The impact of environmental sounds on food reward

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\textbf{A B S T R A C T}

Wanting and liking are both components of food reward, but they manifest in fundamentally different neural substrates. While wanting denotes anticipatory and motivational behaviors, liking is associated with consummatory and hedonic experiences. These distinct constructs have also been quantitatively dissociated in behavioral paradigms. Indeed, internal, physiological, and interoceptive states affect the degree to which the food presented is valued. However, how contextual sensory cues might impact these appetitive and rewarding responses to food remains unexplored. In light of the increasing empirical focus on sound in food research, we investigated the influence of environmental soundscapes on explicit liking, explicit wanting, implicit wanting, choice frequency, and reaction time of healthy/unhealthy food using an online version of the Leeds Food Preference Questionnaire (LFPQ). Soft nature sounds and loud restaurant noises were employed to induce emotional relaxation and arousal respectively. One hundred and one healthy university students completed a repeated-measure design of the LFPQ; once with each soundscape playing in the background. Generalized linear mixed model analyses detected a significant interaction effect between soundscape and food type on choice frequency, yet the post hoc analyses did not reach significance. No interaction effects between soundscape and food type on wanting or liking were discovered. However, hypothesis-driven analyses found that nature sounds increase explicit liking of healthy (vs. unhealthy) foods, while no effect of soundscape on any wanting measures (explicit or implicit) were observed. Finally, exploratory analyses indicated that restaurant noise (vs. nature sound) induced faster response times for both healthy and unhealthy foods. The study exemplifies that in an online setting, contextual auditory manipulation of certain food reward measures and decision processes is feasible.

1. Theoretical background

1.1. Intrinsic properties of food reward

Intrinsic rewarding properties of food influence a cascade of downstream psychological and physiological factors \cite{51}. Conceptually, these include pleasure, motivation, and learning mechanisms \cite{10}. Computational models have primarily revolved around the latter, but both hedonic pleasure and incentive motivation/salience, popularly referred to as ‘liking’ and ‘wanting’, are equally critical in the reward circuitry of the brain and are arguably even stronger predictors of actual food-seeking behavior, appetite control, and weight gain than learning \cite{9}. Although they are interconnected, liking and wanting manifest in fundamentally different neural substrates \cite{14, 57}. While anticipatory and motivational behaviors of wanting are governed by the striatal dopaminergic system, consummatory and hedonic eating experiences of liking are associated with the ‘hedonic hotspots’ in the endogenous opioid system \cite{43, 59}.

However, the vast majority of methods employed to behaviorally quantify these distinct constructs of food reward has been confined to self-report measures such as preference for or desire to. These are typically measured by means of explicit ratings scales (e.g., visual analogue scales; VAS) and do not include implicit measurements (e.g., reaction time; for a review, see \cite{45}). Only a few instruments have adopted more
comprehensive frameworks to operationalize the multidimensionality of food reward. The Leeds Food Preference Questionnaire (LFPQ), originally developed by Finlayson, King, & Blundell [27], instrumentalizes both explicit and implicit responses of food reward in a single paradigm. In particular, the LFPQ can behaviorally dissociate explicit liking, explicit wanting, implicit wanting, and relative preference through motivation and pleasure ratings and a reaction time-based forced-choice methodology. This computer-based platform has since then been adapted in multiple usages and languages, primarily to investigate different homeostatic and bodily influences on food reward, such as hunger, weight, and/or exercise status [7, 17, 18, 26, 28, 65].

1.2. Contextual influences on food reward

Besides the internal, physiological and interoceptive states, human valuation of food is also affected by external factors (see Fig. 1 for a detailed representation). In fact, a large body of sensory and consumer research has demonstrated myriad effects of contextual cues in the eating environment on food experience, valuation, and behavior [35, 52]. Particularly, auditory contributions to this field have in the past decade emerged drastically with numerous studies highlighting the underrated power of sound and music [54, 56]. These include changes in food choice [31, 64], attention [48, 49], and taste/flavor evaluation [33, 60].

Similarly, the subjective and self-reported measure of liking has been frequently studied in the context of food and sound. The empirical consensus is that louder (compared to softer) background music/restaurant noise decreases consumers’ flavor liking [3, 15]. As Bravo-Moncayo et al. [15] suggests, such phenomena can be explained by means of attentional processes, whereby “louder noise may diminish the ability to attend to specific elements of the experience”. A complementary explanation can be reasoned through evidence of sensation/emotion transference [55], affective priming [58], or embodied cognition [66], all in which the ambient soundscapes induce emotional alteration. Using biometric measures, Xu et al. [63] and Biswas, Lund, & Szocs [11] demonstrated that listening to negatively associated music and loud music respectively, elevated physiological arousal, which was further associated with other behavioral and perceptual implications (i.e., food choice and taste intensity). This suggests that particularly loud (vs. soft) noise is effective in inducing increased (vs. decreased) arousal states, which in turn reduces experiential food liking. In contrast, positively associated environmental sounds, such as bird song or ocean waves, seemingly promote emotional relaxation [4] and thereby congruently healthy food choices [50].

1.3. Hypothesis development

Collectively, the literature indicates that contextual auditory cues can indeed influence internal physiological and psychological states, subsequently resulting in various downstream drivers of food choice and consumption [8, 36, 41] as presented in the conceptual model of food reward and associated drivers in (Fig. 1). However, the current evidence on sound-evoked food reward is centered around measures of subjective liking. In light of this empirical framework and its limitations, we aimed to expand the current measurements of food reward. Particularly, we investigated the impact of environmental sounds on various reward metrics captured by the LFPQ. We manipulated both volume and type background sound to reinforce the emotional induction of the soundscapes and thereby determine the combined auditory effect on explicit liking, explicit and implicit wanting, as well as choice of healthy and unhealthy foods. We expected that soft nature sounds, inducing low arousal and relaxation, would increase reward (valuation) of healthy (vs. unhealthy) food, whereas loud restaurant noise, inducing high arousal and stress, would instead diminish the effect for any of the food options [15]. We did not formulate any a priori hypotheses regarding the specific reward metrics. However, since explicit liking and personal preferences may be a more grounded attribute, one might expect that the possibly more context-dependent and momentary wanting would be more susceptible to sensory nudges, resulting in a higher degree of fluctuations between auditory conditions.

2. Methods

2.1. Participants

One hundred and nine healthy Danish university and postgraduate
students aged 18–35 years were recruited through the SONA recruitment system at the Cognition and Behavior (COBE) Lab, Aarhus University, Denmark (https://aucobe.sona-systems.com). All participants fulfilled the screening criteria and reported having normal or corrected-to-normal hearing, normal or corrected-to-normal vision without color blindness, no food allergies, and no dietary restraints. Eight participants were omitted from the analysis due to invalid data (e.g., due to the use of a smartphone instead of a computer), resulting in a valid sample size of 101 (mean age ± SD = 23.56 ± 3.04 years; mean BMI ± SD = 22.97 ± 3.55 kg/m²; 54% females) all of whom provided informed consent. The study was conducted in accordance with the ethical standards laid out in the Declaration of Helsinki. All participants were compensated monetarily for their participation (100 DKK).

2.2. Food images

Sixteen high-resolution standardized ‘ready-to-eat’ food images from the Full4Health Image Collection (http://nutritionalneuroscience.eu/index.php/resources/f4h-image-collection) [20] were selected for the current study (Fig. 2). The selection was primarily based on Danish consumers’ eating habits. Images were also matched on nutrition information. To accommodate the division between healthy vs. unhealthy foods, the images were divided based on fat and calorie content, resulting in eight food items in each category with no fat nor caloric overlap between the extremes of the two categories. That is, the food item with the highest fat/calorie content from the healthy food category was lower than the food item with the lowest fat/calorie content from the unhealthy food category (Table 1). The food categories were furthermore balanced and classified as either being sweet or savory.

2.3. Environmental soundscapes

Two environmental soundscapes were used for the study—nature sounds (oceans waves) and restaurant noise (chattering and tableware noises)—both retrieved from Freesound (https://freesound.org). The nature soundscape was chosen to induce relaxation [4, 22] and the restaurant noise soundscape was chosen to induce arousal [2, 15]. To intensify the emotional response, the volume levels of the soundscapes were furthermore manipulated based on the Loudness Unit Full Scale (LUFS) by the European Broadcast Union (EBU) standards [25]. Particularly, the nature sound level was decreased to approximately –30 LUFS, while the restaurant noise was increased to approximately –4 LUFS via Logic Pro-Version 10.6.1 (Apple Inc). This was done to ensure the sound intensity (dB) matched ~50 dB (nature) and ~70 dB (noise) after audio calibration. These soundscapes were then validated in a separate online test (N= 91) in which participants listened to each soundscape and rated them in terms of relaxation/arousal on a VAS from 1 to 9. As expected, the nature sounds (mean rating ± SD = 1.88 ± 1.26) were perceived as being more relaxing (vs. arousing) compared to restaurant noise (mean rating ± SD = 7.49 ± 1.04). The final soundscapes used for the study can be heard at: https://soundcloud.com/d

![Fig. 2. Ready-to-eat food images included in the study retrieved from the Full4Health Image Collection [20].](image-url)
2.4. Leeds food preference questionnaire

The LFPQ is a two-part computer-based instrument. One part (single foods) consists of a series of VAS ratings measuring explicit liking and explicit wanting. Another part (paired foods) adopts a forced-choice methodology in which implicit wanting and relative preference (choice frequency) are quantified. The two parts are presented in a randomized order. We adopted a Danish translation of the LFPQ [47]. The original LFPQ includes four food categories in the analysis, namely low fat sweet, low fat savory, high fat sweet, high fat savory. However, due to the nature of our study objective, we simply focused on the two categories, healthy and unhealthy, while controlling for taste categorization (sweet or savory).

2.4.1. Single foods – explicit liking and explicit wanting

The 16 food images are randomly presented one by one to the participants who are asked to rate on a 100-unit VAS “How much would you like the taste of this food right now?” (explicit liking) and “How much do you want some of this food right now?” (explicit wanting). In the translation for the explicit liking question, we changed the phrasing slightly from the original LFPQ (“How pleasant would it be to taste some of this food now?”) in order to accommodate the Danish language. The two questions are counterbalanced and have different font colors so that participants better can discriminate and comply with the task (Fig. 3A, 3B).

2.4.2. Paired foods – implicit wanting and choice frequency

The participants are presented series of food image pairs with the instruction “Which food do you most want to eat right now?” All food pairs are presented such that all food images from one category (healthy and savory vs. healthy and sweet vs. unhealthy and savory vs. unhealthy and sweet) are presented with each food from the alternative categories, resulting in a total of 96 food pairs of food choices. The trials are shown in a randomized order with an optional break after every 32 trials to alleviate fatigue. Before each trial, a fixation cross is presented for 500 ms to facilitate visual centralization (Fig. 3C, 3D). Participants are asked to respond as fast and accurately as possible (using the keys ‘F’ for left press and ‘J’ for right press.) Reaction times are covertly measured. Originally, the measure of implicit wanting comprised of mean raw reaction time (the faster the reaction time, the higher the implicit wanting). However, we computed a measure of implicit wanting as a weighting of reaction time relative to choice frequency, in line with previous LFPQ studies [17, 45]. Here, both choice (positively contributing) and non-choice (negatively contributing) are recorded to calculate a weighted implicit wanting score (using a frequency-weighted algorithm). A positive score indicates a more rapid preference for a given food category relative to the alternatives in the task and a negative score indicates the opposite. A score of zero indicates equal preference.

2.5. Procedure

Due to the COVID-19 pandemic, physical attendance was not possible, and therefore we employed an online version of the LFPQ. The

![Fig. 3. Example of A) explicit wanting (“How much do you want to eat this food right now?”) and B) explicit liking (“How much would you like the taste of this food right now?”) in the single food trials based on VAS ratings, as well as C), D) implicit wanting (“Which food do you most want to eat right now?”) in the paired food trials using a forced-choice methodology.](atti-peng-li/sets/lfpq_sounds)
Participants then underwent a series of instructive practice trials to familiarize with the tasks. We conformed a repeated measure design with the LFPQ being completed twice—once with soft nature sounds and once with the loud restaurant noise playing in background—including a 10 min break in between to alleviate mental fatigue [12]. The two soundscapes thus served as experimental blocks and were randomized between participants, such that half of the participant first completed the LFPQ with nature sounds and then restaurant noise (and vice versa for the other half). Within each block, the order of trial type (VAS and forced choice) was also randomized within participants. At the end, as a manipulation check, the soundscapes were again rated with regard to arousal/relaxation on a VAS (1 = very relaxing; 9 = very arousing), equivalent to the pre-validation test (Fig. 4).

3. Data analysis

All data was exported from Gorilla [67] and analyzed in R for Mac OS version 4.0.2. A manipulation check was performed using a pairwise t-test based on VAS ratings to confirm that the two soundscapes were in fact perceived as being arousing/relaxing (1 = very relaxing; 9 = very arousing). To increase comparability between reward measures, we calculated an ‘appeal bias’ for healthy > unhealthy foods, resulting in a single index for each reward measure, i.e., explicit liking, explicit wanting, choice frequency, and implicit wanting (by subtracting mean unhealthy food scores from mean healthy food scores; for each measure). These were used in a partial correlation analysis in order to obtain an overview of these related, yet distinct constructs of reward, irrespectively of condition. To investigate the effects of sound on these constructs, we carried out generalized linear mixed models (GLMMs) via the glm() function of the lme4 package. The GLMMs account for the hierarchical structure, non-independence of observations from individual participants in the repeated measure design and to satisfy the normality assumptions without transformation. Explicit liking, explicit wanting, and implicit wanting were fitted using a Gaussian distribution with the restricted maximum likelihood (REML) method [30] and choice frequency using Poisson distribution [13]. In all models, the independent variables were comprised of ‘Sound condition’ (Nature vs. Noise) and ‘Food type’ (Healthy vs. Unhealthy) which were coded as fixed effects. ‘Participant ID’ entered the model as a random effect. Furthermore, we controlled for possible confounds by adding ‘BMI’ and ‘Hunger status’ as covariates to the models. However, none of the covariates contributed significantly to any of the models, and as we did not have any a priori hypotheses regarding these factors, they were therefore removed from the analyses. The dependent variables of interest included ‘Explicit liking’, ‘Explicit wanting’, ‘Implicit wanting’, and ‘Choice frequency’. Omnibus tests were carried out to test the main effects and interactions between the fixed independent variables. If a significant interaction was indicated by the GLMM, Bonferroni-corrected post hoc analyses were performed on the simple main effects. Finally, we carried out an exploratory analysis on ‘Reaction time’ with same GLMM model inputs as indicated above, but specified under the Gamma distribution [39].

4. Results

4.1. Manipulation check

The nature soundscape (mean rating ± SD = 2.33 ± 1.42) was perceived as being significantly more relaxing (vs. arousing) compared to the noise soundscape (mean rating ± SD = 7.18 ± 1.75; p < .001). We also tested for valence (pleasantness) of the soundscapes. The nature soundscape (mean rating ± SD = 2.53 ± 1.64) was similarly perceived as being significantly more pleasant (vs. unpleasant) compared to the noise soundscape (mean rating ± SD = 6.65 ± 1.70; p < .001).

4.2. Partial correlation between reward measures

Based on the healthy appeal bias scores, we found partial correlations between explicit liking and explicit wanting (r = 0.78; p < .001) and choice frequency and implicit wanting (r = 0.31 p = .002) after controlling for the remaining variables (Table 2).

|                      | Explicit liking | Explicit wanting | Choice frequency | Implicit wanting |
|----------------------|----------------|------------------|------------------|-----------------|
| Explicit liking      | 1.00           | r = 0.78; p < .001 | r = 0.01; p = .904 | r = -0.07; p = .512 |
| Explicit wanting     | –              | 1.00              | r = -0.12; p = .239 | r = -0.02; p = .815 |
| Choice frequency     | –              | –                 | 1.00              | r = 0.31; p = .002 |
| Implicit wanting     | –              | –                 | –                 | 1.00 |

Fig. 4. Flowchart of experimental procedure. Participants completed the LFPQ twice—once with nature sounds and once with restaurant noise playing in the background. The order of sound condition (nature and noise) and trial type (VAS or choice; within sound condition) was randomized between participants.
4.3. Single foods

4.3.1. Explicit liking

No effect of sound condition was found on explicit liking ($F_{1,3114} = 1.29; p = .256$). However, there was a main effect of food type on explicit liking ($F_{1,3114} = 4.90; p = .028$) with healthy (vs unhealthy) food being explicitly liked more ($t_{3204} = 2.09; p = .036$). We did not detect any significant interaction effects between sound condition and food type ($F_{1,3114} = 3.17; p = .075$; Table 3). Despite no significance, we carried out hypothesis-driven post hoc analyses to explore this relatively low $p$-value (see Section 1.3. Hypothesis development). The analyses showed that in the nature sound condition, participants liked the healthy (vs. unhealthy) food more ($t_{1609} = 2.66; p = .016$), but no difference in liking between the two food categories was detected in the noise sound condition ($t_{1609} = 0.29; p = 1.000$; Fig. 5A).

4.3.2. Explicit wanting

No effect of sound condition was found on explicit wanting ($F_{1,3114} = 1.19; p = .275$), but we discovered a robust main effect of food type ($F_{1,3114} = 28.82; p < .001$; Table 3) with healthy (vs unhealthy) food being explicitly wanted more across both sound conditions ($t_{3204} = 5.17; p < .001$; Fig. 5B).

4.4. Paired foods

4.4.1. Choice frequency

No main effect of sound condition was found on choice frequency ($x^2_{1} = 0.54; p = .550$), but we observed an interaction effect between food type and sound condition ($x^2_{1} = 6.49; p = .011$; Table 3). However, post hoc analyses did not yield any significance ($t_{1200} = 1.99; p = .065$; Fig. 5C).

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Fig. 5. Interaction plots of A) explicit liking, B) explicit wanting, C) choice frequency, and D) implicit wanting between sound condition (nature vs. noise) and food type (healthy vs. unhealthy). Error bars represent standard error.
Table 3
Overview of omnibus tests for single and paired foods measures, i.e., explicit liking and explicit wanting, choice frequency and implicit wanting.

| Fixed effects | Single foods | Paired foods |
|---------------|--------------|--------------|
|               | Explicit liking | Explicit wanting | Choice frequency | Implicit wanting |
| Sound (condition) | $F_{(1,3114)}=1.29; \, p=.256$ | $F_{(1,3114)}=1.19; \, p=.275$ |  |  |
| Food (type) | $F_{(1,3114)}=4.90; \, p=.028^*$ | $F_{(1,3114)}=28.82; \, p<.001^{**}$ |  |  |
| Sound × Food | $F_{(1,3114)}=3.17; \, p=.075$ | $F_{(1,3114)}=0.93; \, p=.339$ |  |  |

**Fig. 6.** Interaction plots of reaction time between sound condition (nature vs. noise) and food type (healthy vs. unhealthy). Error bars represent standard error.

4.4.2. Implicit wanting

We did not find any significant effect of sound condition ($F_{(1602)}=0.19; \, p=.646$) nor food type ($F_{(1602)}=2.16; \, p=.142$) on implicit wanting score (Table 3; Fig. 5D).

4.4.3. Reaction time

Following the main analyses of reward metrics, we carried out an exploratory analysis of reaction time. Here, we observed a main effect of sound condition on reaction time ($x^2(1)=24.44; \, p<.001$; ) with participant responding faster during the noise (vs. nature) sound condition ($x^2(19,237)=2.91; \, p=.004$; Fig. 6). No effect of food type ($x^2(1)=0.74; \, p=.390$) nor its interaction with sound condition ($x^2(1)=0.47; \, p=.493$) was discovered (Fig. 6).

5. Discussion

In light of the increasing acknowledgement of auditory influences in sensory and consumer research and various related fields, more comprehensive outcome measures are necessary to understand the widespread effects of sound on food perception, valuation, and behavior. By using LFPQ, the current study was able to explore the influence of environmental sounds on a range of distinct measures of food reward. Specifically, we investigated the impact of relaxing nature sounds and stressful restaurant noises on explicit liking, explicit wanting, choice frequency, implicit wanting, and reaction time.

5.1. Potential mechanisms of sound-induced food reward

Similar to previous studies employing the LFPQ [26, 28], there was an expectedly high degree of correlation, especially between explicit liking and explicit wanting. Notably, to control for other measures, we reported the partial correlation coefficients using the healthy appeal bias scores, which was not the case for abovementioned studies. Nevertheless, despite these interconnections, they were still dissociable, when tapping into each specific auditory conditions. In particular, nature sounds were able to provoke reward valuation differences between healthy and unhealthy foods. That is, we detected an increase in explicit liking for healthy food only during the nature but not noise sound condition. However, the effect sizes were relatively small. In the same vein, an interaction between sound condition and food type with regards to relative preference, as measured by choice frequency, was observed. Only in the nature sound condition, healthy (vs. unhealthy) foods were chosen slightly more, whereas there was no difference when participants listened to restaurant noise. Thus, as hypothesized, we observed a tendency for soft nature sounds to increase explicit liking and food choice of healthy over unhealthy foods. Yet, surprisingly, sound did not influence any wanting measures, even though one might anticipate that wanting would be more susceptible to sensory nudges than liking. Furthermore, and in line with our hypothesis, we did not observe any reward measure differences between healthy and unhealthy foods in the loud restaurant noise condition.

The underlying mechanism of this unique influence of nature sounds may be explained through the theories of sensation/emotion transference and embodied cognition [46, 61]. In a more relaxed psychological state, physiologically induced by the soft nature sounds, participants are able to value and explicitly choose the healthier and ‘rational’ alternative. In contrast, with the distracting and louder restaurant noises in the background, participants’ cognitive resources may get depleted [19], leading to less reflective and arguably ‘irrational’ thinking upon their valuation and choices. In fact, fast tempo and high volume of sound, both of which elevate physiological arousal [11, 38], have been reported to reduce one’s cognitive abilities, such as decision accuracy [23], task performance [42], and creative thinking [40].

In the context of food, several studies have pointed out that louder/stressful (vs. softer/relaxing) noise/sounds can diminish the pleasantness [34], taste intensity [62], and purchase intent [15] of the evaluated food/beverage. In line with previous evidence, our findings thus suggest that psychologically and physiologically relaxing nature sounds can to some degree enhance consumers’ preference (at least liking and choice) for healthy foods, whereas environmental noise diminishes these effects rather than sensitizing the alternative (i.e., unhealthy foods). Notably, these inferences are only valid under the assumption that low fat/calorie food choice is in fact considered the rational food choice, which might not necessarily be the case in all circumstances for all individuals. This might be true in an obese population, but for restraint eaters, choosing more calorie-dense foods is arguably the better decision.

Hence, another plausible route by which this phenomenon can be understood, is through the lens of semantic congruency effects [37]. Sonic attributes associated with the notion of healthy eating, including sounds of the ocean, can in fact promote healthier food choices and direct visual attention (more fixations) towards healthy food items [50]. Sonic attributes associated with the notion of healthy eating, including sounds of the ocean, can in fact promote healthier food choices and direct visual attention (more fixations) towards healthy food items [50]. Similar effects has been demonstrated in field studies, in which ethnically congruent music ‘nudges’ consumers towards congruent food purchases [44, 64]. Accordingly, the nature sounds in the present study may have contextually primed congruently healthy (vs. unhealthy) food choice and hedonic evaluation, as measured by choice frequency and explicit liking ratings.

Surprisingly, none of the wanting measures (explicit nor implicit) were affected by the type of background sounds. One might have expected that the possibly more context-dependent and momentary wanting, as opposed to the more ‘grounded’ liking, would be more susceptible to sensory nudges. Yet, we observed the opposite. This nullfinding illustrates that liking and wanting are indeed distinct constructs of reward, despite their reportedly strong association.

Nevertheless, it is particularly surprising that we did not detect any
effect for the implicit measure of wanting given that we found an interaction effect for choice frequency, i.e., one of the variables to compute implicit wanting. This discrepancy may simply be due to the nature of the data generated. The algorithm inputs (choice frequency and reaction time) were based on one data point for each single trial, while the frequency-weighted algorithm of implicit wanting yielded merely a single aggregated value per participant per condition.

We therefore, decomposed the measure of implicit wanting, by exploring the raw reaction times. Here, we did not find any interaction effects, but an overall effect of sound condition, whereby the restaurant noise (vs. nature sound) condition triggered faster reaction times towards any of the foods. Rather than noise being a driver of increased wanting, this finding may simply be a reflection of elevated arousal levels induced by the louder noise, resulting in a more stressful and therefore faster and less deliberate response (‘system 1 thinking’; [32]). On the other hand, the softer nature sounds, which instead induce relaxation, potentially facilitates more cognitive and reflective decision processes, popularly referred to as ‘system 2 thinking’, as reflected by slower reaction times. Hence, the two measures employed to compute implicit wanting, namely frequency choice and reaction time, did not follow same tendency, which may additionally explain why there was no auditory effects on implicit wanting.

5.2. Practical implications

Our study highlights the seemingly conspicuous yet underrated effects of sound on food valuation and choice. The findings demonstrate that soundscapes composed to influence our arousal states are subject to psychiatric conditions [1], but it might also be beneficial for conditions of maladaptive eating. In obese patients [21], individuals with eating disorders [53], or even the controversial notion of ‘food addicts’ [51]—all conditions in which the neural and behavioral relationship between liking and wanting is disturbed—musical therapy with tailored soundscapes could potentially help clinicians tap into the specific drivers and components of food reward. This online auditory adaptation of the LFPQ thus offers new and convenient possibilities for studying distinct measures of food reward for both commercial and clinical significance.

5.3. Limitations

Notwithstanding these practical implications, the present study involves several limitations stemming from the fact that the experiment was conducted online. Due to the current situation of COVID-19, it was not possible to carry out the study in a physical location. As a mitigation against random participant recruitment often found in online testing, all participants were recruited through a well-established participant pool, making them highly familiar with onsite as well as online experimental procedures. In addition, we aimed to provide as clear and concise instructions as possible in the online platform. Nevertheless, we were unable to ensure that participants in fact understood the instructions or completed the tasks correctly. One may also point out the online nature of the study and therefore different operating systems of participants. However, it should be noted that Gorilla has performed relatively well in visual reaction time test, with consistently low variability across the browsers and operating systems [16].

Moreover, based on the sound pre-validation test as well as manipulation check, we have rather naïvely inferred that the paradigm’s incorporated soundscapes have modulated arousal only. First, we cannot guarantee that this was in fact the case, e.g., due to variation in the online sound calibration step, which in itself is a constraint. Secondly, the nature soundscape was rated to be more relaxing but also more pleasant, and vice versa for the noise soundscape. Consequently, the rewarding effects of sound-evoked emotions might have been driven by a combination of valence and arousal. Because emotional responses are an integration of different dimensions/domains of emotions [6, 29], a complete disentanglement is most likely unfeasible. Thirdly, due to the manipulation of both volume (loud vs. soft) and type (restaurant noise vs. nature sounds), we cannot disentangle which auditory feature generated the observed responses. Importantly, the purpose of this soundscape compositions was to prompt the highest emotional response regardless of acoustic parameters.

Furthermore, we observed that healthy foods were liked more than unhealthy foods irrespectively of sound condition, although one could argue that unhealthy foods would be viewed as more palatable and therefore more liked. By employing different inclusion criteria for participation in order to differentiate between specific populations, e.g., obese individuals, restraint eaters, or cognitively impaired patients, we would likely have observed diverging outcomes.

Finally, we confined our analyses to two and not four food categories as previous studies using the LFPQ have done. Stratifying the foods into categories of sweet and savory in addition to healthy and unhealthy would have caused different and possibly more comparable results with previous LFPQ studies. Although we did control for taste categorization, this was outside the scope of our research aim, as we were not a priori interested in any taste-related effects, such as in sensory specific satiety/desire [5, 24].

6. Conclusion

Taken together, this study has underlined the importance of the often-underrated effects of environmental sounds on food valuation and behavior. By bridging theory and practice from sensory, nutritional, and psychological sciences, we have demonstrated that relaxing nature sounds can increase certain reward responses to healthier foods, as determined by explicit liking and relative preference, but not other metrics, including explicit and implicit wanting. Furthermore, the findings suggest that stressful restaurant noises may provoke less deliberate food choices, as indicated by a shortened decision process time. The present study thus exemplifies that contextual manipulation of reward measures is feasible in online settings. In circumstances where onsite behavioral experimentation is impractical, faster and more convenient online adaptations may be a reasonable trade-off and a supplementary methodology to procedures with physiological measurements.

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.

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