA was used to evaluate the CATA findings (Carr et al., 2009; Meyners et al., 2013). This involved determining the cosine values between the auditory conditions and emotion attributes derived from the correspondence analysis of the CATA questions. By measuring the cosine of the angle (ranging from -1 to 1) formed between each attribute and condition, it was possible to determine the strength of their relationship. Absolute cosines below 0.707 indicate a negligible relationship (Carr et al., 2009).

2.8.5. Physiological responses

Average values of the physiological parameters, including SCL, HR, and RSP rate, were extracted. The 10-min baseline period was used as reference. The percentage change from the baseline was calculated according to the equation below (Lin et al., 2011; Miller and Ditto, 1989)

$$Percentage\ change\ (\%) = \frac{(each\ value\ during\ testing - each\ value\ during\ baseline)}{each\ value\ during\ baseline} \times 100\%$$

One-way ANOVA was applied to the modified data with music and sound conditions as factor. Tukey *post-hoc* comparisons were conducted when significance was obtained (i.e., $p < 0.05$).

2.8.6. Multiple Factor Analysis (MFA)

MFA enabled the simultaneous analysis of datasets of variables to study the relationship between observations and variables (Escofier and Pagès, 1984). In this study, MFA was applied to the TCATA sensory duration, as well as emotional and physiological measures across all samples and conditions. This allowed the relationship between the sensory responses, physiological measures, and emotional measurements when food was consumed under the different sound and music conditions, to be gauged.

3. Results

3.1. Affective dimensions

Changes in the affective dimensions after consumption of chocolate ice cream under the different auditory conditions.

Differences in valence, arousal, and dominance were observed across various music and sound conditions. EM and EMES conditions exhibited higher levels of arousal compared to the ES condition. As seen in Fig. 2, differences conditions were observed in terms of affective dimensions associated with music and/or sound conditions. Specifically, there were significant differences in terms of valence ($F_{(6, 482)} = 20.57$, $p < 0.001$, partial eta squared (η_p^2) = 0.21), arousal ($F_{(6, 482)} = 13.25$, $p < 0.001$, $\eta_p^2 = 0.14$), and dominance ($F_{(6, 482)} = 1.15$, $p < 0.001$, $\eta_p^2 = 0.01$).

The CM, CS, and CMCS conditions were significantly higher in valence compared to the EM, ES, and EMES conditions. In terms of arousal, EM, ES, and EMES conditions were significantly higher in terms of arousal as compared to the CM, CS, and CMCS conditions. There were no significant differences between the silent (control) and music and/or sound conditions in terms of dominance.

3.2. Effect of music and sound conditions on emotions evoked

Emotions elicited after consuming chocolate ice cream under music and/or sound conditions varying on arousal.

Consuming chocolate ice cream under the different auditory conditions evoked varying emotional responses. Specifically, calm conditions (CM, CS, and CMCS) were correlated to more positive emotions, whereas ES and EMES were associated with more negative emotions. Multidimensional alignment (MDA) was applied to determine the cosine values between different sound and/or music conditions and the emotions cited when consuming chocolate ice cream. Table 1 highlights the MDA results that show the positive or negative correlations between emotions and ice cream consumption under varying music and/or sound conditions with different levels of arousal. Cosine values > 0 suggest a strong relationship between combined auditory conditions and the emotional attributes (Carr et al., 2009).

With chocolate ice cream, the calm music and/or sound conditions (CM, CS, and CMCS) were positively correlated with the emotions of at

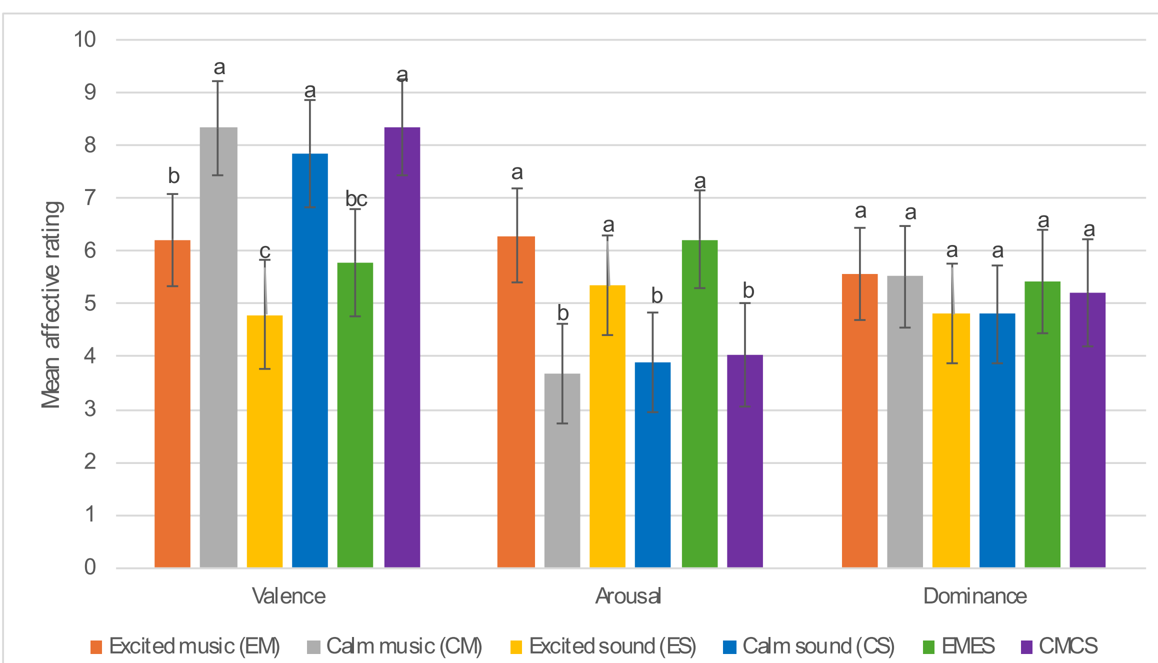


Fig. 2. Differences in valence, arousal, and dominance during consumption of chocolate ice cream under various music and sound conditions. The music and sound conditions included exciting music (EM), calm music (CM), exciting sound (ES), calm sound (CS), EMES and CMCS conditions. Mean affective ratings of music and sound conditions with different small letters (a–e) indicate significant differences in affective ratings. Error bars indicate the standard error of the mean.

Table 1
Cosine values between music and/or sound conditions and the terms used to describe the emotions obtained by Correspondence Analysis. Values in green and red indicate high positive and negative correlations respectively for the emotion terms obtained when ice cream samples were consumed under different music and/or sound conditions.

Emotions	EM	CM	ES	CS	EMES	CMCS
Anxious	0.101	−0.773	0.888	−0.586	0.963	−0.733
At ease	−0.694	0.976	−0.860	0.972	−0.856	0.991
Boredom	−0.365	−0.444	0.618	−0.249	0.639	−0.431
Calm	−0.695	0.975	−0.827	0.985	−0.828	0.971
Lonely	−0.282	−0.372	0.360	−0.312	0.494	−0.244
Pleasant	−0.653	0.978	−0.873	0.976	−0.854	0.976
Relaxed	−0.656	0.980	−0.879	0.925	−0.910	0.899
Satisfied	−0.092	0.295	−0.496	0.106	−0.525	0.223
Tired	0.013	−0.704	0.831	−0.556	0.917	−0.716
Uneasy	0.151	−0.812	0.976	−0.653	0.938	−0.782
Unhappy	−0.154	−0.616	0.811	−0.409	0.876	−0.542
Interested	0.306	−0.052	−0.268	−0.256	−0.288	−0.100
Joy	−0.425	0.895	−0.870	0.825	−0.960	0.914
Active	0.958	−0.613	0.262	−0.787	0.275	−0.635
Enthusiastic	0.948	−0.814	0.582	−0.913	0.557	−0.857
Energetic	0.973	−0.780	0.495	−0.884	0.513	−0.785
Unable to concentrate	0.427	−0.913	0.968	−0.794	0.975	−0.858
Annoyed	0.139	−0.799	0.900	−0.619	0.975	−0.732
Restless	0.286	−0.856	0.996	−0.728	0.931	−0.818
Excited	0.911	−0.831	0.663	−0.861	0.661	−0.828
Valence	−0.386	0.886	−0.952	0.776	−0.984	0.865
Arousal	0.861	−0.849	0.642	−0.892	0.561	−0.845
Dominance	0.431	0.019	−0.260	−0.206	−0.414	−0.066

ease, calm, pleasant, relaxed, and joy. The exciting music (EM) was positively correlated with emotions of active, enthusiastic, energetic, and excited. The exciting sound (ES) and EMES conditions were positively correlated with emotions of anxious, tired, uneasy, unhappy, unable to concentrated, annoyed, and restless.

3.3. Correspondence analysis (CA)

The sensory perception of ice cream can be influenced by music and sounds that are associated with varying levels of arousal. Calm auditory conditions tend to be associated with positive sensory attributes, while excited auditory conditions are often correlated to negative sensory attributes. Appendix A.5 depicts the overall TCATA curves for chocolate gelato consumed while listening to six different music and/or sounds (EM, ES, CM, CS, EMES, and CMCS) conditions. Only attributes that reached significance (represented as highlighted lines in the TCATA curves) will be discussed.

To further summarise the TCATA results, CA was carried out on the durations for which each attribute was selected. The results shown in Fig. 3 highlighted significant differences in terms of the sensory attributes of the ice cream under different music and/or sound condition ($\chi^2_{(36)} = 11228.63$; $p < 0.05$).

Dimension 1 explained 93.72% of the variance. Ice cream samples consumed under CM, CS, and CMCS conditions had high negative scores that were correlated with sweet, vanilla and creamy attributes. Samples consumed under the EM, ES, and EMES conditions had high positive scores that were further correlated with roasted and bitter attributes.

3.4. Electrophysiological responses

Changes in physiological measures with music and sounds during consumption of chocolate ice cream.

Skin conductance level (SCL), heart rate (HR), and respiration rate (RSP) were found to be influenced by different music and sound conditions. Notably, EMES and EM resulted higher percentage changes in

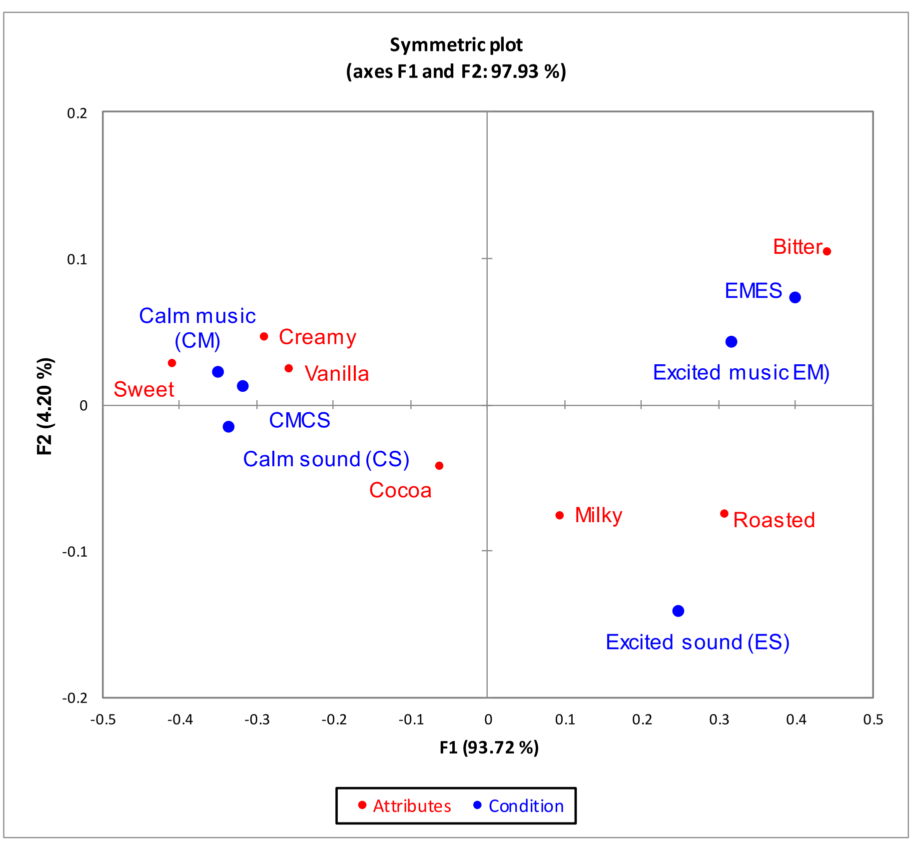


Fig. 3. The first two components of the CA factor map based on aggregated TCATA data over the whole evaluation duration. Different colours represent the music and/or sound conditions (blue) and sensory attributes (red).

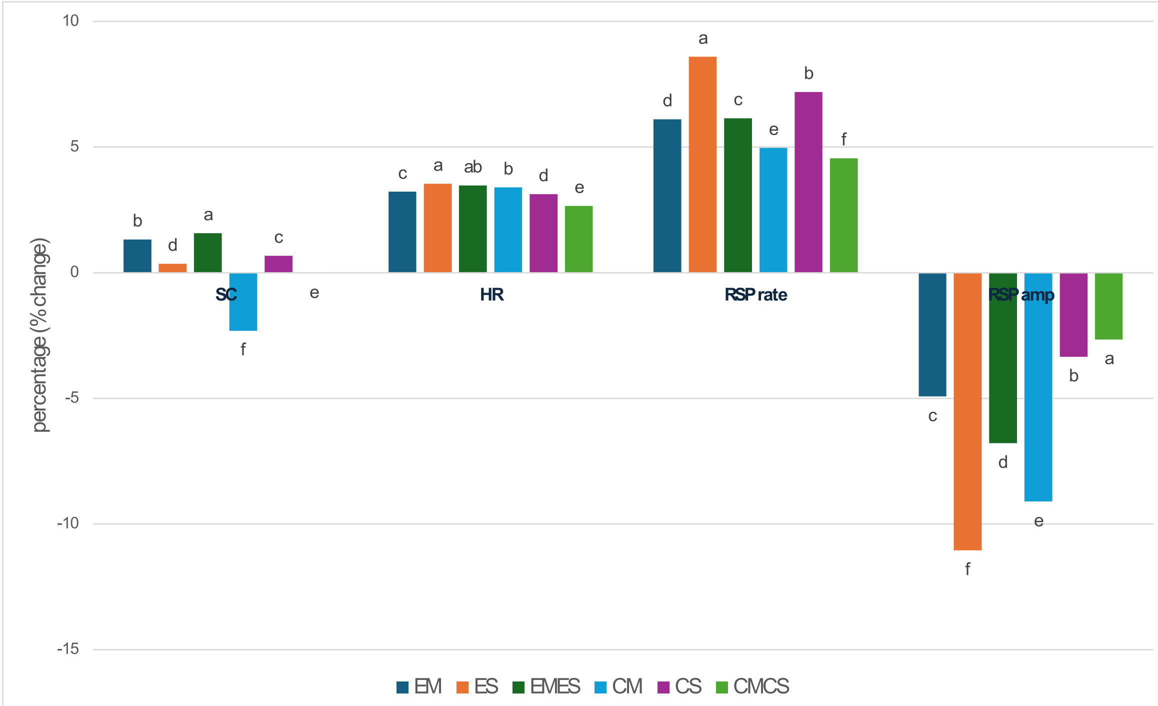


Fig. 4. Physiological measure values using skin conductance response (SC), heart rate (HR), respiration rate (RSP rate), and respiration amplitude (RSP amp). Values were calculated based on the changes in baseline condition compared to exciting music (EM), calm music (CM), exciting sound (ES), calm sound (CS), EMES, and CMCS conditions. Percentage changes of music and sound conditions with different small letters (a–g) indicated significant in physiological measures values.

SCL compared to ES. On the other hand, ES induced higher percentage changes in HR and RSP compared to EM. The results of the one-way ANOVA showed significant effects of music and/or sounds on SCL ($F (6, 482) = 56835.805$, $p < 0.01$, $\eta_p^2 = 1.00$), HR ($F (6, 482) = 353.88$, $p < 0.01$, $\eta_p^2 = 0.82$), RSP rate ($F (6, 482) = 446256.57$, $p < 0.01$, $\eta_p^2 = 1.00$), and RSP amplitude ($F (6, 482) = 661594.86$, $p < 0.01$, $\eta_p^2 = 1.00$) measures only (Fig. 4).

In terms of physiological measures, SCL was linked to significantly higher percentage changes under the EMES condition, followed by the EM, CS, ES, CMCS, and CM conditions. Heart rate (HR) resulted in significantly higher percentage changes under the ES condition, followed by the EMES, CM, EM, CS, and CMCS conditions. Additionally, respiration rate (RSP rate) resulted in significantly higher percentage changes under the ES condition, followed by the CS, EMES, EM, CM, and CMCS conditions.

3.5. Multiple Factor Analysis (MFA) of sensory, emotional, and physiological responses obtained when consuming chocolate ice cream under different music and sound conditions

Consuming ice cream while listening to auditory conditions varying in arousal levels impacted physiological, emotional, affective, and sensory responses. Calm conditions tend to evoke more positive emotions and positive sensory attributes, whereas excited conditions are more likely to elicit negative emotions and negative sensory attributes. The MFA biplot in Fig. 5 illustrates the relationship between physiological measures, emotion measures, affective responses, and sensory perception across different music and/or sounds conditions with varying levels of arousal. F1 and F2 explained a total of 71.88% of the total variance. F1 explained 51.18% of the variance and differentiated the samples consumed in the excited conditions (EM, ES, and EMES) from those consumed under the calm conditions (CM, CS, and CMCS) (Fig. 5). Chocolate ice cream samples consumed under CM, CS, and CMCS had high positive scores along F1 that were correlated to perceptions of sweet, creamy, cocoa, and vanilla, affective responses of valence, emotions of pleasant, joy, relaxed, calm and at ease, as well as physiological measure of RSP amp. In contrast, ice cream samples consumed under the excited conditions had high negative scores along F1 that were correlated with perceptions of bitter, milky, and roasted, affective responses associated with arousal, and emotions that included active, enthusiastic, energetic, excited, unable to concentrate, annoyed, restless, tired, uneasy, anxious, boredom, and lonely.

4. Discussion

The research reported here aimed to investigate how music and sounds with varying levels of arousal impact the perception of chocolate ice cream flavours. The results revealed that consuming ice cream while listening to music and/or sounds with different arousal levels significantly affected flavour perception. In our study, we noted the concept of “sensory dominance,” which suggests that certain senses, in this case, the sense of hearing, can have a stronger influence on flavour perception compared to taste and smell (Spence and Shankar, 2010). Additionally, the phenomenon of “sensation transference” (Spence et al., 2019) helped us understand how the different auditory stimuli can influence the perception of flavours. Overall, this study demonstrated that music and sound conditions with varying levels of arousal have the potential to impact how chocolate ice cream flavours are perceived. This research underscores the essential role of auditory stimuli in shaping sensory experiences and the perception of flavours.

4.1. Exciting music and sound conditions were associated with low valence and high arousal ratings, while calm conditions were associated with high valence and low arousal ratings

The results of this study showed how exciting music and sound conditions were linked to low valence and high arousal ratings, while calm conditions were associated with high valence and low arousal ratings. The findings are confirmed by previous results that reported the emotional impact of different types of music and sounds. Exciting music

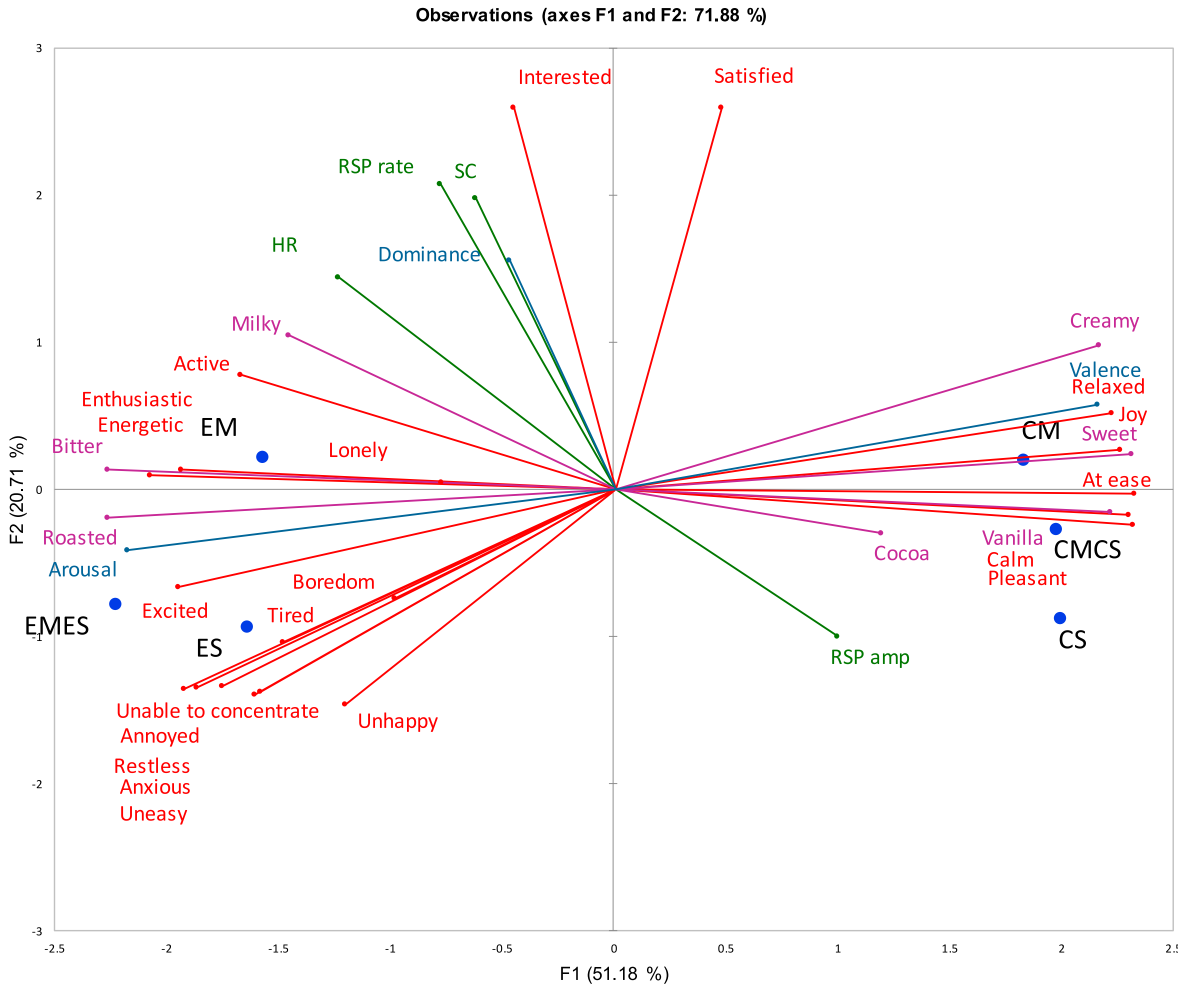


Fig. 5. Multiple Factor Analysis (MFA) biplot of Factor 1 and Factor 2 for physiological responses (green), emotions (red), sensory attributes (purple), and affective responses (blue) for chocolate ice cream consumed under exciting music (EM), exciting sound (ES), calm music (CM), calm sound (CS), EMES, and CMCS conditions.

and sounds, such as heavy metal and specific ambient noises used in this study, are linked to high arousal and low valence, often leading to negative emotional experiences. This aligns with studies by Gomez and Danuser (2004), Whiteford et al. (2018), and Susino and Schubert (2019), which observed similar arousal and valence patterns in heavy metal and other high-energy music genres. Additionally, our study emphasises the influence of context on shaping emotional responses to music and sound. For example, Dimitriev et al. (2023) and Xu et al. (2019), have shown that environmental sounds can influence emotional experiences, suggesting that external factors significantly impact how music and sounds are emotionally perceived.

In this study, music genres such as pop and heavy metal had high ratings in arousal and low ratings in valence. A study conducted by Sweeney and Wyber (2002) indicated that fast-paced music also resulted in higher arousal levels. Dimitriev et al. (2023) found that exciting music (folk-pop) was perceived as unpleasant but arousing, indicating that arousing music can be perceived negatively in terms of valence. Heavy metal music has consistently been found to elicit high arousal but is also perceived as unpleasant in terms of valence, according to studies by Gomez and Danuser (2004) and Whiteford et al. (2018). These findings suggest that heavy metal music generates arousal but is often associated with negative emotional experiences, including dissonance, dislike, and disgust. Similarly, research by Susino and Schubert (2019) found that heavy metal and hip-hop music were perceived as expressing more negative emotions compared to pop music. The study reported above-chance representation of high arousal and negative valence emotions in heavy metal and hip-hop music conditions, whereas pop music did not demonstrate the same pattern. Additionally, Marti-Marca et al. (2020) observed that metal music evoked high arousal and negative emotions, further emphasizing that certain music genres, like heavy metal, tend to elicit negative emotional experiences. A recent study by Vella et al. (2024) examined the effects of classical music and heavy metal on mood in relation to music preference. They found that the heavy metal stimulus generally led to increased hostility and a high arousal/negative mood state. However, for those individuals with a preference for heavy metal, listening to the genre resulted in positive mood changes, including increased joviality, positive affect, and serenity, as well as reduced hostility and negative affect.

In this study, exciting sounds like those found in train stations, dog barks, and car engine noises, or a combination of exciting music and sound, received high ratings in arousal and low ratings in valence. Findings from other studies suggest that exciting music and sounds are often associated with negative valence and emotions. Xu et al. (2019a) studied the influence of different environments on emotional experiences while consuming chocolate ice cream. A bus stop environment was rated as significantly lower in valence, arousal, and dominance compared to other environments. These studies demonstrate the complexities of emotional experiences and how both music and external factors can regulate affective responses.

Another interesting finding in the current study was that EM, ES, and EMES were rated high in arousal, though not significantly between them. However, ES had significantly lower valence compared to EM. Nadon et al. (2021) examined arousal to background music on adults' selective attention. The study compared the effects of stimulating and relaxing music on performance in a Stroop-type task, with two music-matched noise conditions (stimulating music-matched noise and relaxing music-matched noise). The findings of their study demonstrated that music conditions (both stimulating music and relaxing music) were rated higher in valence compared to the noise conditions.

This research study found that calm music genres such as classical and jazz, as well as soothing sounds like birds chirping, rain, waves, and water bubbles, were associated with low arousal and high valence. These findings are supported by multiple studies. Classical music Gomez and Danuser (2004); Garza Villarreal et al., 2012; Marti-Marca et al. (2020); Yamamoto et al. (2007), jazz music (Marti-Marca et al. (2020), and lullaby music (Dimitriev et al. (2023) all induced low arousal and positive valence in participants.

4.2. How does music and sounds that vary in arousal influence emotions and sensory perception of chocolate ice cream?

The results of this research contribute to the existing body of knowledge by providing detailed insights into how different auditory environments affect emotional experiences and flavour perception. It was found that calm music and sounds are associated with positive emotions and the perception of sweetness and creaminess, while exciting music and sounds correlate with arousal and perceptions of bitterness and roasted flavours. According to Mehrabian and Russell (1974), arousal can influence approach-avoidance behaviours. They reported that various aspects, such as physical approach, preference, liking or positive attitudes, exploration, performance, and affiliation are all maximised at a moderate level of arousal.

CM, CS, and a combination of CMCS that resulted in high valence and low arousal ratings are associated with positive emotions such as joy, relaxation, and feelings of calm and pleasantness. Research conducted by Lin et al. (2019, 2022a) revealed that liked music, as well as ambient sounds such as those found in parks and cafés, were associated with high valence and low arousal levels. These auditory conditions had a positive impact on participants' perception of sweetness and creaminess when consuming chocolate ice cream. Additionally, Xu et al. (2019a) reported that consuming ice cream in a café was associated with higher valence and arousal ratings, leading to an increase in positive emotions, as well as increased perceptions of sweetness, cocoa, and milky flavours. These findings emphasise the potential impact of sound environments on emotional experiences and flavour perception.

EM was found to be positively correlated with emotions such as arousal, activity, enthusiasm, energy, and excitement, as well as perceptions of roasted and bitter flavours (Motoki et al., 2022). Additionally, disliked music, unpleasant sounds, and combinations of the two were rated significantly higher in arousal and were positively correlated with negative emotions such as uneasiness, unhappiness, anxiety, tiredness, loneliness, boredom, restlessness, annoyance, and difficulty concentrating. These emotional states were further associated with perceptions of bitterness and roasted flavours (Lin et al., 2022a).

ES and a mixture of EMES conditions were positively correlated with emotions of anxiety, tiredness, uneasiness, unhappiness, inability to concentrate, annoyance, and restlessness, which were further associated with perceptions of roasted and bitter flavours. These findings are in line with previous research on the impact of sound environments on emotions and flavour perception. For example, Lin et al. (2019) demonstrated that bar sounds, rated as the most arousing and least pleasant, were linked to perceptions of bitterness, roasted, and cocoa flavours when consuming chocolate ice cream. Additionally, Xu et al. (2019b) showed that eating ice cream near a bus stop, rated significantly lower in valence, arousal, and dominance, was correlated with negative emotions and perceptions of bitterness and roasted flavours. Guedes et al. (2023) found that bitterness was positively associated with negative emotions like sadness, fear, and anger, as well as arousal, in a study exploring the impact of different soundtracks on taste perception. These findings suggest that sound environments, emotions, and taste perceptions are intricately linked, with excited sound conditions and negative emotions being tied to perceptions of roasted and bitter flavours.

The novelty of these findings lies in the exploration of the intricate relationships between sound environments, emotions, and flavour perception. The findings provide new insights into how specific sound conditions varying in arousal are connected to a range of emotions and how these emotional states are associated with perceptions of flavour. This understanding of the complex connections between sound, emotions, and flavour offers fresh perspectives and implications for fields such as food and beverage marketing, sensory perception research, and the design of sound environments in dining and tasting experiences.

4.3. Can electrophysiology measures explain changes in sensory perception when consuming ice cream while listening to music and sounds varying in arousal?

In this study, electrophysiological measures may play a role in explaining changes in sensory perception while consuming ice cream under high arousal auditory conditions. The findings align with results reported by Kantono et al. (2019) and Xu et al. (2019b), who found that disliked or highly arousing sound environments were correlated with negative emotions and perceptions of bitterness in food. EM and EMES showed significantly higher SCL and respiratory rates, and were correlated with roasted and bitterness perceptions. Yamamoto et al. (2007) demonstrated that music with high tempo (which is likely the case for the EM and EMES conditions) led to significantly higher respiration rates compared to music with low tempo for both high-arousal stressful and low-arousal stressful tasks. In addition, Gomez and Danuser (2004) found that SCL was significantly higher for highly arousing music (heavy metal) than other types of music (classical). Moreover, the study by Kantono et al. (2019) found that eating ice cream while listening to disliked music resulted in a significantly higher SCL and was linked to negatively rated emotions such as disappointment and disgust. These emotions, in turn, were associated with bitterness, creaminess, and vanilla.

The research findings showed that both ES and EMES were associated with significantly higher HR and respiration rates, as well as negative emotions such as anxiety, tiredness, and annoyance. These negative emotions were further correlated with perceptions of roasted and bitterness. Gomez and Danuser (2004) and Xu et al. (2019a) provide valuable insights into how different sounds and environments can affect physiological and emotional responses. Gomez and Danuser (2004) discovered that highly arousing noises increased heart rate significantly compared to low arousal sounds, such as the sound of a stream with bird twitter. Xu et al. (2019a) investigated the influence of background soundscapes on food perception, emotions, and electrophysiological measures during the consumption of chocolate ice cream. They found that the café-machine soundscape was significantly associated with negative emotions such as anger, disgust, disappointment, and contempt, and was further correlated with perceptions of creamy and bitter. However, the measure of arousal was not determined in this study. This soundscape resulted in higher heart rate, skin conductance level, and respiration rates compared to the café-forest and café-bird soundscapes. Moreover, Xu et al. (2019b) also examined the impact of eating ice cream in different environments. They reported the bus stop environment to be significantly lower in terms of valence, arousal, and dominance. This environment resulted in higher frequencies of negative emotions like inability to concentrate, uncertainty about things, negativity, tiredness, tension, unhappiness, annoyance, and anxiety, which were further associated with the perception of bitterness and roasted, as well as a higher heart rate. These findings highlight the relationship between auditory stimuli, physiological measures, and emotional experiences that influence flavour perception.

The research findings showed that listening to calming music can lead to a higher heart rate, as well as positive emotions such as joy, relaxation, calmness, pleasantness, and feeling at ease are linked to the perception of sweetness and creaminess. Lynar et al. (2017) reported that self-selected "uplifting" music resulted in significantly higher HR and emotions of joy and engagement compared to classical music, jazz music, and white noise. In contrast, Kantono et al. (2019) found that liked music that had higher valence and arousal ratings was associated with a higher HR and positive emotions like enjoyment, happiness, love, and satisfaction. These positive emotions were then correlated to perceptions of sweetness and milkiness in chocolate gelato. Xu et al. (2019a) found that eating ice cream in university and cafe settings, which were rated higher in valence and arousal, led to more positive emotions like happiness, pleasure, and joy, and perceptions of sweetness, cocoa, and milkiness. Furthermore, they noted that SCL increased significantly when consuming ice cream in a study area compared to a laboratory, indicating a possible impact of the environment on sensory perception of ice cream.

Listening to calm sounds while consuming ice cream was found to be associated with a significantly higher SCL. Moreover, the emotions of joy, relaxation, calmness, pleasantness, and a sense of ease, were positively correlated with the perceptions of sweetness and creaminess. This finding is supported by Xu et al. (2019b) who found that café-forest and café-bird soundscapes were associated with significantly higher positive emotions of amusement, happiness, enjoyment, love, and satisfaction, which in turn were positively correlated with the perception of ice cream sweetness. Hence, exposure to calming sounds in the eating environment can influence physiological responses, which in turn can enhance the sensory and emotional experience of consuming food.

These findings highlight the significant impact of auditory stimuli, such as music and sound, on our electrophysiological responses, emotions, and perceptions during the consumption of ice cream. Understanding how different sounds and environments can influence our heart rate, skin conductance level, emotional state, and sensory perception can have practical implications across various domains. In the hospitality industry, this incorporating calming music and positive environmental cues can create more immersive and pleasant dining experiences, enhancing customers' enjoyment and satisfaction with their products. Healthcare providers can also benefit from this research by incorporating soothing sounds and pleasant surroundings in patient care environments, promoting relaxation and well-being, which may improve patient outcomes. Additionally, consumer behaviour researchers can leverage these insights to better understand how sensory inputs and emotional responses impact food preferences and choices.

5. Conclusion

The study showed how consuming ice cream in different auditory environments, varying in arousal levels, influences emotional and sensory perception. It was found that calm music and sounds (CM, CS, and CMCS) increased positive feelings, while excited music and sounds (EM, ES, and EMES) heightened arousal and brought forth both positive and negative emotions. These auditory conditions also influenced sensory perception of the ice cream, as calm conditions were associated with sweet, vanilla, and creamy attributes, while excited conditions were linked to roasted and bitter attributes. In terms of electrophysiological responses, the EMES condition caused an increase in skin conductance, while the ES condition raised heart and respiration rates. Overall, the presence of calm conditions enhanced positive emotional and sensory experiences, whereas the presence of excited conditions triggered negative emotional and sensory responses. This research advances theoretical frameworks in environmental psychology and sensory science by demonstrating how auditory stimuli impact emotional and sensory experiences. It supports those theories that suggest that high arousal auditory stimuli can induce negative emotions, while low arousal auditory stimuli promote positive emotions and perceptions. These findings provide valuable insights into the influence of auditory environments on affective states and sensory perception, offering a better understanding of how specific auditory conditions can modulate consumer experiences and emotional responses.

A limitation of this study is the experimental setting, which might not accurately reflect real-world environments where multiple sensory inputs interact simultaneously. Future research in this area could focus on developing more sophisticated experimental settings that better mimic the complex sensory interactions found in real-world environments. This could involve creating multisensory environments that incorporate not only sound, but also visual and olfactory stimuli to more accurately reflect the richness of real-life experiences. Additionally, longitudinal studies could provide insights into how repeated exposure to certain sound environments affects long-term emotional and sensory experiences.

In practical terms, the present study has implications for those situations where external cues influence emotional and sensory experiences. Understanding how different sounds affect emotional valence and arousal can be applied in retail or hospitality settings to enhance customer experience. Furthermore, it may improve people's sensory experiences, including food and drink, in various contexts. Future studies may explore the long-term effects of different auditory conditions and eating habits on mood and emotional well-being, leading to personalised strategies for mood regulation and psychological stability.

Implications for gastronomy

This study demonstrates the connection between ice cream flavour perception, music, and emotion. Calm soundscapes and music enhanced the sense of sweetness and creaminess by evoking enjoyment and relaxation while eating. Conversely, exciting music and soundscapes amplified the perception of roasted and bitter flavours, aligning with the need for more stimulating experiences. Restaurants may tailor the soundscapes to highlight particular dishes on the menu. Flavourful, roasted foods might be enhanced by lively and upbeat music, while desserts could be enhanced by serene and calm tunes. Food designers could explore creating dishes that pair optimally with specific auditory experiences, crafting a multi-sensory dining experience.

CRediT authorship contribution statement

Yi Hsuan Tiffany Lin: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel Shepherd:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Kevin Kantono:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal analysis, Conceptualization. **Charles Spence:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation. **Nazimah Hamid:** Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Methodology, Funding acquisition, Conceptualization.

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.

Appendices

Appendix A.1. Musical genres, recording artists, and songs used in the current study

Genre	Music description	Song/Artist
Classical	Piano, clearer texture, elegance	Symphony in D Major, Wq. 183, No. 1:II. Largo *Carl Philipp Emanuel Beach, Rebecca Miller*
Folk	Transformative, uplifting, urbane	Orchid *Rosie Carney*
Alternative	Inventive, inspiring, sensual	Say Amen (Saturday Night) *Panic! At The Disco*
Rock	Atmospheric, cluttering mannered	Whatever It Takes *Imagine Dragons*
Country	Heart-warming, guitar, country	Slow Burn *Kacey Musgraves*
Pop	Strong beat, invigorating, generic	Woman Like Me *Little Mix [ft. Nicki Minaj]*
Soul	Rattling, raw, ghetto	Love Lies *Khalid and Normani*
Blues	Gospel, radio like, emotional	Sun on My Face *Seasick Steve*
Jazz	Swings, calm, slow	After You've Gone *Eddie Henderson*
Heavy metal	Loud, sharp, metal	Zombie *Bad Wolves*
Religious	Religious, calming, slow	Reckless Love *Cory Asbury*
Funk	Groovy, 1980s-like	Finesse (Remix) *Burno Mars feat. [Cardi B]*
Hip hop	Rapping, slow beats, rhythmic	Sunny Vizion *Don't Say (Prod by9AM)*
Electronica	Electronic, dance, high beat	The Middle *Zedd, Maren Morris and Grey*

Appendix A.2. Sounds used in the current study

Sounds/Links
1. Forest (accessed on April 28, 2019) https://drive.google.com/file/d/1YBVJWm_qeQ5C_ZPg499al1L4gJkoDkvL/view?usp=sharing
2. Train station (accessed on April 28, 2019) https://drive.google.com/file/d/1J_2vtPpCCC38mPt6wU7r8yZ4vqbKAnB6/view?usp=sharing
3. Airport (accessed on April 28, 2019) https://drive.google.com/file/d/156vlfDJHmUS_VpPcLBwJlB2W5Chu4GQo/view?usp=sharing
4. Restaurant chatting (accessed on April 28, 2019) https://drive.google.com/file/d/1p_C6y82klRlZCtosQCi95ORyQtPZD1Nh/view?usp=sharing
5. Warm applause (accessed on April 28, 2019) https://drive.google.com/file/d/1Kq1fbGBvnjtYZG8_pczlaXmhOzbtaNk6/view?usp=sharing
6. Dog barks (accessed on April 28, 2019) https://drive.google.com/file/d/1KDIhSYuIieEwXgFFBNB77GSet_v4Mgrn/view?usp=sharing
7. The sound of a car engine (accessed on April 28, 2019) https://drive.google.com/file/d/171tZ5aWu3S-OMGHhy_Cvfh8HzJDA6n1G/view?usp=sharing
8. Video game sound (League of Legends) (accessed on April 28, 2019) https://drive.google.com/file/d/1gOvHyY2hi3JkUN9FKhXidgxeGTva30WD/view?usp=sharing
9. Birds chirping (accessed on April 28, 2019) https://drive.google.com/file/d/1KQPL8Jmr7Hb6wi-dD8ksWjlfn8VHb1Dc/view?usp=sharing
10. Raining (accessed on April 28, 2019) https://drive.google.com/file/d/1oXzQiQgxL1j32z0dl4kXSj23I7szB3Fn/view?usp=sharing
11. Steak grilling (accessed on April 28, 2019) https://drive.google.com/file/d/1jQD9uNp1J8rlr9G-h_G303cug8QP4oax/view?usp=sharing
12. Waves (accessed on April 28, 2019) https://drive.google.com/file/d/1VHNM3KJ09mLJkDfGzBQ1AIG82D4AJJMT/view?usp=sharing
13. Water bubbling sound (accessed on April 28, 2019) https://drive.google.com/file/d/1lpIQ3qQpD9lzadKrMJecuMmgmiONCMFz/view?usp=sharing
14. Clock sound (accessed on April 28, 2019) https://drive.google.com/file/d/1TH6uNCp5EIm_eJujCIxFu-XzOk09X-Sg/view?usp=sharing

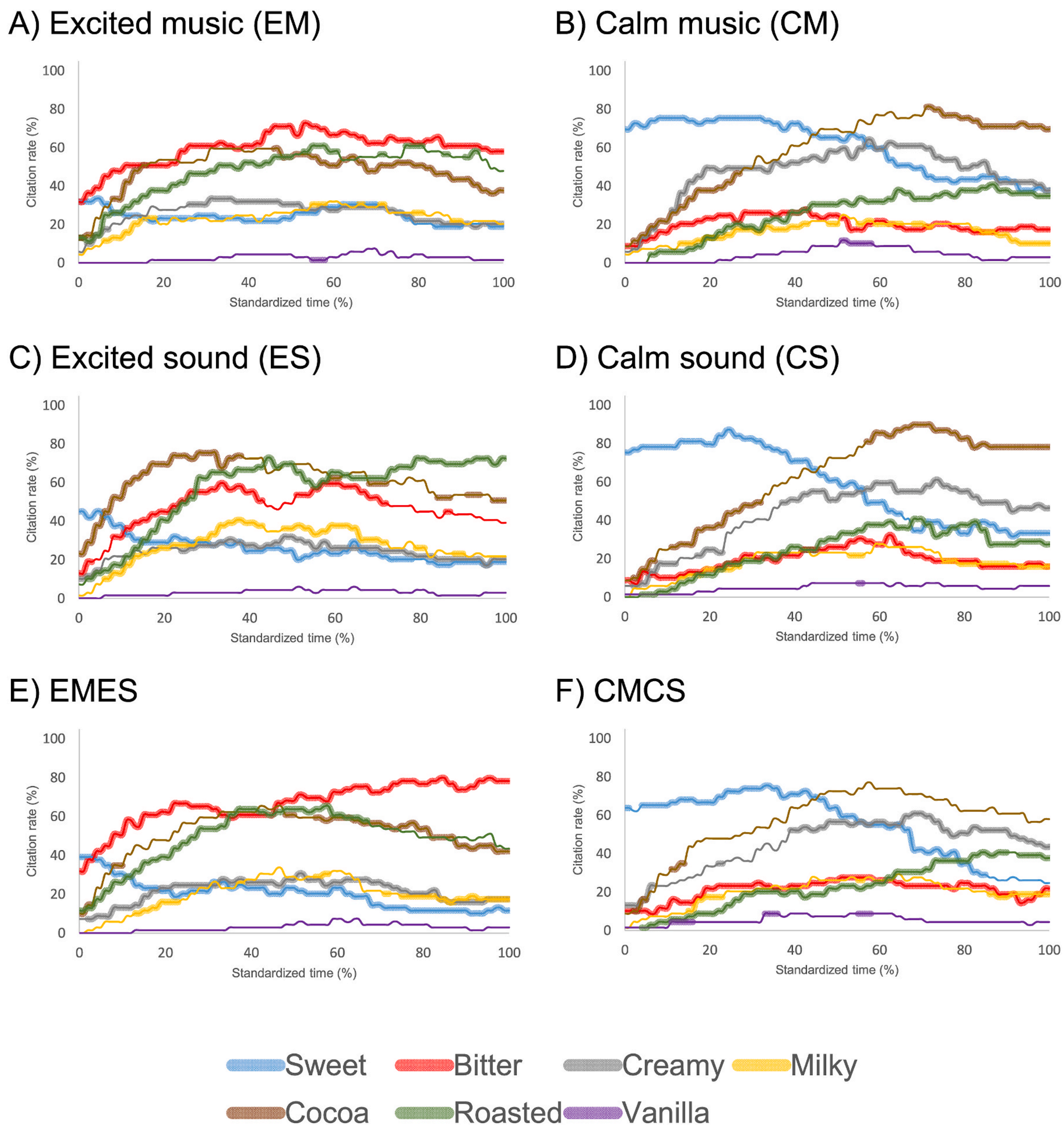
Appendix A.3. Sensory attributes and descriptions of chocolate ice cream

Sensory attributes	Description	Reference standard
Sweet (taste)	Taste associated with sugar	Hershey Milk chocolate
Bitter (taste)	Taste associated with caffeine or quinine solutions	Hershey Dark chocolate
Cocoa (flavour)	Characteristic flavour associated with cocoa	Hershey Milk chocolate
Milky (flavour)	Characteristic flavour associated with milk	Fresh milk (Anchor™, New Zealand)
Creamy (texture)	Texture associated with cream	Fresh cream (Anchor™, New Zealand)
Vanilla (flavour)	A woody, slightly chemical, aroma associated with vanilla bean	Heilala Vanilla Pure Vanilla Extract + Fresh milk (Anchor™, New Zealand)
Roasted (flavour)	A burnt, somewhat bitter character present in a product that has been cooked at a high temperature, typical of very strong dark coffee	Hershey Milk chocolate + 3 highly roasted coffee beans

Appendix A.4. Description and examples of emotion terms used in this study

Emotion attribute	Examples	Description
Active	Drinking wine with friends or parents at a party	Engaging or ready to engage in physically energetic pursuits
Annoyed	The store sold food that was out of date	Slightly angry; irritated
Anxious	I made a big mistake, and the opponent took immediately advantage of my mistake	Feeling or showing worry, nervousness, or unease about something with an uncertain outcome
At ease	Having a holiday with family	Free from worry or awkwardness; relaxed
Boredom	One can be bored by eating traditional meals; simple biscuits, tasteless and dry	Feeling bored
Calm	An atmosphere where no one is fighting or arguing and there is no stress or tension	Not showing or feeling nervousness, anger, or other strong emotions
Energetic	A person who is very active and does not feel tired easily.	Showing or involving great activity or vitality
Enthusiastic	Cheerful picture and graphics; drinking at a party	Having or showing intense and eager enjoyment, interest, or approval
Excited	A barking dog when the mailman comes to the door	Very enthusiastic and eager
Interested	Feel like eating product; curious about taste	Having an interest or involvement; not impartial
Joy	Happy with product information; strong smell makes you happy; cheerful picture and graphics	A feeling of great pleasure and happiness
Lonely	Eating or drinking alone	Sad because one has no friends or company
Pleasant	Drinking wine with friends or parents	Giving a sense of happy satisfaction or enjoyment
Relaxed	Walking on the beach; water, after or during sports activities	Free from tension and anxiety
Restless	You cannot sit down and instead pace around more	Unable to rest or relax as a result of anxiety or boredom
Satisfied	I am satisfied after my late lunch; I am very satisfied with the flavour of the food.	Peaceful, happiness, calm, feeling when an outcome is above expectations.
Tired	Working for 12h without a break	In need of sleep or rest
Unable to concentrate	Reading at a noisy bus stop	Can't focus all one's attention on a particular object or activity
Uneasy	A person sitting in a chair with only three legs	Causing or feeling anxiety; troubled or uncomfortable
Unhappy	Food perceived as being too watery and artificial	Not happy

Appendix A.5



Appendix A.5TCATA curves for chocolate ice cream consumed under: (A) exciting music, (B) calm music, (C) exciting sound, (D) calm sound, (E) EMES, and (F) CMCS conditions. Reference lines (highlighted) indicate those citation proportions that were statistically significant and not selected by chance.

Appendix A.5 depicts the overall TCATA curves for chocolate gelato consumed while listening to six different music and/or sounds (EM, ES, CM, CS, EMES, and CMCS) conditions. Only attributes that reached significance (represented as highlighted lines in the TCATA curves) will be discussed.

Sweetness and creaminess were strongly associated with the CM, CS, and CMCS conditions. Sweetness was cited under the CM condition throughout consumption (0–100% ST). It increased from 0 to 22% ST, reaching a maximum citation rate of 75.36% at 22% ST before decreasing from 22 to 100% ST. In the CMCS condition, sweetness was increasingly cited from 4 to 33% ST, reaching a maximum citation rate of 75.36% at 33% ST, before decreasing further from 33 to 85% ST. As for the CS condition, sweetness increased from 0 to 24% ST, with the highest citation rate of 86.96% at 24% ST compared to other conditions, before decreasing from 24 to 65% ST, and again from 68 to 100% ST.

Creaminess was the most highly cited attribute under the CM condition (11–100% ST), increasing from 11 to 57% ST, and reaching the maximum citation rate of 63.77% at 57% compared to other conditions. It then decreased from 57% to 100% ST. Similarly, in the CS condition, creaminess increased from 37 to 74% ST, reaching a maximum citation rate of 60.87% at 74% ST, that then decreased from 74 to 100% ST. In the CMCS condition, creaminess increased from 39 to 68% ST, reaching a maximum citation rate of 60.87% at 68% ST, before decreasing from 68 to 100% ST.

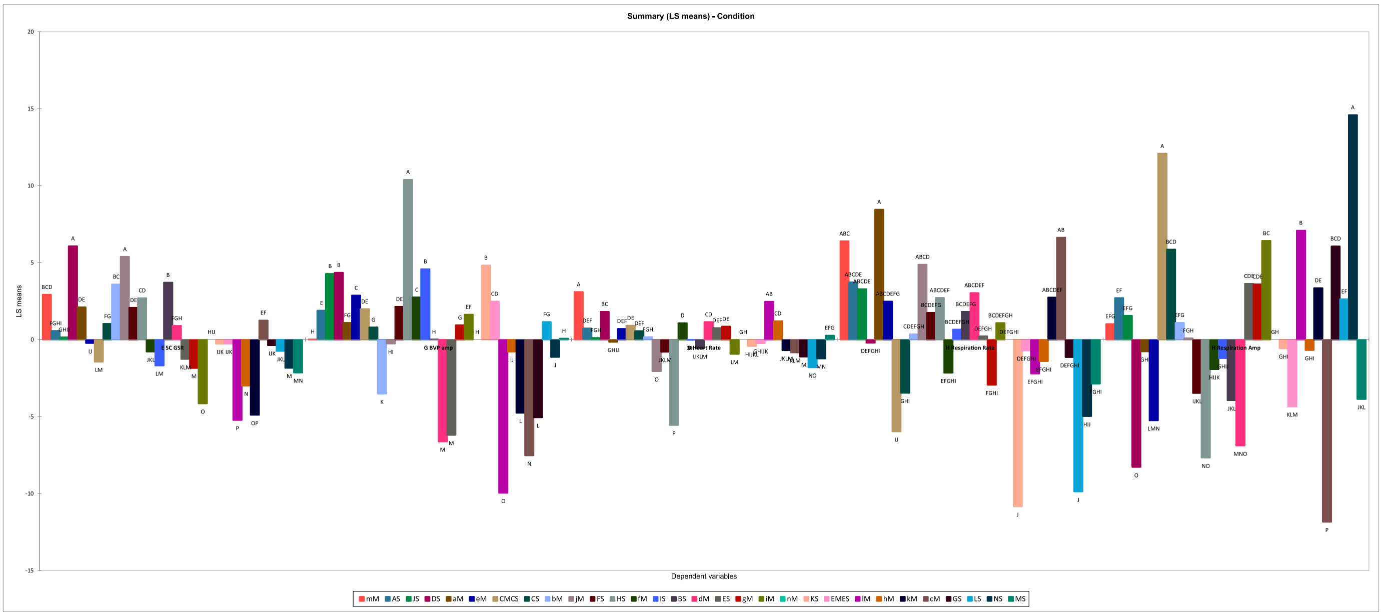
Bitterness and roasted were highly associated with EM, ES, EMES conditions. Bitterness was consistently cited under EMES and EM conditions throughout consumption (0–100% ST). In the EMES condition, bitterness citation increased from 0 to 84% ST, reaching the highest maximum citation rate of 79.71% at 84% ST compared to other conditions. It then decreased from 84 to 100% ST. Similarly, in the EM condition, bitterness citation increased from 0 to 53% ST, with a maximum citation rate of 72.46% at 53% ST, before decreasing from 53 to 100% ST. In the ES condition, bitterness citation increased from 8 to 33% ST, reaching a maximum citation rate of 59.42% at 33% ST. However, it then decreased in citation from 33 to 43% ST, and again from 51 to 72% ST.

Roasted was most frequently cited under the ES condition (2–100% ST). It increased in citation from 2 to 100% ST, with the highest maximum citation rate of 72.46% at 100% ST compared to other conditions. In the EMES condition, sweetness increased from 0 to 37% ST, reaching a maximum citation rate of 63.77% at 37% ST, before decreasing from 37 to 67% ST. In the EM condition, sweetness increased from 0 to 55% ST, reaching a maximum citation rate of 60.87% at 55% ST before decreasing from 55 to 61% ST.

Cocoa was the most frequently cited attribute under the ES condition in early consumption (0–38% ST), increasing from 0 to 29% ST, with the highest maximum citation rate of 75.36% at 29% compared to CM, CS, and EM conditions. It then decreased in citation from 29% to 38% ST. On the other hand, cocoa was cited at the end of consumption for the EM, CM, CS, and EMES conditions. The longest duration of cocoa citation was observed under the EM condition from 46 to 100% ST, with the maximum citation rate of 59.42% at 46% ST, followed by a decrease from 46 to 100% ST. In the EMES condition, cocoa decreased from 55 to 100% ST, reaching a maximum citation rate of 59.42% at 55% ST. Although EM and EMES conditions showed a longer duration of cocoa citation, calm conditions (CM and CS) had higher citation rate than excited music and sound conditions. In the CS condition, cocoa increased from 57 to 68% ST, reaching the maximum citation rate of 89.86% at 68%. It then decreased from 71 to 100% ST. Similarly, in the CM condition, cocoa reached its maximum citation rate of 81.16% at 71% ST, followed by a decrease from 71 to 100% ST.

Appendix A.6. Sound selection from participants

	Excited		Calm	
Classical	M01	0.00%	M01	39.13%
Folk	M02	4.35%	M02	8.70%
Alternative	M03	4.35%	M03	4.35%
Rock	M04	8.70%	M04	0.00%
Country	M05	0.00%	M05	4.35%
Pop	M06	17.39%	M06	0.00%
Soul	M07	0.00%	M07	0.00%
Blues	M08	0.00%	M08	0.00%
Jazz	M09	0.00%	M09	39.13%
Heavy metal	M10	43.48%	M10	0.00%
Religious	M11	0.00%	M11	0.00%
Funk	M12	8.70%	M12	0.00%
Hip hop	M13	0.00%	M13	0.00%
Electronica	M14	13.04%	M14	4.35%
Forest	S01	0.00%	S01	0.00%
Train station	S02	26.09%	S02	0.00%
Airport	S03	4.35%	S03	4.35%
Restaurant chatting	S04	4.35%	S04	4.35%
Warm applause	S05	8.70%	S05	0.00%
Dog barks	S06	13.04%	S06	4.35%
The sound of a car engine	S07	30.43%	S07	0.00%
Video game sound (League of Legends)	S08	0.00%	S08	0.00%
Birds chirping	S09	4.35%	S09	13.04%
Raining	S10	0.00%	S10	17.39%
Steak grilling	S11	0.00%	S11	4.35%
Waves	S12	4.35%	S12	21.74%
Water bubbling sound	S13	4.35%	S13	21.74%
Clock sound	S14	0.00%	S14	8.70%



Appendix A.7. Physiological measure values using skin conductance response (SC), blood volume pulse amplitude (BVP amp), heart rate (HR), respiration rate (RSP rate), and respiration amplitude (RSP amp). Values were calculated based on the changes in baseline condition compared to excited music (EM), calm music (CM), excited sound (ES), calm sound (CS), EMES, and CMCS conditions without ice cream eating. Percentage changes of music and sound conditions with different small letters (a-g) indicated significant in physiological measures values.

Appendix A.8. Ice cream preparation and presentation

The bitter-sweet chocolate ice cream samples were formulated using a mixture of cream (51.54%), milk (15.38%), sugar (15.38%), and cocoa powder (7.69%). These ingredients were poured into an ice-cream maker (Cuisinart ICE-100 Compressor Ice Cream and Gelato Maker, Stamford, USA, Cuisinart) and churned until the mixture thickened. The samples were then placed in 250 mL polystyrene cups and stored in a commercial-grade freezer (Fisher and Paykel, NZ) at −18 °C for at least 24 h to ensure sample consistency prior to serving. All ice cream samples were tempered for 1 min at room temperature prior to serving. A scoop of the ice cream sample (5.0 ± 0.8 g) was placed individually in a sealed 15 mL white plastic container (45 mm diameter) coded with a three-digit random number. The serving temperature (−12 ± 2 °C) was strictly monitored to maintain consistency across samples and participants (Bower and Baxter, 2003), and sample presentation was randomized and counterbalanced across participants (MacFie et al., 1989). The participants were given a 30 s break in between samples and instructed to drink water to cleanse their palate.

Data availability

Data will be made available on request.

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