Psychoacoustic characteristics of music soundtracks moderate juice taste perception

Noor Fajrina Farah Istiani[1] Massimiliano Masullo [2] Luigi Maffei [3]
Department of Architecture and Industrial Design, University of Campania "Luigi Vanvitelli",
Via San Lorenzo – Abazia San Lorenzo, Aversa (CE), Italy

Gennaro Ruggiero [4]
Department of Psychology, University of Campania "Luigi Vanvitelli", Caserta, Italy
Viale Ellittico 31, Caserta, Italy

Marco Francini [5]
Conservatorio Statale di Musica di Benevento "Nicola Sala",
Via M. La Vipera, 1, Benevento, Italy

ABSTRACT

Eating and drinking constitute the most multisensory aspect of our daily lives. Altering external sensory factors, particularly auditory stimuli, has been suggested as a promising factor for influencing taste perception. In this context, this study investigated the effect of music on the taste of orange juice in a multisensory and controlled indoor environment laboratory (Sens i-Lab). We conducted a juice-tasting experiment, focusing on individuals' flavour perception while exposed to eight music soundtracks that were created, manipulating three sonic attributes (Articulation, Tempo, and Pitch). The audio stimuli underwent analysis using various psychoacoustic parameters, including sound pressure level, loudness, sharpness, roughness, fluctuation, and tonality. Correlation analysis revealed specific patterns between the average taste ratings of orange juice and the psychometric characteristics of eight music soundtracks. The sweet flavour exhibited negative correlations with roughness. Besides, the sour and bitter taste showed positive correlations with sound level.

1. INTRODUCTION

Enjoying food and drinks involves various senses, including internal aspects like taste and external stimuli [1]. Recent interest has grown in exploring how sounds and music can influence food and beverages' aroma and basic taste attributes. Musical sounds may vary according to the characteristics of notes, instruments, compositions, and ready music soundtracks [2–9]. Studies examining cross-modal correspondences between tastes and music have found correlations between auditory characteristics and flavours. For instance, vanilla

[1] noorfajrinafarah.istiani@unicampania.it
[2] massimiliano.masullo@unicampania.it
[3] luigi.maffei@unicampania.it
[4] gennaro.ruggiero@unicampania.it
[5] m.francini@conservatorio.bn.it

flavour is linked to slow tempo and legato articulation, while citrus flavour is associated with sharp timbre and staccato articulation [10]. However, whether each musical attribute can exalt the basic tastes like sweet, sour, and bitter remains unclear.

Research on music articulation indicates that soft sounds align with lengthy, consonant, and legato notes, while strong sounds are characterised by short and discordant staccato notes [6]. Cross-modal mapping indicates associations between sweet tastes and consonant chords, and sour tastes with dissonant chords pitch variations affect the intensity of basic taste [10–12]. Furthermore, another study conducted an experiment wherein participants were asked to choose a sound that matched the flavour. Low-frequency trombone melodies were a defining characteristic of the bittersweet sound [4]. On the other hand, high-frequency piano melodies were linked to the sound associated with sweetness and sourness [3,13,14]. Similar outcomes were obtained in recent multisensory experiments [15], which demonstrated the impact of high-frequency tones on elevating the intensity perception of juice sweetness.

Although studies examining composed music soundtracks' impact on the perception of sweetness and sourness have been conducted (i.e. on wine) [8], limited research focused on the correlation between music attributes, their auditory perception, and beverage aroma, flavour and mouthfeel.

As perception of intricate acoustic settings cannot be predicted by descriptors like the A-weighted sound pressure level [16,17], besides traditional acoustic descriptors, psychoacoustic metrics could help to find potential correlations. Recent groundbreaking experimental research by Istiani, Masullo & Ruggiero [18) and Lin et al. [19] showed that some psychoacoustics characteristics of a dining setting sound can significantly affect how much food and drink taste.

While there is a growing interest in applying digital technologies in commercial dining, music sound design is still uncommon in everyday settings. This research emphasises the need to investigate specific music attributes for multisensory stimulation, especially for replicating effects in daily scenarios like home, workplace, or educational settings. In the current study, we are interested in understanding the role of different characteristics of background music sound on taste perception. To this aim, we investigated the correlations between the music soundtrack acoustic and psychoacoustic factors on the taste perception and the mouthfeel of orange juice in a controlled indoor laboratory setting.

2. MATERIAL AND METHODOLOGY

2.1. Participants

A cohort of 60 participants (28 men and 32 women) aged 19 to 40 (M_{age}=25.1 years; SD_{age}=4.8 years) was recruited. The number of participants is in line with the recommendation of Gacula and Rutenbeck [21] of sample sizes between 40 and 100 for evaluating consumer sensory tests. All participants were recruited among faculty members and undergraduate, graduate, and doctorate students of the Department of Architecture and Industrial Design at the University of Campania "Luigi Vanvitelli" (Italy). Every participant voluntarily provided written consent after being fully informed about the study. Every participant in the study stated that they were not suffering from a cold, the flu, or any other transient respiratory issue. They also had no history of taste, smell, or hearing problems. The participants attested to their adherence to the eligibility requirements of the study. In general, none of the people drank juice very often.

2.2. Experiment Setting

The experiment was conducted in the Sens i-Lab, the multisensory and human-centered laboratory of the Department of Architecture and Industrial Design at the University of

Campania "Luigi Vanvitelli" [22]. The test room's microclimate was meticulously controlled and maintained during each testing session, with a z velocity (v_{air}) of less than 0.15 m/s, a relative humidity (R.H.) of 50%, and a constant dry bulb temperature (t_{db}) of 24 °C. Figure 1 shows an illustration of the test room setup.

Figure 1 – Fruit Juice Experiment setup at Sens i-Lab.

2.3. Stimuli

2.3.1 Taste Stimuli

The selection of orange juice as the taste stimulus was based on its widespread consumption in Europe and the United States [23]. To ensure experiment reliability and minimise taste variations arising from juice characteristics, a commercially available unsweetened orange juice with a small amount of sugar (5.5 grams per 100 ml) was chosen. The juice's consistency in ingredients, composition, and particle density distribution was crucial. Maintained at a constant temperature of 24 °C in the test room, the juice aimed for uniform density and odorant characteristics. Yellow plastic cups were employed to prevent participants from guessing the juice's colour accurately, thereby reducing potential biases in their responses. Each participant consumed the beverage individually, with an average consumption of approximately 80-140 ml per trial, based on a sip size of around 10-15 ml during the experiment.

2.3.1 Music Stimuli

Three different musical characteristics, each of them assuming two different levels: Articulation (legato and staccato), Tempo (70 and 120 bpm), and Pitch (low and high), were combined to create eight distinct soundtracks of the same compositions in the same musical key:
- Legato melody with low-frequency notes, from middle C to lower octaves, and 70 bpm;
- Legato melody with high-frequency notes, from middle C to upper octaves, and 70 bpm;
- Staccato melody with low-frequency notes, from middle C to lower octaves, and 70 bpm;
- Staccato melody with high-frequency notes, from middle C to upper octaves, and 70 bpm;
- Legato melody with low-frequency notes, from middle C to lower octaves, and 120 bpm;
- Legato melody with high-frequency notes, from middle C to upper octaves, and 120 bpm;
- Staccato melody with low-frequency notes, from middle C to lower octaves, and 120 bpm.
- Staccato melody with high-frequency notes, from middle C to upper octaves, and 120 bpm.

An additional experimental condition, the "Control" (CTRL), with no sound played back in the test room and the A-weighted sound equivalent level of less than 35 dB(A), was further considered. As this latter condition was not associated with the musical characteristic under investigation, it was excluded from the analyses of this paper. The eight remaining auditory conditions were labelled as follows: Leg70Low, Leg70High, Leg120Low, Leg120High, Sta70Low, Sta70High, Sta120Low, and Sta120High.

To get binaural recordings of the music and to analyse the acoustic and psychoacoustic meters of the music, a portable four-channel system (Sqobold, Head Acoustics) equipped with a binaural headset (BHS II, Head Acoustics) was used. Two-minute-long, noise-free music samples were extracted and analysed using the Artemis suite 14.1 software. In line with the suggestion of ISO/TS 12913-3 [24] and of Yang & Masullo [25] findings, only the maximum values between the left and right channels of binaural, acoustics (L_{eq}, L_{Aeq}, L_{A5}, L_{A95}, L_{A5}-L_{A95}, and L_{eq}-L_{Aeq}) and psychoacoustics (N, N_5, and N_{95}; S, S_5, and S_{95}; F, F_{10}, and F_{50}; R, R_{10}, and R_{50}; T), metrics were considered (Table 1).

Table 1: Acoustics and psychoacoustic descriptors of music stimuli

		Leg70Low	Leg70High	Leg120Low	Leg120High	Sta70Low	Sta70High	Sta120Low	Sta120High
Sound Level [dB]	L_{eq}	61.4	63.6	61.9	63.1	60.4	60.5	58.0	62.8
	L_{Aeq}	58.3	63.3	58.9	62.4	55.9	59.9	54.6	62.5
	L_{A5}	62.3	70.7	63.3	69.8	61.0	67.9	59.5	70.6
	L_{A95}	47.6	43.0	50.7	48.2	46.9	43.0	47.5	46.7
	L_{A5}-L_{A95}	14.7	27.8	12.7	21.6	14.1	25.0	12.0	23.8
	L_{eq}-L_{Aeq}	3.1	0.3	3.0	0.7	4.5	0.6	3.4	0.3
Loudness [sone$_{GF}$]	N	8.27	5.75	9.03	7.42	7.17	4.86	5.81	5.86
	N_5	12.40	11.60	13.40	11.40	11.50	9.42	10.60	10.90
	N_{95}	3.86	2.51	4.42	3.99	4.03	2.46	2.83	3.19
Sharpness [acum]	S	1.480	1.490	1.680	1.530	1.410	1.720	1.700	1.720
	S_5	2.290	2.410	2.540	2.380	2.260	2.910	2.850	2.770
	S_{95}	0.924	0.801	1.060	0.970	0.844	0.929	0.939	1.020
Fluctuation Str. [vacil]	F	0.097	0.184	0.126	0.106	0.088	0.174	0.272	0.171
	F_{10}	0.147	0.256	0.253	0.164	0.138	0.255	0.352	0.224
	F_{50}	0.088	0.179	0.092	0.102	0.079	0.164	0.266	0.168
Roughness [asper]	R	0.366	0.166	0.320	0.222	0.367	0.174	0.273	0.180
	R_{10}	0.584	0.264	0.474	0.316	0.601	0.252	0.378	0.226
	R_{50}	0.336	0.154	0.285	0.207	0.332	0.168	0.253	0.183
Tonality [tuHMS]	T	0.829	1.06	0.744	1.07	0.73	0.774	0.498	0.858

Table 1 shows that the sound levels of legato music soundtracks are higher than those of staccato, except for the case of 120 bpm and high pitch. Leg70High has the highest A-weighted sound equivalent level among 63.3 dB(A), while the staccato music soundtracks with low-pitch have the lowest. Moreover, the dynamic of the A-weighted sound equivalent level is explained by the difference L_{A5}-L_{A95}, which has higher values with high-pitch conditions. As also expected, the difference between L_{eq}-L_{Aeq} can describe the low-frequency content of soundtracks, which are higher for low than high pitch.

Considering the psychoacoustic metrics, we can observe that the average loudness values of the legato music soundtracks are louder than those of staccato, while sharpness results higher in staccato and high-pitch music (Sta70High and Sta120High = 1.72 acum). Moreover, music with low pitch has higher roughness than those with high pitch, and fluctuation strength is higher combining a fast tempo [120 bpm] and low Pitch.

2.4. Procedure

The participants were seated at desks within the Sens i-Lab testing. Nine identical yellow cups containing orange juice were arranged on the desk and numbered from 1 to 9, left to right. Participants were instructed to assess the scent and flavour of each cup. The experiment commenced with the initiation of music stimuli. Using PsychoPy software [26], eight different music tracks and a control (no sound) were randomly played back for each participant through a laptop and a Sennheiser HD 200 Pro headset. Participants rinsed their mouths with water before and between sessions.

First, subjects evaluated the aroma intensity of the juice on a 7-point Likert scale. Then, they tasted the orange juice while the music played in the background. After consumption, participants used the same scale (from 1 "Not at all" to 7 "Extremely") to rate the juice's sweetness, sourness, and bitterness along with its freshness and thickness, and finally, to give their overall valence for the juice and music. Additionally, participants rated their arousal level regarding the music from 1 (Calm) to 7 (Excited). Biometric data, including weight and height, were collected, along with participant socio-demographics such as age, gender, juice consumption frequency, and general preference for sweet beverages. The entire experimental cycle, comprising nine rounds, lasted approximately 20-25 minutes.

2.4. Data Analysis

The acoustics and psychoacoustic descriptors of the eight music soundtracks were correlated with the average participant ratings on each taste attribute (sweetness, sourness, bitterness), mouthfeel rating (freshness, thickness), and their overall liking of fruit juice and each music soundtrack valence rating. This was done by calculating Pearson's correlation coefficients.

3. RESULTS AND DISCUSSION

Table 2 shows the correlation matrix among the acoustics and psychoacoustic metrics of the eight music soundtracks, the juice taste (sweetness, sourness, and bitterness) and mouthfeel (freshness and thickness) ratings of the juice, the general liking of the juice (juice valence) and music (music valence).

Table 2: Correlation matrix between acoustic, psychoacoustic metrics, juice taste and mouthfeel ratings, and valence.

	Sweetness	Sourness	Bitterness	Freshness	Thickness	Juice Val	Music Val	Music Arou
L_{eq}	0.401	-0.379	-0.486	0.037	-0.254	0.422	0.333	-0.015
L_{Aeq}	0.645	-0.539	-0.621	0.342	-0.538	0.606	0.637	0.088
L_{A5}	0.687	-0.535	-0.647	0.438	-0.628	0.658	0.668	0.096
L_{A95}	-0.394	**0.724***	**0.874****	-0.24	0.225	**-0.786***	-0.482	0.551
L_{A5}-L_{A95}	0.669	-0.695	**-0.840****	0.422	-0.555	**0.812***	0.692	-0.159
L_{eq}-L_{Aeq}	**-0.783***	0.606	0.644	-0.607	**0.742***	-0.685	**-0.843****	-0.184
N	-0.329	0.399	0.54	-0.549	0.43	-0.548	-0.493	0.058
N_5	-0.373	0.303	0.331	-0.479	0.394	-0.406	-0.343	0.086
N_{95}	-0.376	0.582	0.658	-0.562	0.391	-0.631	-0.663	0.146
S	0.166	0.192	0.227	0.431	**-0.813***	-0.241	0.534	0.431
S_5	0.198	0.048	0.05	0.51	**-0.741***	-0.048	0.542	0.618
S_{95}	0.004	0.482	0.618	0.076	-0.518	-0.62	0.118	**0.748***
F	0.105	-0.056	-0.055	0.695	-0.343	0.161	0.502	0.388
F_{10}	0.092	0.073	0.078	0.584	-0.44	0.048	0.517	0.441
F_{50}	0.142	-0.127	-0.127	**0.738***	-0.306	0.236	0.5	0.353
R	-0.698	0.492	0.592	**-0.724***	**0.770***	-0.684	**-0.833***	-0.227
R_{10}	-0.673	0.391	0.463	**-0.781***	**0.820***	-0.573	**-0.836****	-0.379
R_{50}	**-0.712***	0.491	0.593	**-0.720***	**0.765***	-0.706	**-0.838****	-0.216
T	0.601	-0.572	-0.602	0.161	-0.139	0.665	0.355	-0.142
Sweetness	—	-0.649	-0.439	0.639	-0.51	**0.741***	**0.756***	0.150
Sourness		—	0.877**	-0.281	0.098	**-0.821***	-0.644	0.440
Bitterness			—	-0.152	0.159	**-0.829***	-0.548	0.561
Fresh				—	-0.447	0.486	0.674	0.607
Thickness					—	-0.167	**-0.724***	-0.436
Juice Val						—	0.604	-0.317
Music Val							—	0.236
Music Arousal								—

Nota. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3.1. Correlation matrix between acoustic, psychoacoustic metrics, and juice taste rating

The result shows that the *sweetness* rating of the orange juice has a significant negative correlation with the low-frequency content, L-L_A, ($r=-0.783$, $p<0.05$), as well as with the roughness, R_{50} ($r=-0.712$, $p<0.05$). On the other hand, the *sourness* taste rating of the juice has a significantly positive correlation with the 95th percentile of the A-weighted sound level, L_{A95} ($r=0.724$, $p<0.05$). The juice *bitterness* has positively correlated with the 95th percentile A-weighted sound level, L_{A95} ($r=0.874$, $p<0.01$), but has a negative correlation with sound variability, L_{A5}-L_{A95} (r=-0.840, p<0.01). Moreover, the *bitterness* positively correlates with the juice *sourness* rating (r=0.877, p<0.01).

Overall, the correlation shows that people perceive orange juice to be less sweet while listening to the high sound level in the low frequency and the high roughness levels of the music. Music with low pitch has higher roughness. Therefore, the result indicates that the sweet taste is highly associated with the high frequency of the sound, as popularly mentioned in earlier studies [3,13,14,15].

On the other hand, orange juice's sourness is detected to a greater extent at higher sound levels. Also, the bitterness of the juice is indicated more when the music has a high sound level with low sound variability. These findings support the earlier notion that suggested a positive association between unpleasantness and sound level as well as sound roughness [27]. Specifically, taste unpleasantness implies orange juice's sourness and bitterness,

3.2. Correlation matrix between acoustic, psychoacoustic metrics, and juice mouthfeel rating

In terms of the oral somatosensory or the mouthfeel rating of the orange juice, the *freshness* rating shows a significant negative correlation with the roughness, R (r=-0.724, p<0.05), R_{10} (r=-0.781, p<0.05), R_{50} (r=-0.720, p<0.05), and positive correlation with fluctuation, F_{50} (r=0.738, p<0.05). The thickness rating of juice demonstrates a positive correlation with the low-frequency content in the music, L-L_A, (r=0.742, p<0.05). Moreover, juice thickness also has a negative correlation with the Sharpness S (r=-0.813, p<0.05), S_5 (r=-0.741, p<0.05) and positive correlation with roughness, R (r=0.770, p<0.05), R_{10} (r=0.720, p<0.05), R_{50} (r=0.865, p<0.05).

These results confirm a previous theory about a negative relationship between roughness and pleasantness [27]. In this case, the juice freshness is precisely referred to as a taste of pleasantness. Moreover, results depicted a negative association between music sharpness metrics and perception of orange juice thickness. This effect also specified that the low frequency in the music exalts the perception of juice thickness. This finding adds support to the earlier study [28] regarding the relationship between the thickness level of Pinot Noir wine—which was judged to be noticeably fuller-bodied when tasted with a low frequency. Also, another study mentioned the thickness level of orange juice during listening a low frequency pure tone was rated higher than the control condition [15].

3.3. Correlation matrix between acoustic, psychoacoustic metrics, and juice and music Valence.

The *juice valence* has a significantly negative correlation with the 95th percentile level, L_{A95} (r=-0.786, p<0.05), and a positive correlation with sound variability, L_{A5}-L_{A95} (r=0.812, p<0.05). Further, juice liking also has a positive correlation with sweetness (r=0.741, p<0.05) and a negative correlation with both sourness (r=-0.821, p<0.05) and bitterness rating (r=-0.829, p<0.05) of the juice.

Music valence has a negative correlation with Roughness, R (r=-0.833, p<0.05), R_{10} (r=-0.836, p<0.01), R_{50} (r=-0.838, p<0.01), and with the sound level in the low frequency (L_{eq}-L_{Aeq}) (r=-0.843, p<0.01). Moreover, the results showed that the sweetness rating of orange juice interrelates positively with the music valence (r=0.756, p<0.05).

Lastly, the *music arousal* has a positive correlation with the 95th percentile of sharpness S_{95} (r=0.748, p<0.05).

The outcomes indicate that the juice tasted better when participants listened to music with low sound levels, as implied in the previous study [18]. Furthermore, these findings support an earlier suggestion [27] that postulated a negative link between roughness and pleasantness. The output also evoked that the stronger the musical arousal, the greater the sharpness of the music sound. This suggests that the arousal of music is related to the sensory value resulting from high-frequency components [29].

4. CONCLUSION

This study employed a controlled multisensory laboratory (Sens i-lab) to conduct a juice-tasting experiment focusing on people's perception of flavor while listening to eight different music soundtracks. Psychoacoustics criteria were used to analyse the soundtracks. such as loudness, sharpness, roughness, fluctuation, and tonality, were examined. A-weighted sound equivalent levels were also examined. The current study has three primary findings. First, the results of this study show that there are multiple patterns between the psychoacoustics metrics of the music and the average taste rating of the orange juice according to Pearson correlation analysis. Orange juice's sweet taste had a negative correlation with roughness. Conversely, there was a positive correlation found between the strength of the sound level and the sour flavor, and bitterness. Second, a correlation study shows various trends between the orange juice's mouthfeel rating and the music's psychoacoustics metrics. The freshness of the juice had a negative correlation with roughness, and the juice thickness rating was negatively correlated with sharpness and positively correlated with roughness. Lastly, we indicate the positive relation between music valence and the sweet taste perception of the juice.

Our knowledge on how music settings with different acoustic and psychoacoustic properties can affect the flavor of healthy orange juice options can be expanded by the results presented here. This result has applications in the real world. For instance, background music at restaurants can be promptly changed. As a context, more than half of individuals in European nations today do not consume enough fruits and vegetables to meet dietary standards, thus eating while listening to enjoyable music might help enhance the appetite for nutritious food and beverages [30–32]. The necessity of examining musical characteristics for multisensory stimulation is highlighted by this study, particularly to replicate results in everyday contexts such as the home, office, or classroom.

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