Research Article

Received: 23 August 2023 Revised: 19 February 2024 Accepted article published: 5 March 2024 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.13432

Wearable sensors to measure the influence of sonic seasoning on wine consumers in a live context: a preliminary proof-of-concept study

Lucia Billeci,[a] Chiara Sanmartin,[b,c] Alessandro Tonacci,[a*] Isabella Taglieri,[b,c] Giuseppe Ferroni,[b] Roberto Marangoni[d,e] and Francesca Venturi[b,c,d]

Abstract

BACKGROUND: Any action capable of creating expectations about product quality would be able to modulate experienced pleasantness. In this context, during the 2022 edition of the Internet Festival (Pisa, Italy) a 'social experiment' was promoted to set up an affordable and reliable methodology based on wearable sensors to measure the emotions aroused in a live context on consumers by different kinds of wines. Therefore, five wines (two faulty ones and three high-quality samples) were proposed to 50 non-selected consumers in an arousing context with live jazz music as background. Both explicit (questionnaires) and two different approaches for implicit methods (electrocardiogram (ECG) recorded by wearable sensors *vs.* smartphones), the latter performed on a subgroup of 16, to measure the emotions aroused by wines and music were utilized synergistically.

RESULTS: According to our findings: (i) wine undoubtedly generates a significant emotional response on consumers; (ii) this answer is multifaceted and attributable to the quality level of the wine tasted. In fact, all things being equal, while drinking wine even untrained consumers can perfectly recognize good wines compared to products of lower quality; (iii) high-quality wines are able to induce a spectrum of positive emotions, as observed by the analysis of ECG signals, especially when they are coupled with background music.

CONCLUSION: The framework has certainly played to the advantage of good-quality wines, fostering their positive emotional characteristics on the palate even of some less experienced consumers, thanks to a dragging effect towards a positive mood generated by the surrounding conditions (good music in a beautiful location).

Keywords: ECG; emotions; psychophysiology; synesthesia; wearable sensors; wine

INTRODUCTION

Taste perception results from integrating sensations generated by all stimuli.[1] In more depth, concerning stimuli from the surrounding environment, sound and music seem to play a pivotal role in the frame of so-called 'sonic seasoning'.[2] Therefore, over the last decade or so, an understanding of how sounds and music affect sensory perception of foods has been the subject of studies that are increasingly accurate, demonstrating that such environmental stimuli play a key role.[3,4] Numerous studies[5-8] show how people can associate basic tastes with some auditory parameters (e.g., pitch). That the occasion of consumption can influence the emotional experience in the consumption of the product has also been verified through the modeling of structural equations developed by Calvo-Porral *et al*.[9]

Among the most important drinks known to elicit emotions is wine, for which Ristic *et al*. have highlighted a link between the occasion of consumption and sensory perception.[10] It has been observed that consuming wine at restaurants or in social contexts arouses more intense positive emotions than the same evaluation carried out under laboratory conditions. Silva *et al*. also report that consumers prefer to consume wine in convivial situations.[11]

Anything that generates expectations about product quality is potentially able to modulate the pleasantness experienced, and

* *Correspondence to: Alessandro Tonacci, Institute of Clinical Physiology, National Research Council of Italy (IFC-CNR), Via Moruzzi 1, 56124 Pisa, Italy. E-mail: alessandro.tonacci@cnr.it*

a *Institute of Clinical Physiology, National Research Council of Italy (IFC-CNR), Pisa, Italy*

b *Department of Agriculture, Food and Environment, University of Pisa, Pisa, Italy*

c *Interdepartmental Research Centre 'Nutraceuticals and Food for Health', University of Pisa, Pisa, Italy*

d *Interdepartmental Centre for Complex Systems Studies, University of Pisa, Pisa, Italy*

e *Department of Biology, University of Pisa, Pisa, Italy*

the context influences the evaluation of emotions and sensory terms more than wine.[12,13] Therefore, emotions are to be considered a major point in the framework of sensory assessment, being strongly associated with the way consumers prefer or interact with some given foodstuffs, in turn leading to specific purchase choices. However, in the sensory community, the study of emotions is still poorly considered when taking into account strategies to evaluate food preferences or quality. At present, emotional assessment can be performed using two main approaches, relying on completely different paradigms. Traditional principles mainly rely on the so-called 'explicit methods', which include self-reported verbal or written choices performed by an individual or group, towards a foodstuff in a standardized manner. Such methods are well accepted by the community, quick, affordable, and easy to administer, overall; however, they can be affected by cognitive and judgment biases, which can jeopardize the reliability of the test. Fortunately, recent advancements in the field of information technology has shed new light on a different approach, based on implicit measurements, which appear to be feasible also in the complex field of sensory analysis, representing a useful complement to the aforementioned explicit methods.[14] Such an approach makes use of implicit measures, not self-reported, able to infer emotions during a given task, including sensory ones, and relying on the study of the responses of the central nervous sytem[15] (CNS) or autonomic nervous system[16] (ANS) via the recording of biological signals.

Among implicit methods, the electrocardiogram (ECG) represents the electrical activity of the heart and can be investigated through the study of the heart rate (HR) and its variability (HRV). The features extracted with such an approach can be related to both the sympathetic (SNS) and parasympathetic (PNS) branches of the ANS, in turn related to arousal/stress and relaxation mechanisms for the human body.[16] Such information can be easily derived even applying simple, low-cost consumer devices, including fitness-like chest straps or even, especially in recent times, particular smartwatches.[17,18]

On the other hand, electrodermal activity (EDA) relates to the activity of sweat glands. As far as emotional arousal occurs, sudoriferous glands activate, producing sweat, in some instances perceived macroscopically. Sweat is a biological fluid made up of several compounds, including water, electrolytes, fatty acids, lactic acid, and nitrogen metabolites.[19] Such a composition means that sweat is a good electrical conductor, thus making it possible to study the activity of sweat glands through the electrical signal (resistance or conductance) produced, capturing it through minimally invasive wearable sensors. As such, EDA activity is strongly related to SNS activation[20] and can be particularly useful to detect specific, sudden changes in the SNS activity due to quick sensory triggers via the study of its phasic activity.[21,22]

While few data are available in the literature[5] concerning the use of explicit methods (i.e., questionnaires) to measure the influence of sonic seasoning on wine experience in a live context, and despite having already studied the influence of wine only on the biomedical signals mentioned above,[23,24] to the best of our knowledge no data are available about the affordability of wearable sensors in this specific scenario.

Therefore, an innovative 'social experiment' was performed during the 2022 Internet Festival (IF) (Pisa, Italy) in a real live context, to set up an affordable, reliable methodology to measure the influence of sonic seasoning on the emotions aroused on consumers during wine tasting.

In this regard a set of five wines (two faulty and three high-quality samples) were proposed to 50 non-selected volunteers. To highlight the role played by sonic seasoning, each wine was assessed in a two-step process: with or without live jazz music in the background.

During the event, both explicit (questionnaires) and implicit (ECG) methods to measure the emotions aroused by wines and background were utilized in a synergic approach, as explained in more detail in subsequent sections.

MATERIALS AND METHODS

Reference scenario: IF 2022, Pisa, Italy

IF is a scientific–technological educational event that has taken place every year since 2011, in the Italian city of Pisa, headquarters for several universities, research centers and schools for advanced studies, very active also in the field of applied sciences and technology. IF includes events organized throughout the city center, attracting every year thousands of people not only from the scientific universe and academia, but also including families, children, pupils and all the members of civil society. Each of the IF events has a motto around which all the activities are centered, and, for the 2022 event, the motto was '#imperfezione' (the Italian term for 'imperfection', 'flaw' or 'defect'). Within the 2022 event, a joint team composed of scientists from the University of Pisa and the National Research Council of Italy, together with the local musical association 'Associazione Musicale Sinestesica', which organizes 'CantinaJazz', a multisensory format based on wine–music synesthesia, consisting of composing and playing synesthetic jazz music related to wine tasting, participating in the event named 'Emotional imperfections', attended by 50 intrigued and motivated people from civil society who were allowed to participate in the event by signing an appropriate waiver. This privacy statement permitted the organizers to collect physiological signals (ECG) and/or emotional indications (questionnaires) from each participant for the purpose related to the event and subsequent scientific information, in a completely anonymous manner. For practical reasons, each wine was tasted simultaneously by all volunteers involved in the experiment.

Wines

The wines utilized for the experiment (Table 1) were previously characterized by a trained panel working at the Department of Agriculture, Food and Environment (DAFE) of the University of Pisa to determine their main sensory properties (data not shown), together with their overall pleasantness. The panel was composed of eight trained judges (five females and three males aged 23–63 years), mostly expert in wine sensory analysis.

According to the method generally applied by the panel at DAFE,[23,24] the acceptability limit for overall pleasantness was fixed at six points on a scale ranging from zero (undrinkable sample) to nine (optimum quality level).

Emotional questionnaires

The emotional questionnaire was set up starting from a recent literature review.[1] Among the words widely proposed for the emotional description of foods and beverages, eight terms (fear, rage, sadness, disgust, joy, serenity, positive surprise, negative surprise) were selected to represent both positive and negative emotions in their meaning.

At the end of each tasting section, all the participants were asked to fill in, in 3 min, an anonymous Google Form to rate on a scale 0–9 each of terms selected to provide the emotional profile aroused by each wine tasted. Furthermore, in the same Google Form the judges were invited to evaluate the overall pleasantness of each wine tasted as a hedonic parameter (data not shown).

HR measurement

The ECG signal, recorded during the tasting session of the different wines in a subgroup (16 subjects) of the subjects attending the event, was employed to extract the HR feature. As previously mentioned, since the aim of the present investigation was concerned with the performance of a pilot, exploratory study, and for organizational and technical reasons, we tested two different modalities for data acquisition in order to compare their usage and reliability during a semi-structured scenario and 'quasi-real-life' experience. Specifically, in six subjects, HR data were acquired using a commercial wearable device, while ten subjects directly used a smartphone app.

Wearable device acquisition

The wearable device selected to capture the ECG signal and allow detection of HR was the Zephyr BioHarness 3 (Zephyr Technology, Annapolis, MD, USA; Fig. 1).[25] The device consists of a chest strap and an electronics module contained within a chassis, in turn attached to the strap. The device, powered only by an internal rechargeable lithium polymer cell, stores and transmits, by Bluetooth, vital sign data including HR, respiration rate, body orientation and activity. Overall, the application of this device is not invasive, the sensor being small, lightweight and interfaced to the human body by a chest strap, which is worn by the subject without putting creams or gels on the skin.

Passive sensors placed within the strap detect heart ECG signals through conductive pads. A pressure sensor pad in the strap on the subject's left-hand side detects expansion of the rib cage due to breathing action. An internal three-axis accelerometer measures the subject's activity level and the orientation of the device (subject standing, supine, prone, inverted). Regarding HR – the feature of interest in the present study – the acquisition ranges from 25 to 240 bpm, and the signal is acquired at a sampling frequency of 250 Hz.

As mentioned before, physiological data acquired in the six participants agreeing to use the wearable device were sent wirelessly by Bluetooth or 802.15.4 to a receiving device equipped with a graphical user interface. In our specific use case scenario, the device was connected to a smartphone using one of the commercial apps supporting the sensorized strap, namely the BMi HR monitor, selected as being free to use and available for both Android and iOS. After configuration of the individual settings and connection to the device, the app visualizes and stores the HR as the absolute value of beats per minute, as well as the percentage of the stored maximum HR value of the user.

The user started the recording 5 min before the beginning of the tasting session, in order to record the baseline HR activity. Then, the operators manually annotated the time interval for each phase of the task (specified later) in order to associate each of the HR values extracted to one specific phase. At the end of the

Table 1. Main description of the five wines used for the test

Sample code	Wine	Designation of origin	Year	Alcohol content (%)	Area of production	Overall pleasantness
1	Red table wine (RTW)	N/A	2021	13.0	N/A	4.5 ± 0.3
2	White table wine (WTW)	N/A	2021	12.0	N/A	4.9 ± 0.2
3	Brunello di Montalcino (BM)	DOCG	2018	14.5	Montalcino (SI–Italy)	7.8 ± 0.4
4	Vin Santo Riserva (VS)	DOCG	2016	15.5	Arezzo (AR–Italy)	8.2 ± 0.3
5	Vin santo Occhio di Pernice (ODP)	DOCG	2015	17.0	Arezzo (AR–Italy)	8.5 ± 0.5

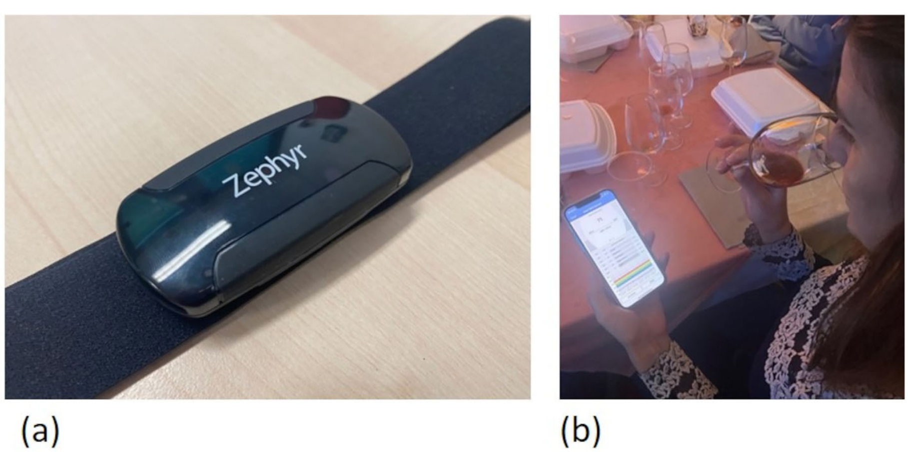
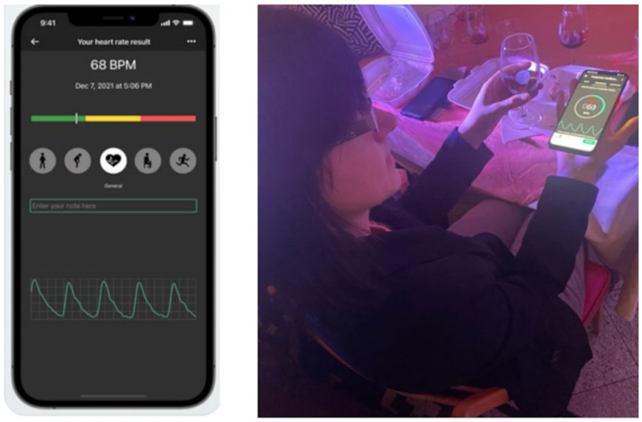


Figure 1. (a) Zephyr BioHarness 3 device. (b) Subject wearing the Zephyr BioHarness 3 device communicating with the smartphone during the tasting.



(a) (b)

Figure 2. (a) Heart rate Monitor Plus app recording photoplethysmographic signal. (b) Subject using the app during tasting.

session, the user terminated the recording, exported the csv file and sent it to the operators by Bluetooth.

Smartphone acquisition

As mentioned above, for the other ten subjects participating in the event and giving their consent to the physiological study, for computing the HR during the tasting session, we used an app available for both Android and iOS called HR Plus. Based on a different principle of operation from that described in the previous section, the app allows recording the HR using the smartphone camera (see Fig. 2). The principle of obtaining HR using the camera is quite different and based on the fact that the camera captures videos of the fingertip and the HR is estimated using the photoplethysmography (PPG) technique. PPG uses low-intensity infrared light. When light travels through biological tissues, it is absorbed by bones, by skin pigments and, even more strongly, by both venous and arterial blood, so that changes in blood flow are detected by PPG sensors as changes in light intensity. This method than allows checking even small changes in blood volume due to the differences in the voltage signal, in turn proportional to the amount of blood flowing through the vessels.[26]

In the present study, the recording of HR during the task was not performed continuously, in order to keep annoyance to minimum levels for the volunteers, thus avoiding the subjects tested having to keep the fingerprint still on the smartphone camera throughout the whole session. Thus, the participants were instructed to start and end the recording for each of the testing phases and to label the recording with the name of the related phase. At the end of the session, each subject sent the screenshots of the recording to the operators.

HR analysis

For each recording, we identified 11 different phases of the session, as described in Table 2. Throughout the whole experiment (phases A–K) the jazz music was alternatively played during phases C, E, G, I and K, and stopped during the other phases.

For the data obtained with the Zephyr device, we segmented the csv file obtained by the app according to the timestamp annotated during the session with the support of a Matlab (MathWorks, Inc., Natick, MA, USA) script. Then, we computed the mean HR for

Table 2. Different phases for each recording session

Recording phase	Sample	Pairing with music
A	—	—
B	1	No
C	1	Yes
D	2	No
E	2	Yes
F	3	No
G	3	Yes
H	4	No
I	4	Yes
J	5	No
K	5	Yes

each phase and each subject. Regarding the data obtained with the App, the output was already represented by a mean value, so we simply annotated the mean HR value for each phase and each subject.

Statistical analysis

The analysis relating to the emotional questionnaires among the different wines was performed using PERMANOVA (included in the Vegan 2.6-4 R Package),[27] while the pairwise comparison applied the pairwise Adonis package.[28] Subsequently, a principal coordinate analysis (PCoA) ordination method was performed, to investigate how to reduce the dimensionality of the variables studied, and how much each of them is relevant to distinguish among the different kinds of wines. Furthermore, a 'permutest. betadisper' was executed in order to check for the reliability of the PERMANOVA and PCoA. All these routines are part of the previously cited Vegan R package.

The analysis related to HR values among the different phases was performed using analysis of variance (ANOVA). Post hoc analysis was obtained by applying paired sample *t*-tests for each couple of phases. Statistical significance was set at $P < 0.05$.

RESULTS

Emotional questionnaires

To analyze the data from the emotional questionnaires the PERMANOVA test was performed on the entire dataset of the experiment, obtaining the results shown in Table 3. The original data were first transformed into a distance matrix, as requested by the method. Among the possible metrics usually employed to compute the distance, we selected Gower's metric, which turned out to be the most suitable approach for our data. Gower's distance is defined according to Gower.[29]

Informally speaking, Gower's metric computes how much two values of a variable are different each other with respect to the maximum difference that the dataset includes for that variable. Results showed that the types of wine evaluated by the participants in the experiment were perceived as significantly different at a threshold of 0.1%, and therefore with a significance well above the usual threshold of 5%. On an emotional level, therefore, the votes were not randomly dispersed but identified distinct characteristics.

The pairwise test (Table 4) revealed that the judgments expressed towards the two faulty wines served first (wines 1 and 2) are not significantly different: on an emotional level, they were

Table 3. Results of the PERMANOVA test

	d.f.	Sum of squares	R^2	F	Pr (>F)	Significance level
Type_wine	4	3497.1	0.44815	30.047	0.001	***
Residuals	148	4306.4	0.55185			
Totals	152	7803.5	1.00000			

*** $P \leq 0.001$.

Table 4. Results of the PERMANOVA pairwise test

	Pairs	d.f.	Sums of squares	F model	R^2	P-value	P-adjusted	Significance
1	WTW *vs.* RTW	1	0.05128379	0.8789212	0.01694178	0.404	1.00	
2	WTW *vs.* BM	1	1.25731485	30.3543068	0.35562713	0.001	0.01	**
3	WTW *vs.* VS	1	1.83584626	45.5980571	0.44880836	0.001	0.01	**
4	WTW *vs.* ODP	1	2.27703439	60.2720240	0.52286775	0.001	0.01	**
5	RTW *vs.* BM	1	1.93320030	51.6766030	0.46273437	0.001	0.01	**
6	RTW *vs.* VS	1	2.68656164	73.7851142	0.54742777	0.001	0.01	**
7	RTW *vs.* ODP	1	3.22985166	94.7974600	0.61239674	0.001	0.01	**
8	BM *vs.* VS	1	0.06242736	2.6635590	0.03936475	0.064	0.64	
9	BM *vs.* ODP	1	0.20096992	9.5510991	0.12985665	0.001	0.01	**
10	VS *vs.* ODP	1	0.05107950	2.5093251	0.03717005	0.067	0.67	

Abbreviations: BM, Brunello di Montalcino; RTW, red table wine; ODP, Vin Santo Occhio di Pernice; VS, Vin Santo Riserva; WTW, white table wine.
** Adjusted $P \leq 0.01$.

superimposable. Both, however, were significantly different from the trio of quality wines served later (wines 3–5), underlining a strong emotional discontinuity given that the significance was 1%. In the final trio, wine 3 (Brunello di Montalcino DOCG) did not arouse emotions very different from wine 4 (Vinsanto Riserva DOCG), but it was sufficiently different from wine 5 (Vinsanto Occhio di Pernice DOCG). Finally, the two sweet wines (coded 4 and 5) were not emotionally very different from each other.

The PERMANOVA test allows us to recognize which wines carry the greater part of the emotional variability, but it is unable to show whether there are emotional variables specifically triggered by or associated with some wines. To investigate this point, a PCoA was performed: Fig. 3 shows the graphical output, relative to the first two components PCoA1 and PCoA2, accounting together for 96% of the dataset variability overall.

To validate the PCoA results, a 'permutation and dispersion' test[30] was employed using the permatest.betadisper function of the Vegan R package. This test checks whether a PERMANOVA (and then, the relative PCoA) can be affected by different data dispersions for the different groups; like the non-parametric methods such as PERMANOVA and PCoA, homogeneity of the dispersion between groups is assumed. This test should be not significant in validating a significant PERMANOVA or PCoA. By computing the dispersion and, subsequently, the permutation test, we obtain a highly significant result, as shown in Table 5.

The reasons for this result can be observed by reference to the dispersion diagram shown in Fig. 4: the dispersion for the two faulty wines, 'WTW' and 'RTW', corresponding to white and red wine, respectively, is much greater with respect to that of the other three 'good' wines. In fact, the dispersion test repeated for {'WTW', 'RTW'} and {'BM', 'VS', 'ODP'} separately led to non-significant values, as shown in Tables 6 and 7.

The visual interpretation of these two tests is reported in the dispersion diagrams in Figs 5 and 6: taken separately, 'faulty' and 'good' wines show clusters that are homogeneous for dispersion, making the PCoA valid.

These new axes carry 74% (PCoA1) and 14% (PCoA2), respectively, of the total variance of the dataset, thus accounting for 88% of the total variance, when taken together. In Table 8 the contribution of each original emotional variable in the generation of the new latent variables PCoA1 and PCoA2 is reported.

These results show that any emotional variable is significant in defining new latent PCoA axes, even if with different r^2 values. By exploring the projections of the original emotional variables on the new latent axes, we discovered that for PCoA1 the most relevant contributions are given by: 'Negative surprise' (−0.95), 'Disgust' (−0.82) and 'Serenity' (0.80), while for PCoA2 the most important were: 'Fear' (0.91), 'Rage' (0.89) and 'Sadness' (0.83). As a side remark, we note that, PCoA1 and PCoA2 being mutually orthogonal, the emotional variables 'Fear', 'Rage' and 'Sadness' seem to be relatively independent from 'Negative surprise' and 'Disgust', as the former are associated with PCoA1, whereas the latter are associated with PCoA2, thus suggesting that at a psychological level these emotions can be processed independently from each other; however, this hypothesis cannot be investigated with the data obtained in this experiment, and is only a suggestion for future investigations.

HR measurements

The mean HR for all the subjects throughout the different phases has been reported on a plot depicted in Fig. 7. According to Fig. 7, and due to the relatively low sample size included in the pilot, it is evident that every recording period has a significant standard deviation, but showing a quite important modulation of response

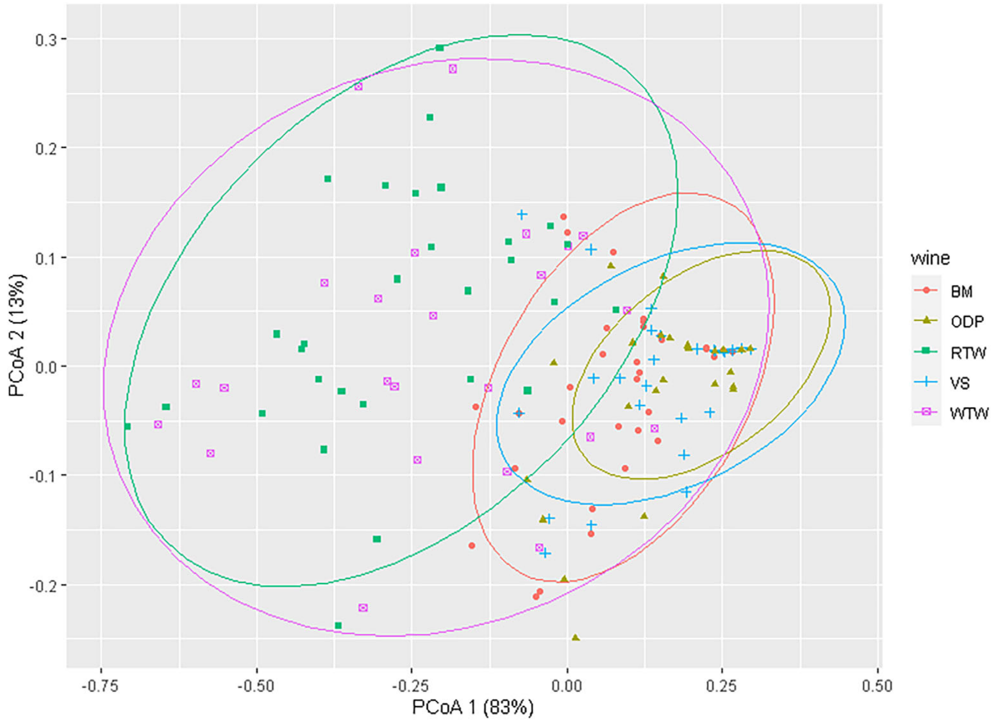


Figure 3. Graphical output, relative to the first two components PCoA1 and PCoA2, which cumulatively account for 96% of the total variance of the dataset. The ellipses indicate 95% confidence in finding a point of the defined group within. BM, Brunello di Montalcino; PCoA, principal coordinate analysis; RTW, red table wine; ODP, Vin Santo Occhio di Pernice; VS, Vin Santo Riserva; WTW, white table wine.

Table 5. Results of the dispersion and permutation test

Response: distances

	d.f.	Sum of squares	Mean square	F	N perm	Pr (>F)	
Groups	4	0.38227	0.095567	13.386	999	0.001	***
Residuals	148	1.05664	0.007139				

Abbreviation: perm, Permutations.
*** Adjusted $P \leq 0.001$.

in the various phases. Under such premises, in order to increase the meaningfulness of the results, we aggregated the data of all faulty and all good wines, respectively. Results are reported in Fig. 8. According to the data aggregation, all kinds of stimuli led the HR to increase with respect to the baseline; in addition, the presentation of good wines produced greater HR increases than in the case of faulty wines, especially when combined with music administration. In Fig. 9 we show the results obtained in the two subgroups of subjects using the two different acquisition methodologies previously cited. Although the recordings with the two instrumentations were not recorded in the same group of subjects and so a direct comparison could not be performed, we can observe that the trend of the measures is the same; therefore, we can hypothesize a good agreement between the two instruments.

In order to provide an idea of the trends occurring, as an exploratory analysis we compared the different phases of tasting using *t*-tests. Results are reported in Table 9. According to the analysis depicted in Table 9, it is evident that the effects on HR of the merging of good wine presentation and music are statistically significant even in a relatively small cohort. The same applies when analyzing the differences between good and faulty wines when both are associated with music. The effect of music can be also distinguishable from the effect of wine-only in good wines. Notably, the effect of music is visible for good wines but not for faulty ones.

DISCUSSION

According to our data, even in a relatively small group composed of 16 ordinary consumers, wine is capable of generating a variation in HR, possibly related to emotional aspects concerned with the compound tasted. An HR increase brought about by alcohol has already been seen by a popular meta-analysis[31] taking into account the 6 h following its consumption due to some specific physiological factors, unconnected per se to emotions. Indeed, alcohol is known to stimulate the activity of the SNS and to slow down that of the PNS, modulating their balance overall, and affecting the HR within 10 h after its consumption.[32-34] This reduction in vagal tone shortly after alcohol consumption has also been reported elsewhere,[35,36] together with a reduction in baroreflex sensitivity, in turn resulting in failure to sense the HR increase

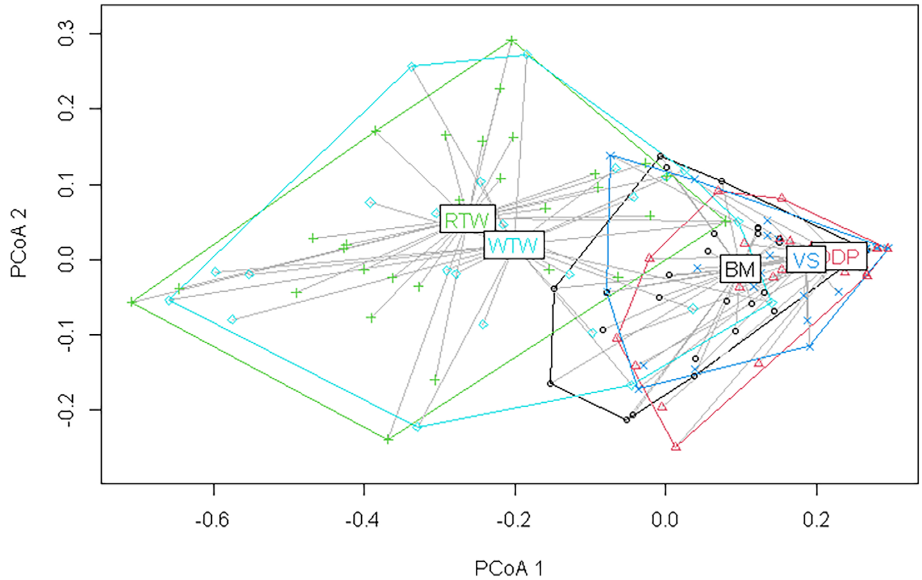


Figure 4. Dispersion diagram of the whole dataset with respect to the PCoA main coordinates. 'WTW' and 'RTW' (faulty) wines show a dispersion much higher than that of the other three (good) wines, thus leading to significant results of the permutation test. BM, Brunello di Montalcino; RTW, red table wine; ODP, Vin Santo Occhio di Pernice; PCoA, principal coordinate analysis; VS, Vin Santo Riserva; WTW, white table wine.

Table 6. Results of the dispersion and permutation test for faulty wines

Response: distances {'WTW', 'RTW'}

	d.f.	Sum of squares	Mean square	*F*	*N* perm	Pr (>*F*)
Groups	1	0.00952	0.0095159	1.272	999	0.249
Residuals	51	0.38154	0.0074812			

Abbreviations: perm, Permutations; RTW, red table wine; WTW, white table wine.

Table 7. Results of the dispersion and permutation test for good wines

Response: distances {'BM', 'VS', 'ODP'}

	d.f.	Sum of squares	Mean square	*F*	*N* perm	Pr (>*F*)
Groups	2	0.02876	0.0143782	1.447	999	0.26
Residuals	97	0.96387	0.0099368			

Abbreviations: BM, Brunello di Montalcino; perm, Permutations; ODP, Vin Santo Occhio di Pernice; VS, Vin Santo Riserva.

and the overall maintenance of cardiovascular homeostasis.[36-38] Another reason driving increased HR after alcohol consumption could be also related to reduction in plasma potassium concentration.[39]

However, such phenomena, not directly concerned with emotions, only partially explain the results obtained in our study, and can deal only with the HR differences between baseline and wine tasting phases. When it comes to the different reactions to various wines, such results can be explained only by the different reactions driven by emotions produced by the intrinsic composition of such drinks. Indeed, it is apparent that the physiological response concerned with wine tasting is mediated by the wine quality. In fact, good quality and faulty wines elicit different reactions in all the individuals assessed, regardless of their experience with wine consumption, with significantly higher HR values for the first category. As such, even untrained consumers are able to recognize good wines from wines of low quality, according to their physiological reactions. Despite not having a literature counterpart for such assumptions on wine samples, our results are in line with findings obtained in studies dealing with the consumption of yoghurt, where the HR of participants was positively correlated with the overall liking of the compounds perceived.[40] Similarly, different ANS responses were seen in response to the consumption of differently perceived breakfast drinks.[41] However, different trials with a different edible compound (i.e., beer, chocolate) failed to report significant HR changes in response to positively *versus* negatively perceived foodstuff,[42,43] highlighting the possible compound-specific ANS response in such a scenario.

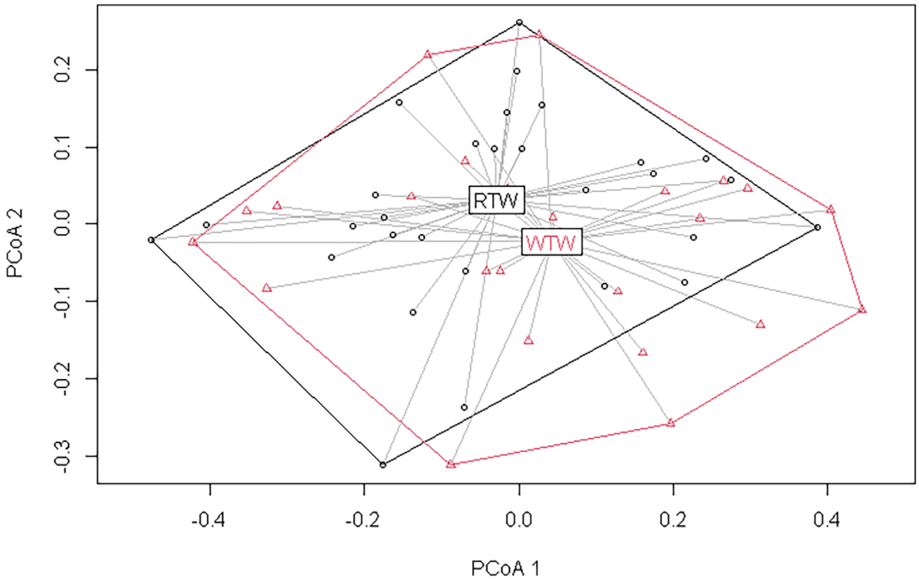


Figure 5. Dispersion diagram for {'WTW', 'RTW'} selected sub-dataset (faulty wines). The dispersion index for these two groups is very similar, making the permutation test not significant. RTW, red table wine; WTW, white table wine.

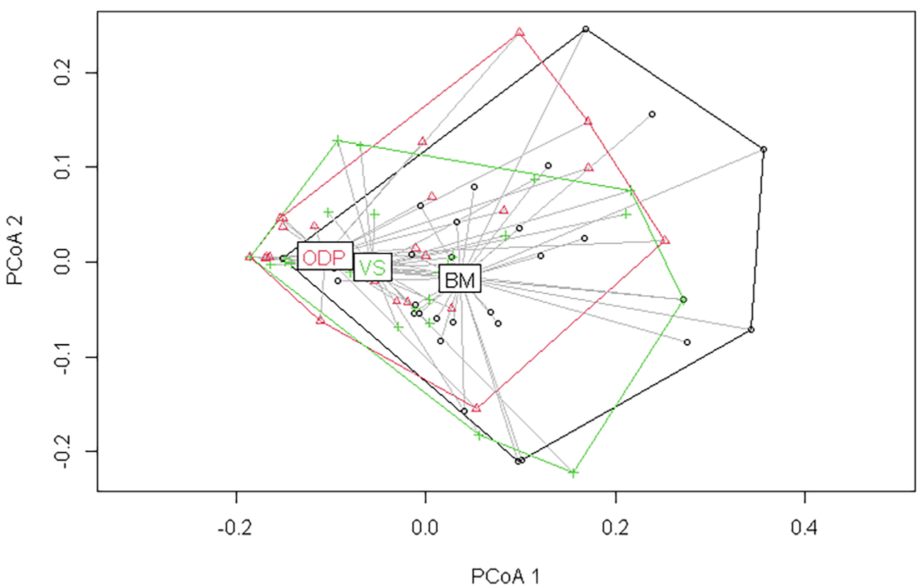


Figure 6. Dispersion diagram for {'BM', 'VS', 'ODP'} selected sub-dataset (good-quality wines). The dispersion index for these three groups is very similar, making the permutation test not significant. BM, Brunello di Montalcino; VS, Vin Santo Riserva; WTW, white table wine

Table 8. Projections of the original emotional variables on the new latent axes, principal coordinate analysis (PCoA) 1 and PCoA 2

Descriptor	PCoA1	PCoA2	R^2	Pr (>*r*)	
Overall pleasantness	0.79750	0.60332	0.8856	0.001	***
Fear	−0.40640	0.91370	0.6696	0.001	***
Rage	−0.45153	0.89225	0.9786	0.001	***
Sadness	−0.55422	0.83237	0.7103	0.001	***
Disgust	−0.82246	0.56883	0.7573	0.001	***
Joy	0.78194	0.62335	0.8474	0.001	***
Serenity	0.80922	0.58741	0.8055	0.001	***
Positive surprise	0.72661	0.68705	0.8082	0.001	***
Negative surprise	−0.95362	0.30102	0.8070	0.001	***

*** $P \leq 0.001$.

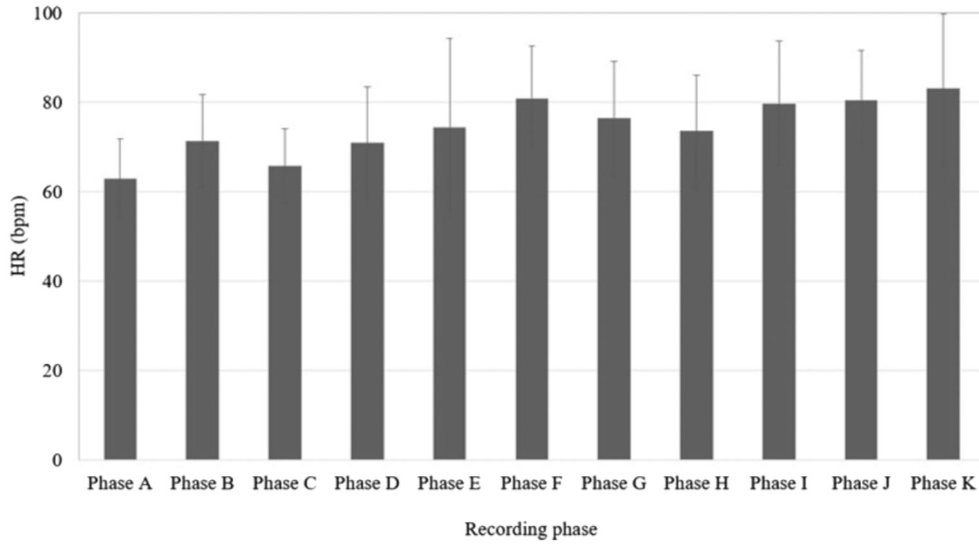


Figure 7. Mean heart rate (HR) values for all subjects within the different phases.

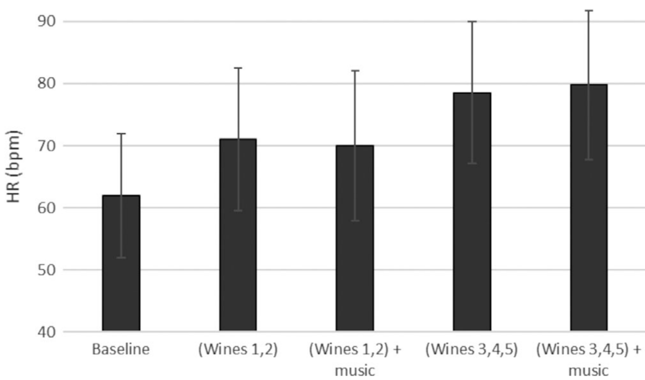


Figure 8. Mean heart rate (HR) values for all subjects aggregated for faulty and good wines.

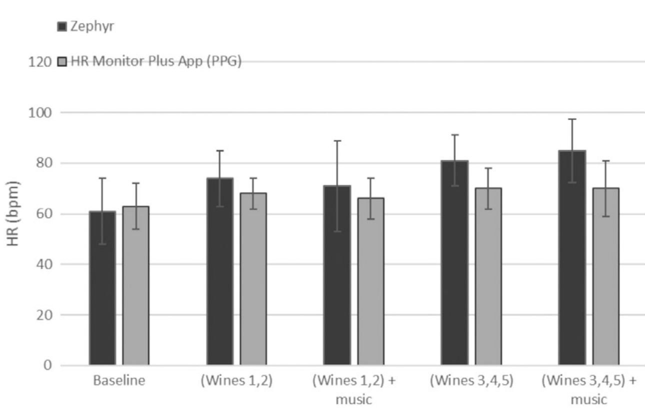


Figure 9. Comparison of heart rate (HR) values for the two different methods adopted in this study.

Table 9. Comparison of heart rate values among the different phases

Comparison	*P*-value
Baseline *vs*. faulty wines	0.30
Baseline *vs*. faulty wines + music	0.80
Baseline *vs*. good wines	0.06
Baseline vs. good wines + music	0.02*
Faulty wines *vs*. good wines	**<0.001****
Faulty wines + music *vs*. good wines + music	0.02*
Faulty wines *vs*. faulty wines + music	0.80
Good wines *vs*. good wines + music	0.05*
Faulty wines *vs*. good wines + music	**<0.001****

Note: Comparison surviving Bonferroni correction are highlighted in bold.
*$P \leq 0.05$;
** $P \leq 0.01$.

Another important point raised by our study deals with the interaction between the chemosensory experience and the surrounding scenario when it comes to the effects on the HR. In the present research, the effects of the jazz music appear to be positive for modifying the perception of good-quality wines, further improving the levels of emotions generated, according to the physiological reactions produced. Overall, it is known that music and chemosensory stimuli are both, and singularly, able to modulate the ANS reactions of human beings depending on the emotional value of the stimulus itself (e.g., relaxing, arousing).[44] However, our results are interesting when compared with the literature on the topic, where findings towards increased happiness during a moderate alcohol consumption session was observed both in an unpleasant ambiance and – even in a shorter response time – in a pleasant scenario,[45] this finding being somewhat consistent with our results. One of the first bedrocks in this sense in the scientific research[46] demonstrated that the kind of music we listen to is able to change our perception of wine tasting.[47] Furthermore, the consonant association between wine and music is able to promote reinforcement also in terms of emotional reactions within the given experimental scenario,[48] especially in less musically experienced consumers.[49] Music effects on the modulation of wine perception were also demonstrated in an interesting neuromarketing study, applying an EEG to check for central effects on the brain;[50] however, the systematic approach performed in the present study in methodological terms for both music distribution and ANS recording, and evaluation, is deemed unprecedented, thus representing a significant addition to the current literature.

The physiological reasons for such an effect are not fully clear, but, taking inspiration from Spence and Wang,[46] some circuitry associated with the attention focus via cross-modal correspondences between the different sensory stimuli can be hypothesized, as with a sort of neural cross-wiring. More specific insights on it are, however, worth investigation.

Examining our results in more depth, we deem the effect of music to be relevant only for good wines and not faulty ones. This might be for different reasons, among which the fact that a positive synesthesia between different sensory modalities could have driven HR to increase significantly, whereas when the wine was faulty the effect of music was masked by the negative perception of a faulty wine, and thus not producing significant HR variations in this regard. It can therefore be concluded that there is a role for both kinds of stimuli on the autonomic reactivity, with higher importance assigned to chemosensory stimulation than to auditory stimulation.

Finally, as for the technological perspective, the application of minimally invasive tools to assess the HR response in such a scenario was demonstrated to be technically viable and feasible, according to the collected acceptance by the volunteers, and potentially applicable also in population studies, where questionnaires still represent the elective approach to the problem.[51,52] Since no particular drawbacks have been encountered with the smartphone PPG-based tool, its application could be feasible where large amounts of data must be collected, such as at large social events or in similar scenarios; the discomfort caused by the need for the user to keep their finger on the smartphone camera during data acquisition needs to be considered, representing the main limitation of this approach, which should be taken into account when designing the experiment.

Study limitations

The results obtained should be considered under some limitations. First, as reported above, the eventual discomfort caused by the specific acquisition method concerned with the smartphone usage should be considered during the experimental design. Second, the promising results obtained could be also due to the high motivation of the volunteers involved in the present study; therefore, the generalizability of the results appears questionable, also because of the small sample size, unless further research extends such findings to other scenarios. Third, for the present study we purposely ignored the application of other tools potentially able to better characterize the physiological reactions concerned with emotions provoked by sensory stimulation in the relevant context, including those for studying EDA or EEG. According to the literature and our previous experience,[23,24] such extensions could grant further useful information about the dynamics of such physiological responses. In addition, recent studies have questioned the use of HRV markers in some specific scenarios;[53] thus, a multimodal assessment of physiological response could provide a more reliable evaluation of the subject's emotional state. Fourth, we purposely focused on the technological methodology to assess whether our approach was sufficient to detect changes eventually provoked by the specific scenario; however, we omitted to collect data related to the prior psychological and psychophysical state of the volunteers, which might have affected the final outcome of the experiment. Finally, the selection of music was performed according to the deep experience and expertise in the field of the Associazione Musicale Sinestesica and was not done systematically based on scientifically validated, quantitative indicators. Future work should deal with that, promoting a scientifically driven choice of tracks associated with wines.

CONCLUSIONS AND FUTURE WORK

Despite the limitations listed above, our study demonstrates the ability of wine to generate an emotional response in ordinary consumers, detectable also through implicit measurements, including physiological response assessment. Such response can be attributable not just to the chemical composition of wines (e.g., to alcohol effects), but also to the quality level of the wine tasted, as demonstrated by the different responses produced by good wines on all consumers compared to those generated by low-quality wines. The application of music to the specific context made wines better perceived, notably those with higher quality, and especially in less experienced consumers, possibly due to the positive effects of the surrounding environment on the participants' overall mood.

It should also be added that, focusing specifically on our framework, since the implicit measurement concerning physiological responses was performed on a subgroup of participants, and data concerning emotions generated, collected by means of questionnaires, showed a noteworthy dispersion of results among participants, it was quite difficult to retrieve significant differences concerning physiological reactions to sensory stimuli. Therefore, for future research, in order to find statistically relevant physiological (and related emotional) differences in such a small group of consumers, one might use completely different wines in terms of their quality or, alternatively, one might significantly increase the sample size of participants that are actually monitored.

Taken together, such findings might help promote further research towards physiological effects of wine and music in similar scenarios, the results of which could be later applied also in the promising framework of neuromarketing.

ACKNOWLEDGEMENTS

This work was supported by the CNR project FOE-2021 DBA. AD005.225 'NUTRAGE'. We thank Dr Emiliano Loconsolo as the artistic director for managing the live musical performance during the event; we also thank the National Association Città del Vino (Città del Vino [cittadelvino.it]) together with the wineries Villa le Prata (Montalcino (SI), Tuscany) and La Vialla (Arezzo, Tuscany) for providing wines 3 and 4, 5, respectively.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

1 Modesti M, Tonacci A, Sansone F, Billeci L, Bellincontro A, Cacopardo G *et al.*, E-senses, panel tests and wearable sensors: a teamwork for food quality assessment and prediction of Consumer's choices. *Chem* **10**:244 (2022). https://doi.org/10.3390/chemosensors10070244.

2 Guedes D, Garrido MV, Lamy E, Cavalheiro BP and Prada M, Crossmodal interactions between audition and taste: a systematic review and narrative synthesis. *Food Quality Preference* **107**:104856 (2023). https://doi.org/10.1016/j.foodqual.2023.104856.
3 Spence C, Reinoso-Carvalho F, Velasco C and Wang QJ, Extrinsic auditory contributions to food perception & consumer behaviour: an interdisciplinary review. *Multisens Res* **32**:275–318 (2019). https://doi.org/10.1163/22134808-20191403.
4 Reinoso-Carvalho F, Gunn L, Molina G, Narumi T, Spence C, Suzuki Y *et al*., A sprinkle of emotions vs a pinch of crossmodality: towards globally meaningful sonic seasoning strategies for enhanced multisensory tasting experiences. *J Bus Res* **117**:389–399 (2020). https://doi.org/10.1016/j.jbusres.2020.04.055.
5 Wang QJ and Spence C, Assessing the effect of musical congruency on wine tasting in a live performance setting. *I-Perception* **6**: 2041669515593027 (2015). https://doi.org/10.1177/2041669515593027.
6 Wang QJ and Spence C, "A sweet smile": the modulatory role of emotion in how extrinsic factors influence taste evaluation. *Cognit Emot* **32**:1052–1061 (2018). https://doi.org/10.1080/02699931.2017.1386623.
7 Guedes D, Prada M, Garrido MV and Lamy E, The taste & affect music database: subjective rating norms for a new set of musical stimuli. *Behav Res Methods* **55**:1121–1140 (2023). https://doi.org/10.3758/s13428-022-01862-z.
8 Wang QJ, Wang S and Spence C, "turn up the taste": assessing the role of taste intensity and emotion in mediating Crossmodal correspondences between basic tastes and pitch. *Chem Senses* **41**:345–356 (2016). https://doi.org/10.1093/chemse/bjw007.
9 Calvo-Porral C, Ruiz-Vega A and Lévy-Mangin JP, How consumer involvement influences consumption-elicited emotions and satisfaction. *Int J Mark Res* **63**:251–267 (2021). https://doi.org/10.1177/1470785319838747.
10 Ristic R, Danner L, Johnson TE, Meiselman HL, Hoek AC, Jiranek V *et al*., Wine-related aromas for different seasons and occasions: hedonic and emotional responses of wine consumers from Australia, UK and USA. *Food Qual Prefer* **71**:250–260 (2019). https://doi.org/10.1016/j.foodqual.2018.07.011.
11 Silva AP, Jager G, van Bommel R, van Zyl H, Voss HP, Hogg T *et al*., Functional or emotional? How Dutch and Portuguese conceptualise beer, wine and non-alcoholic beer consumption. *Food Qual Prefer* **49**:54–65 (2016). https://doi.org/10.1016/j.foodqual.2015.11.007.
12 Sinesio F, Moneta E, di Marzo S, Zoboli GP and Abbà S, Influence of wine traits and context on liking, intention to consume, wine-evoked emotions and perceived sensory sensations. *Food Qual. Prefer.* **93**:104268 (2021). https://doi.org/10.1016/j.foodqual.2021.104268.
13 Plassmann H, Shiv B and Rangel A, Marketing actions can modulate neural representations of experienced pleasantness. *Proc Natl Acad Sci U S A* **105**:1050–1054 (2008). https://doi.org/10.1073/pnas.070692910.
14 De Wijk R and Noldus LPJJ, Using implicit rather than explicit measures of emotions. *Food Qual. Prefer.* **92**:104125 (2021). https://doi.org/10.1016/j.foodqual.2020.104125.
15 Domingos C, Marôco JL, Miranda M, Silva C, Melo X and Borrego C, Repeatability of brain activity as measured by a 32-channel EEG system during resistance exercise in healthy young adults. *Int J Environ Res Public Health* **20**:1992 (2023). https://doi.org/10.3390/ijerph20031992.
16 Shaffer F and Ginsberg JP, An overview of heart rate variability metrics and norms. *Front Public Health* **5**:258 (2017). https://doi.org/10.3389/fpubh.2017.00258.
17 Di Palma S, Tonacci A, Narzisi A, Domenici C, Pioggia G, Muratori F *et al*., Monitoring of autonomic response to sociocognitive tasks during treatment in children with autism Spectrum disorders by wearable technologies: a feasibility study. *Comput Biol Med* **85**:143–152 (2017).
18 Tonacci A, Chemical senses and consumer technologies: a journey from the human physiology towards the metaverse, in *Zooming Innovation in Consumer Technologies Conference (ZINC)*. IEEE, Novi Sad, Serbia, p. 1 (2023).
19 Zernecke R, Kleemann AM, Haegler K, Albrecht J, Vollmer B, Linn J *et al*., Chemosensory properties of human sweat. *Chem Senses* **35**:101–108 (2010). https://doi.org/10.1093/chemse/bjp087.
20 Nepal O, Jha RK, Bhattarai A, Khadka P and Kapoor BK, Galvanic skin response as a simple physiology lab teaching tool- an alternative indicator of sympathetic arousal. *Kathmandu Univ Med J (KUMJ)* **16**: 156–160 (2018).
21 Boucsein W, *Electrodermal Activity*. Springer Science & Business Media, New York, USA (2012).
22 Peeters MWH, Schouten G and Wouters EJM, Wearables for residents of nursing homes with dementia and challenging behaviour: values, attitudes, and needs. *Geron* **20**:1–13 (2021). https://doi.org/10.4017/gt.2021.20.2.7.06.
23 Tonacci A, Billeci L, Di Mambro I, Marangoni R, Sanmartin C and Venturi F, Wearable sensors for assessing the role of olfactory training on the autonomic response to olfactory stimulation. *Sensors* **21**: 770 (2021). https://doi.org/10.3390/s21030770.
24 Billeci L, Sanmartin C, Tonacci A, Taglieri I, Bachi L, Ferroni G *et al*., Wearable sensors to evaluate autonomic response to olfactory stimulation: the influence of short. *Intensive Sensory Training Biosensors* **13**: 478 (2023). https://doi.org/10.3390/bios13040478.
25 Nazari G, Bobos P, MacDermid JC, Sinden KE, Richardson J and Tang A, Psychometric properties of the Zephyr bioharness device: a systematic review. *BMC Sports Sci Med Rehabil* **10**:6 (2018). https://doi.org/10.1186/s13102-018-0094-4.
26 Ayesha AH, Qiao D and Zulkernine F, Heart rate monitoring using PPG with smartphone camera, in *In 2021 IEEE International Conference on Bioinformatics and Biomedicine (BIBM)*. IEEE, Piscataway, NJ, USA, pp. 2985–2991 (2021). https://doi.org/10.1109/BIBM52615.2021.9669735.
27 R package for community ecologists: popular ordination methods, ecological null models & diversity analysis https://github.com/vegandevs/vegan.
28 Martinez Arbizu P, Pairwise Adonis: Pairwise multilevel comparison using adonis. R package version 0.4 (2020). https://github.com/pmartinezarbizu/pairwiseAdonis.
29 Gower JC, A general coefficient of similarity and some of its properties. *Biometrics* **27**:857–871 (1971).
30 Anderson MJ, Distance-based tests for homogeneity of multivariate dispersions. *Biometrics* **62**:245–253 (2006).
31 Tasnim S, Tang C, Musini VM and Wright JM, Effect of alcohol on blood pressure. *Cochrane Database Syst Rev* **7**:CD012787 (2020). https://doi.org/10.1002/14651858.CD012787.pub2.
32 Hering D, Kucharska W, Kara T, Somers VK and Narkiewicz K, Potentiated sympathetic and hemodynamic responses to alcohol in hypertensive vs. normotensive individuals. *J Hypertens* **29**:537–541 (2011). https://doi.org/10.1097/HJH.0b013e328342b2a9.
33 Carter JR, Stream SF, Durocher JJ and Larson RA, Influence of acute alcohol ingestion on sympathetic neural responses to orthostatic stress in humans. *Am J Physiol Endocrinol Metab* **300**:E771–E778 (2011). https://doi.org/10.1152/ajpendo.00674.2010.
34 Spaak J, Merlocco AC, Soleas GJ, Tomlinson G, Morris BL, Picton P *et al*., Dose-related effects of red wine and alcohol on hemodynamics, sympathetic nerve activity, and arterial diameter. *Am J Physiol Heart Circ Physiol* **294**:H605–H612 (2008). https://doi.org/10.1152/ajpheart.01162.2007.
35 Rossinen J, Viitasalo M, Partanen J, Koskinen P, Kupari M and Nieminen MS, Effects of acute alcohol ingestion on heart rate variability in patients with documented coronary artery disease and stable angina pectoris. *Am J Cardiol.* **79**:487–491 (1997).
36 Van de Borne P, Mark AL, Montano N, Mion D and Somers VK, Effects of alcohol on sympathetic activity, hemodynamics, and chemoreflex sensitivity. *Hypertension* **29**:1278–1283 (1997). https://doi.org/10.1161/01.HYP.29.6.1278.
37 Buckman JF, Eddie D, Vaschillo EG, Vaschillo B, Garcia A and Bates ME, Immediate and complex cardiovascular adaptation to an acute alcohol dose. *Alcohol Clin Exp Res* **39**:2334–2344 (2015). https://doi.org/10.1111/acer.12912.
38 Fazio M, Bardelli M, Macaluso L, Fiammengo F, Mattei PL, Bossi M *et al*., Mechanics of the carotid artery wall and baroreflex sensitivity after acute ethanol administration in young healthy volunteers. *Clin Sci (Lond)* **101**:253–260 (2001).
39 Kawano Y, Abe H, Kojima S, Takishita S and Omae T, Interaction of alcohol and an alpha1-blocker on ambulatory blood pressure in patients with essential hypertension. *Am J Hypertens* **13**:307–312 (2000).
40 Gupta MK, Viejo CG, Fuentes S, Torrico DD, Saturno PC, Gras SL *et al*., Digital technologies to assess yoghurt quality traits and consumers acceptability. *J Sci Food Agric* **102**:5642–5652 (2022). https://doi.org/10.1002/jsfa.11911.

41 de Wijk RA, He W, Mensink MG, Verhoeven RH and de Graaf C, ANS responses and facial expressions differentiate between the taste of commercial breakfast drinks. *PloS One* **9**:e93823 (2014).
42 Gonzalez Viejo C, Fuentes S, Howell K, Torrico DD and Dunshea FR, Integration of non-invasive biometrics with sensory analysis techniques to assess acceptability of beer by consumers. *Physiol Behav* **200**:139–147 (2019).
43 Gunaratne TM, Fuentes S, Gunaratne NM, Torrico DD, Gonzalez Viejo C and Dunshea FR, Physiological responses to basic tastes for sensory evaluation of chocolate using biometric techniques. *Foods* **8**:243 (2019). https://doi.org/10.3390/foods8070243.
44 Baccarani A, Donnadieu S, Pellissier S and Brochard R, Relaxing effects of music and odors on physiological recovery after cognitive stress and unexpected absence of multisensory benefit. *Psychophysiology* **60**:e14251 (2023). https://doi.org/10.1111/psyp.14251.
45 Schrieks IC, Stafleu A, Kallen VL, Grootjen M, Witkamp RF and Hendriks HF, The biphasic effects of moderate alcohol consumption with a meal on ambiance-induced mood and autonomic nervous system balance: a randomized crossover trial. *PloS One* **9**:e86199 (2014). https://doi.org/10.1371/journal.pone.0086199.
46 Spence C and Wang QJ, Wine and music (II): can you taste the music? Modulating the experience of wine through music and sound. *Flavour* **4**:33 (2015). https://doi.org/10.1186/s13411-015-0043-z.
47 North AC, The effect of background music on the taste of wine. *Br J Psychol* **103**:293–301 (2012). https://doi.org/10.1111/j.2044-8295.2011.02072.x.
48 Wang Q and Spence C, Assessing the role of emotional associations in mediating Crossmodal correspondences between classical music and red wine. *Beverages* **3**:1 (2017). https://doi.org/10.3390/beverages3010001.
49 Hauck P and Hecht H, Having a drink with Tchaikovsky: the Crossmodal influence of background music on the taste of beverages. *Multisens Res* **32**:1–24 (2019). https://doi.org/10.1163/22134808-20181321.
50 Hsu L and Chen YJ, Music and wine tasting: an experimental neuromarketing study. *British Food J* **122**:2725–2737 (2019). https://doi.org/10.1108/BFJ-06-2019-0434.
51 Monteleone E, Spinelli S, Dinnella C, Endrizzi I, Laureati M, Pagliarini E *et al.*, Exploring influences on food choice in a large population sample: the Italian taste project. *Food Quality Preference* **59**:123–140 (2017).
52 Piochi M, Dinnella C, Spinelli S, Monteleone E and Torri L, Individual differences in responsiveness to oral sensations and odours with chemesthetic activity: relationships between sensory modalities and impact on the hedonic response. *Food Quality Preference* **88**:104112 (2021).
53 Thomas BL, Claassen N, Becker P and Viljoen M, Validity of commonly used heart rate variability markers of autonomic nervous system function. *Neuropsychobiology* **1-13**:14–26 (2019). https://doi.org/10.1159/000495519.