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THE ROLE OF SOUND VALENCE IN SHAPING TASTE PERCEPTION ACROSS DIFFERENT SOUND ENVIRONMENTS

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ABSTRACT

The sensory characteristics of the environments where food and beverages are consumed daily can play an important role in shaping taste perception in individuals. Recent research has shown that modifying external sensory stimuli, such as auditory cues from the environment, can influence taste experiences of sweetness and bitterness through cross-modal interactions. Understanding how different sound environments moderate consumers' taste perception can lead to designing the human experience by manipulating the sound environments. Here, through a laboratory study, we assessed the acoustics and psychoacoustics metrics of seven different sound environments (i.e., from tranquil parks to noisy food courts) where people consume everyday food and beverages: a hotel breakfast room, a food court, a café, a bar, a corner with a vending machine, a green urban park, and piazza. Importantly, while listening to soundtracks of the sound environments, participants rated their valence and the taste perception of unsweetened orange juice. Cluster-based analyses and linear regressions were employed to evaluate the correspondence between valence and taste perception of different sound environment clusters. Regression analyses demonstrated a significant positive relationship between sound valence and sweetness perception, with the cluster of lower sound levels exhibiting the strongest impact.

Keywords: *sound environment, taste perception, multisensory interaction, orange juice*

1. INTRODUCTION

Taste perception is a multisensory process that does not occur in isolation but is shaped by the context in which food and beverages are consumed. Research in cross-modal perception has shown that auditory stimuli can significantly modulate how food tastes, particularly in dining environment settings where sound is rarely neutral [1-2]. In this context, emotionally pleasant extrinsic sounds, often referred to as having high "sound valence", influence shaping food flavor evaluation and liking [3].

While early studies have often focused on the effects of musical stimuli [4], more recent studies have shifted toward exploring the influence of everyday environmental soundscapes. For instance, pleasant music was shown to enhance the taste of chocolate in a dining context [5], while rough, sharp, or loud background noise, such as in traffic-heavy urban settings, can suppress sweetness in orange juice [6-7] and overall food liking [8]. These effects are often attributed to emotional congruency: pleasant sounds evoke positive affect, which then biases taste perception in similarly positive ways.

The concept of "sonic seasoning" has been applied in experimental dining and retail settings to subtly shift consumer taste experiences through background sound [9-10]. However, most of these applications have focused on controlled sound cues to achieve equal average sound pressure levels to create a "pleasant" listening experience [2, 11-12]. However, to our knowledge, less is known about how real-world environmental acoustics, including psychoacoustic metrics like roughness and sharpness, influence taste perception.

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This study aims to bridge that gap by examining how different sound environments, ranging from tranquil parks to noisy food courts, influence taste perception of an unsweetened orange juice. By clustering real soundscapes into three emotional-acoustic groups, we evaluated how sound valence affects perceived sweetness, sourness, and bitterness. We hypothesised that each sound cluster has different influence on the juice taste perception. Ultimately, our findings may inform multisensory design strategies in food service, health, and marketing, highlighting that what we hear can indeed change how we taste.

2. MATERIAL AND METHODOLOGY

2.1 Participants

A total of 110 participants took part in the study, including 56 individuals in Italy and 54 in Indonesia. All participants were university students or staff aged from 19 years old to 49, with normal hearing and no reported taste or smell impairments. The experimental protocol was approved by the ethical committees of both Universities and written informed consent was obtained from all participants.

2.2 Experimental Setting

The experiment was conducted in controlled sensory labs: the Sens i-Lab at the Università degli Studi della Campania "Luigi Vanvitelli" (Italy) [13], and the PARLab at the University of Indonesia. Ambient conditions such as lighting, temperature, and air quality were kept constant throughout the sessions to minimize extraneous sensory influence.

2.3 Sound Stimuli

Seven sound environments were selected to reflect common everyday eating and drinking contexts: hotel breakfast room, café, bar, food court, vending machine corner, urban park, and city piazza. All recordings were made in the city of Aversa in Italy, between 8:00 a.m. and 2:00 p.m. on weekdays during breakfast and lunch, representing various background sound environments. A small portable four-channel system (SQobold Head Acoustics) with a binaural headset (BHS II – Head Acoustics) was used for recording to ensure acoustically accurate captures.

Audio samples lasting 5 min were extracted and analyzed using Artemis Suite 14.3 software. Table 1 shows the values of acoustic descriptors and psychoacoustic metrics of the selected audio samples. According to the ISO/TS 12913-3 guidelines and study findings [14] only the maximum values between the left and right channels were considered.

Table 1. Acoustics descriptors and psychoacoustic metrics of the seven sonic environments: 1) hotel breakfast room, 2) cafe, 3) bar, 4) food court, 5) vending machine space (VM), 6) park and 7) Piazza.

Acoustic and psychoacoustic metrics		Hotel	Cafe	Bar	Food court	VM	Park	Piazza
L_{eq}	dB	64.1	73.5	77.2	74.6	76.5	64.3	74.8
$L_{A,eq}$	dBA	58.7	66.6	71.4	68.3	68.4	48.7	64.3
$L_{A,5}$		64.0	71.3	75.3	71.3	72.7	51.4	68.3
$L_{A,95}$		53.6	60.2	66.1	64.7	61.5	45.2	58.9
$L_{A,5}$-$L_{A,95}$		10.4	11.1	9.2	6.6	11.2	6.2	9.4
L_{eq}-$L_{A,eq}$		5.4	6.9	5.8	6.3	8.1	15.6	10.5
N	sone	9.77	19.45	26.55	22.70	21.90	6.51	17.10
N_5		16.10	27.95	33.60	27.90	30.45	8.11	21.90
N_{95}		7.63	14.55	20.20	19.00	15.95	5.09	13.35
S	acum	1.76	2.25	2.55	2.16	2.03	1.45	1.75
R	asper	0.032	0.032	0.036	0.037	0.037	0.020	0.033
F	vacil	0.019	0.036	0.033	0.025	0.022	0.006	0.025

The seven audio stimuli were played back using a laptop and Sennheiser Series HD 200 Pro headphones. The audio stimulus presentation was randomized through the PsychoPy [15] and counterbalanced across individuals. To reproduce the in-situ sound levels correctly, the playback chain was calibrated and equalized by applying the EQ inverse filters obtained by measurements at the left and right channels of Cortex Manikin MK2.

2.4 Taste Stimulus

The gustatory stimulus was unsweetened orange juice (5.5 g sugar/100 mL) served in identical yellow cups. The test room of the Sens i-Lab was set up to minimize visual and thermal bias. The same juice sample was used across all auditory conditions to examine the effect of the sound environment.

2.5 Procedure

A within-subjects experimental design was prepared. Each participant experienced all seven auditory conditions in a randomized order, allowing for a direct comparison of how different sound contexts influenced taste perception. The auditory conditions were presented using PsychoPy software [15]. Participants were seated, in the Sens i-Lab in Italy and the PARLab in Indonesia, wearing over-ear headphones and an eye mask to focus attention solely on the auditory and gustatory stimuli. Each participant was provided with seven yellow plastic cups of juice arranged left to right in numbered order (1 to 7).

After reviewing the instructions on the screen, participants began each trial by clicking to initiate the sound playback. While listening, participants first evaluated the juice's *aroma* by deeply inhaling from the cup, then tasted the juice. After each tasting, they rated the juice's perceived *sweetness, sourness, bitterness, freshness, and thickness*, as well as the overall appeal of the juice and the *valence of the sound* environment using a 7-point Likert scale. Demographic information and individual juice consumption habits were collected at the end of the session. A water rinse was used between each tasting to clean the palate.

2.6 Data Analysis

A k-means cluster analysis was initially conducted to group the sound environments based on their acoustic and psychoacoustic properties, resulting in three distinct clusters. Subsequently, linear regressions were performed separately within each cluster to assess the relationship between sound valence and perceived taste attributes (sweetness, sourness, and bitterness). This approach enabled the evaluation of how sound–taste correspondences varied depending on the type of acoustic environment. Further, each model examined whether valence ratings could significantly predict the taste attribute within that cluster.

3. RESULTS AND DISCUSSION

3.1 Cluster Analysis of Sound Environment

The k-means cluster analysis was conducted using a range of acoustic and psychoacoustic features, including sound level, fluctuation strength, roughness, and sharpness. Data were analysed using the Lloyd algorithm.

The resulting cluster plot (Figure 1a) reveals three main distinct sound environment clusters, based on their spatial proximity in the Principal Component Analysis (PCA) space derived from a total of 12 acoustic and psychoacoustic input variables (Figure 1b). The variables used for clustering include acoustic descriptors (L_{eq}, $L_{A,eq}$, $L_{A,5}$, $L_{A,95}$, $L_{A,5}$-$L_{A,95}$ and L_{eq}-$L_{A,eq}$) and psychoacoustic metrics (N, N_5, N_{95}, S, R and F).

Cluster 1 (red), which includes the *Park* and *Piazza* environments, represents outdoor settings characterized by relatively low sound levels with low-frequency contents. This is evident from the strong contribution of L_{eq}-$L_{A,eq}$, highlighting the dominant role of these frequencies in shaping the acoustic profile of these spaces. Sounds in this group include some natural elements (e.g., birdsong, wind, leaves) and a surrounding far background road traffic noise resulting in an overall serene and unintrusive auditory environment.

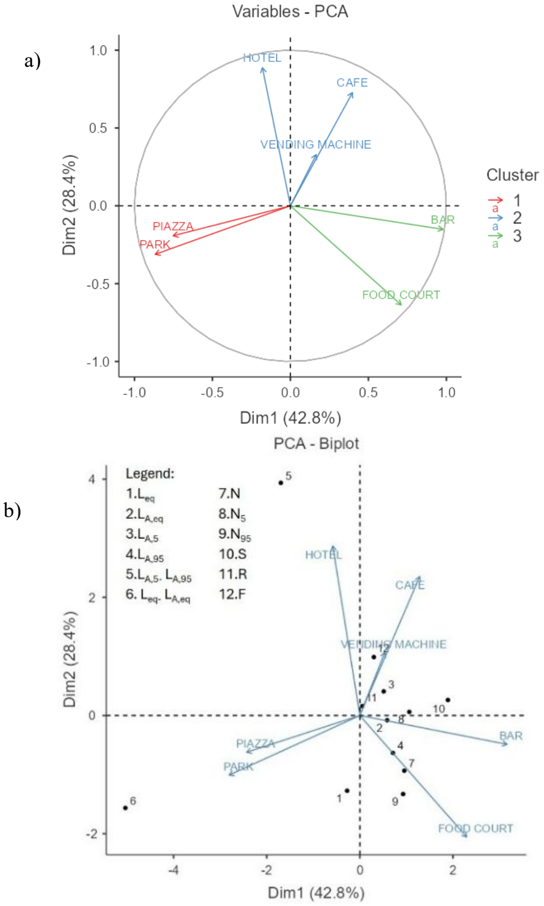

Figure 1. (a) Cluster plot of sound environment (b) PCA plot of sound environment associated with acoustic and psychoacoustic indicators.

Cluster 2 (blue) includes *Hotel*, *Cafe*, and *Vending Machine*. It is related to indoor machines-associated environments with pronounced sound variability. The PCA loadings show strong contributions $L_{A,5}$-$L_{A,95}$, indicators of dynamic and variability over time of the acoustic environment. Additionally, features such as roughness, fluctuation strength, and $L_{A,5}$ contribute notably, highlighting the presence of mechanical or sudden loud sounds like sound of

beverages cans, clinking of cutlery, and machine beeps, especially for vending machine and coffee machine sound.
Cluster 3 (green) includes *Bar* and *Food court*, representing socially energetic environments with high loudness levels. This cluster shows strong loadings on overall loudness- implying consistently high sound levels with less fluctuation between quiet and loud moments. Psychoacoustic attributes like sharpness and tonality are prominent, suggesting a rich mix of music, voices, clinking glasses, and overlapping conversations. These are socially vibrant and acoustically dense settings where the soundscape is continuously energetic, making them perceptually immersive but potentially overwhelming.
Overall, the clustering reveals that sound environments differ not only in their acoustic structure but also in their emotional tone and these differences likely shape how participants perceive taste. This cluster framework provides a meaningful lens through which to interpret the influence of auditory context on gustatory experience in the subsequent regression analyses.

3.2 Regression of sweetness on sound valence

The regression analysis predicted that sound valence was positively associated with perceived sweetness across all clusters, with varying strengths. In Cluster 1 (*Piazza* and *Park*), a moderate and statistically significant relationship was found (β=0.361, R^2=0.157, p<0.0001), suggesting that serene and emotionally positive environments enhance sweetness perception more robustly. These findings are consistent with prior research showing that positive auditory stimuli, such as consonant or harmonious sounds, can enhance sweetness perception through affective cross-modal interactions [2-3]
In Cluster 3 (*Bar* and *Food Court*), the association was also significant, though slightly weaker (β=0.368, R^2=0.144, p<0.0001). These socially vibrant environments, while acoustically more dynamic, still demonstrated an ability to support sweetness enhancement when the sound was rated positively, possibly due to increased arousal in bar music sound and attentional engagement with the tasting experience [5].
By contrast, Cluster 2 (*Hotel*, *Café*, and *Vending Machine*) showed a much weaker association (β=0.257, R^2=0.064, p<0.0001). While still statistically significant, the smaller effect size suggests that machine-dominated may not facilitate sweetness perception as effectively [6].

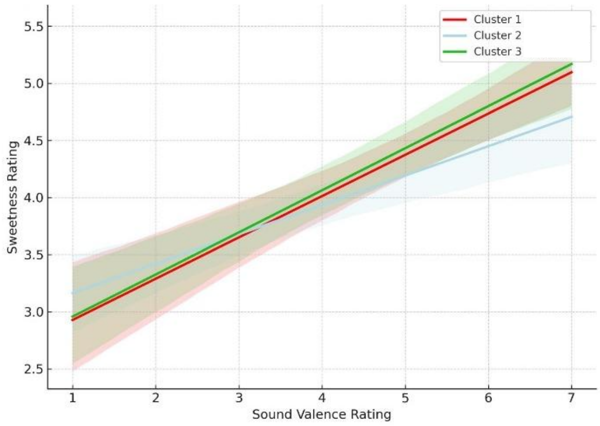

Figure 2. Regression of sweetness on sound valence divided by cluster of sound environment

The findings suggest that sweetness is not solely a function of chemical composition but is also subject to modulation by the emotional quality of the multisensory context in which tasting occurs. In real-world settings, this implies that enhancing the emotional pleasantness of ambient soundscapes may provide a subtle but meaningful way to elevate perceived sweetness without altering a product's ingredients [16-17].

3.3 Regression of sourness on sound valence

For sourness, a negative relationship with sound valence was observed, though the effect was strongest in Cluster 3 (β=-0.204, R^2=0.0447, p=0.0016), followed by Cluster 1 (β=-0.128, R^2=0.0188, p=0.0424), and was non-significant in Cluster 2 (β=-0.069, R^2=0.004, p=0.2306). These findings suggest that emotionally pleasant soundscapes, especially in more dynamic environments, can suppress negative tastes such as sourness. This finding aligns with theories of emotional congruency and attentional bias, which propose that pleasant environments may reduce attentional resources allocated to negative sensory processing [18]. In this case, a more pleasant auditory atmosphere may buffer the perceived intensity of sourness, which consider as negative dimension. The diminished significance effect in Cluster 2 (fig.4) could be attributed to increased sound variability, which may overload cognitive processing and thus weaken the impact of emotional valence on taste judgments.

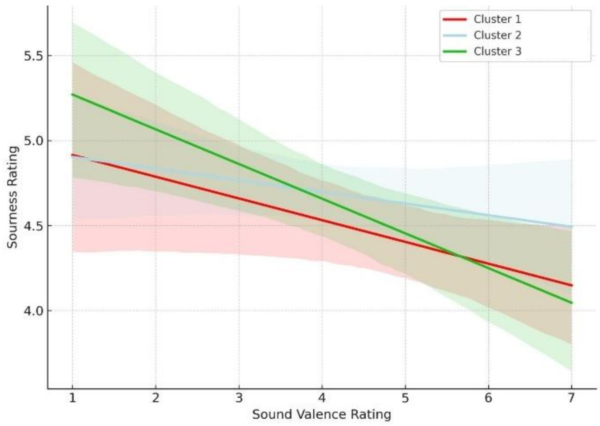

Figure 3. Regression of sourness on sound valence divided by cluster of sound environment

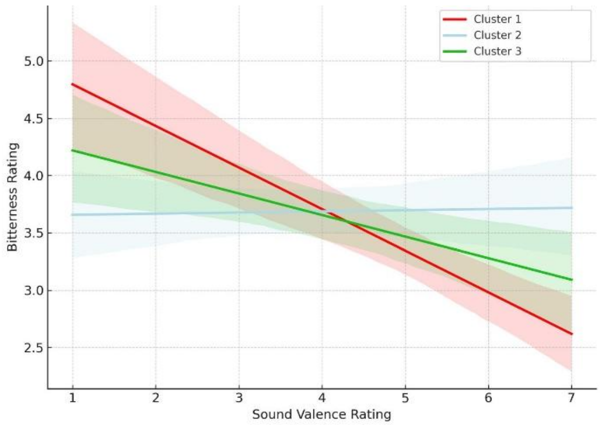

Figure 4. Regression of bitterness on sound valence divided by cluster of sound environment

3.4 Bitterness

In the case of bitterness, a comparable pattern to sourness was found, with emotionally positive soundscapes predicting the attenuation of the perception of bitter tastes. Cluster 1 exhibited a strong negative association (β=-0.363, R^2=0.132, p<0.0001), indicating that acoustically calm and naturalistic environments, such as parks or piazza, substantially decrease the experience of bitterness. Cluster 3 also showed a significant, though more moderate, negative relationship (β=-0.188, R^2=0.0391, p=0.0032), suggesting that socially vibrant and emotionally pleasant soundscapes (e.g., bars and food courts) retain a capacity to diminish bitterness, possibly through distraction or emotional enhancement pathways. Results suggest that participants were less sensitive to bitterness when soundscapes were emotionally positive.

In contrast, Cluster 2 showed no significant association (β=0.0101 R^2=0.000086, p=0.8667), reinforcing the idea that machinery sounds, such as coffee machines in hotel breakfast rooms or vending machine areas, were not lowering the bitterness perception.

Overall, these results highlight the importance of emotional content within soundscapes, not just their acoustic and psychoacoustic metrics intensity [6,8], in shaping taste experiences. This supports emerging multisensory theories which propose that affective congruence across modalities (e.g., pleasant sounds and flavours) enhances the integration and perception of flavour [17]

4. CONCLUSION

This study showed how the emotional valence of acoustic environments significantly influences taste perception, particularly for sweetness. The strongest effects were observed in Cluster 1, emotionally positive and acoustically calm environments, where regression analysis revealed the highest model fit (R^2=0.157, p<0.0001). These environments appear to foster stronger cross-modal integration, enhancing sweetness perception. For sourness and bitterness, valence effects were weaker but consistent, with significant reductions found in Clusters 1 and 3. In contrast, Cluster 2 showed no significant impact, likely due to its machinery sound high sound variability. These results have practical implications for soundscape design in food-related contexts. Pleasant sound environments may enhance flavor experience and support health goals (e.g., reducing added sugar or masking sourness and bitterness) without modifying food ingredients. Future research could explore other emotional dimensions of sound or test similar interventions in real-world dining.

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