Interrelationships between soundscape attributes and sound categories

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ISO/TS 12913–2:2018 (Method A) includes eight attributes for the characterization of the perceived affective quality of soundscapes and also categorizes sound sources into three main types: 'nature', 'human' and 'noise'. This work investigates the interrelationships between soundscape attributes and sound categories according to ISO/TS 12913-2:2018. For this purpose, the sound stimuli were categorized based on their most prevalent components and subsequently listening tests (n=30 participants) were performed, using the Greek-translated attributes of the soundscape circumplex. Statistical analysis was performed and principal component analysis (PCA) was applied to further access the soundscape perception of participants. Results revealed large differentiation between combinations of attributes. The variability explained in the monotonous-pleasant relationship shows a strong negative correlation for human sounds ($\rho = -0.74$) and a positive correlation for noise sounds ($\rho = 0.25$). In the monotonous-chaotic relationship there is a strong negative correlation for noise sounds ($\rho = -0.76$) and a positive correlation for human sounds ($\rho = 0.21$). In the vibrant-pleasant relationship there is a negative correlation for noise sounds ($\rho = -0.56$) and a positive correlation for human sounds ($\rho = 0.39$). In conclusion, this study sheds new light on the interrelationships between perceptual attributes and sound categories, which are important for a more accurate assessment of the perceived affective quality of soundscapes.

I. INTRODUCTION

Soundscape research is a rapidly growing field according to the increasing number of related publications (To *et al.*, 2018), thematic collections in primary acoustics journals(Aletta *et al.*, 2025) and the interest from policy makers and related stakeholders in recent years (Kang, 2023). Adopting a multidisciplinary approach that represents a paradigm shift from traditional noise control policies, it redefines how we view the acoustic environment, placing importance on human experience and highlighting sound as an essential resource rather than just a disturbance. Soundscape is defined (ISO: Geneva, 2014) as the 'acoustic environment as perceived or experienced and/or understood by a person or people, in context'. Therefore, soundscape is understood as a perceptual construct, distinguished from the physical phenomenon (acoustic environment) and exists through human perception of the acoustic environment. The field offers innovative strategies for urban sound management taking into account both objective and subjective criteria, as for example in a noise control intervention study (Van Renterghem *et al.*, 2021) of a raised berm alongside a highway. Before-and-after assessments of both objective noise levels and subjective human responses showed significantly improvement of the acoustic perception and well-being despite practical and design constraints. In addition, the field aiming to enhance urban experiences, by intentionally designing and managing the auditory environment. For example in the case of urban squares (Yang and Kang, 2005) more pleasurable, natural, and culturally meaningful sound experiences can be created by incorporating positive sound elements, such as natural sounds and soundmarks like fountains or singing birds that can attract people and promote relaxation and social interaction. Therefore, the soundscape research approach can inform urban design (Brambilla and Maffei, 2010), and develop comprehensive policies that prioritize the quality of sound environments for the well-being of individuals and communities (Oberman *et al.*, 2020). Overall, soundscape research is drawing interest from various disciplines and stakeholders due to its potential impact on human well-being and quality of life (Kang and Aletta, 2018; Qiu *et al.*, 2018).

An important aspect of soundscape research addressed by the ISO 12913 series is the accurate assessment of the soundscape perception of a population group. The scope of ISO/TS 12913-2:2018 (ISO: Geneva, 2018) is to specify requirements and supporting information on data collection and reporting for soundscape studies, investigations and applications. The ISO/TS 12913-2:2018 standard's scope further extends to provide comparable datasets and soundscape characterizations across different locations, times and samples of people (e.g.(Aletta and Torresin, 2023)), as well as allowing for replicability studies and offering inputs for modelling algorithms in soundscape prediction and design tasks. The ISO/TS 12913-2:2018 (ISO: Geneva, 2018) highlights the importance of harmonizing and standardizing soundscape research and practice, emphasizing the need for a systematic collection of good soundscape design examples and case studies across sectors, including researchers, practitioners and policy makers (Kang, 2023). The standard is a particularly important part of the ISO 12913 series that deals with soundscape definition, conceptual framework, data collection and reporting requirements.

For the assessment of soundscape perception and various related aspects (Ramírez-Esparza *et al.*, 2024), a large number of studies have addressed the issue. For instance, a study comparing the soundscape experience of public spaces in European and Chinese contexts (Aletta *et al.*, 2023a) found that a positive correlation between perceived pleasantness and natural sounds was stronger for European participants. For Chinese participants, vibrant soundscapes were positively correlated with perceived dominance of natural sounds, whereas in Europe, they were associated more with human-generated sounds. An on-site survey was conducted in a study by (Zhu *et al.*, 2023) to obtain the perceptual soundscape dimensions in outdoor public spaces in urban high-rise residential communities based on evaluations of residents. Among the results, it was found that in enclosed communities, sounds from human beings dominated, leading to higher scores in relaxation and communication and a lower score in quietness, distinct from non-enclosed communities where traffic noise dominated. The assessment of the influence of residence location (city, town, village) on the perception of soundscape in a study (Papadakis *et al.*, 2023) revealed that village residents perceived technological sounds as more chaotic than the city residents; city residents perceived natural sounds as more monotonous, more uneventful and less vibrant compared to village residents indicating that urbanization and cultural context can influence soundscape perception. A study by Efranian et al. (Erfanian *et al.*, 2021) aimed to assess the influence of psychological well-being and demographic factors including age, gender, occupation status and education levels on the dimensions of the soundscape circumplex, i.e., pleasantness and eventfulness. Psychological well-being was positively associated with perceived pleasantness, while there was a negative association with eventfulness only for males. Occupation status was identified as a significant factor for both dimensions. The aim of the study by Yu and Kang (Yu and Kang, 2008) was to analyse the effects of social, demographical and behavioural factors as well as long-term sound experience on the subjective evaluation of sound level in urban open public spaces. Among factors, occupation and education were found to correlate to the sound level evaluation more than other factors. Compared to the social, demographical and behavioral factors, the long-term sound experience, i.e. the acoustic environment at home, significantly affect the sound level evaluation in urban open spaces. Finally, in a study by Yu and Kang (Yu and Kang, 2014), cross-cultural differences were found between UK and Taiwan in a number of aspects, including choosing and evaluating the living environment, noise noticeability, annoyance and sleep disturbance, activities and sound preference (e.g. Taipei residents having higher noticeability of noise sources).

The topic of soundscape perception has been extensively studied in relation to park environments, where much of the relevant research in the field was originated. A study by (Ferguson *et al.*, 2024) found that visitors' perception was influenced by the urban density of theirresidence, with visitors from louder, denser urban areas rating park soundscapes as less pleasant. As the authors stated, this suggests that exposure to high levels of urban noise may lead to habituation or a comfort in urban sounds, which can affect the perception of natural soundscapes in parks. The investigation of how individuals' personal views on tranquility affect perception of the sonic environment in cases of urban parks (Filipan *et al.*, 2017), showed that visitors who associate tranquillity with natural sounds or with silence are more often found amongst those that report hearing mechanical sounds (e.g. traffic, airplanes, machines) a lot. These findings suggested that park visitors pay attention more to the sounds they do not expect to hear and that the higher their expectations about the soundscape, the more critical they become in their appraisal of the soundscape. Another study (Guo *et al.*, 2022) examined the capacity of urban parks to contribute to soundscape restorativeness, understood here as contributions to peoples' recovery from attentional fatigue and reflection on life issues. Age was the most influential social and demographic characteristic affecting the perceived soundscape restorativeness, followed by gender, while occupation and educational background showed only limited effects. Using an on-site questionnaire in urban recreational forest parks, a study by (Fang *et al.*, 2021) exploring dimensions of social, demographic and behavioral attributes found that participants of higher education and higher socio-economic status showed lower tolerance towards some sounds (e.g. motorbikes, dogs, surrounding speech, footsteps) and females generally showed higher sensitivity and lower tolerance than males towards several sounds (e.g. insects, playing children, and engines).

An important aspect of soundscape perception is the interrelationships between soundscape attributes and sound categories. Regarding the categorization, in ISO/TS 12913–2:2018 it is stated that: 'The investigated acoustic environment should be characterized by identifying what sound sources can be heard in the area and how dominant they are'. In addition, it is stated that: 'in general, sound sources can be divided into three main types: sounds of technology; sounds of nature; sounds of human beings'. Examples of technological sounds include those from transportation, like the sounds of cars, buses, trains and air planes, as well as those from industry including warning signals and sounds from constructions, plants and machineries. Examples of natural sounds are singing birds, flowing water and wind in vegetation. Examples of the sounds of human beings are mainly voices, footsteps and children at play. However, most relevant studies have focused on general differences between sound categories rather than specific differences in these interrelationships. For example, in a study about the role of soundscape in nature-based rehabilitation (Cerwén *et al.*, 2016), it was found that patients frequently referred to natural sounds as being part of a pleasant and quiet experience that supported recovery and induced 'soft fascination'. Technological (noise) sounds were experienced as disturbing, while perception of human sounds varied depending on loudness and the social context. In similar studies, natural sounds were primarily associated with positive emotions, whereas mechanical and industrial sounds were linked to negative emotions (Moscoso *et al.*, 2018). In addition, (Nilsson *et al.*, 2007) found that the degree to which nature sounds and technological (noise) sounds are heard within the soundscapes is a strong predictor of perceived soundscape quality and road-traffic noise annoyance. Further, to enhance "comfort" aspects of soundscape quality, 'human' sounds originating from human activity were found to be critical to positively influence perception of comfort, contributing to a more favorable overall soundscape (Jo and Jeon, 2020a). In a study of assessment of soundscape quality in suburban green areas and city parks (Nilsson and Berglund, 2006), the effect of natural (e.g., bird song and sounds from water), and technological sounds (e.g. traffic noise) was examined as well as the relationship in terms of equivalent sound levels in order to achieve satisfactory soundscape quality. (Ma *et al.*, 2021) concluded that the preferences for soundscape elements after principal component analysis (PCA) could be classified into the three principal components: 'natural sounds', 'human-made sounds' and ‘mechanical sounds’. In a more relevant study about the interrelationships between soundscape attributes and sound categories, some associations were investigated in urban parks and it was found that a resulting increase in human activity had a negative relationship with calmness, a positive relationship with liveliness and a negative relationship with confusion, with regards to the emotions elicited by the park's soundscape. The greater the number of people who used the parks, regardless of whether they stayed or not and the more their activities did not involve great movement (walking or less movement), the higher the perception of vibrancy (Jo and Jeon, 2020b). In relation to the aforementioned findings, it has been proposed that developing specific descriptors related to perceived sound sources—such as technology, humans, and nature—can enhance predictive models in soundscape studies, thereby improving our ability to understand and manage these environments (Aletta *et al.*, 2016). The common denominator across these findings appears to be the complexity and interdependence among soundscape attributes and sound categories. This understanding is crucial for both theoretical advancements and practical applications, as it emphasizes the need for integrated approaches in research and practice.

A potential theoretical explanation for the interrelationships between soundscape attributes and sound categories, based on Bartlett's schema theory (Bartlett, 1995), could be that individuals use mental frameworks (schemata) to organize and interpret the complex auditory environment. Bartlett's theory suggests that people do not passively record sensory information but actively reconstruct it using pre-existing knowledge structures or schemata, which influence perception and memory. Applying this to soundscapes, listeners categorize sounds (e.g., natural, human, technological) based on their prior experiences and cultural context, which form their auditory schemata. These schemata shape how soundscape attributes are perceived and related to sound categories. For example, a person’s schema for a "natural" soundscape may emphasize bird songs and rustling leaves with specific acoustic qualities, while a "traffic" soundscape schema might focus on engine noise and honking, influencing the perceived pleasantness or eventfulness of the environment. This approach may potentially account for previous studies involving the corresponding category formation of soundscapes (Bones *et al.*, 2018).

The aim of this study is the assessment of soundscape perception by investigating the interrelationships between soundscape attributes and sound categories according to ISO/TS 12913-2:2018 in the case of residents of Chania, Greece. This study originates from the Soundscape Attributes Translation Project (SATP) (Aletta *et al.*, 2023b; Aletta *et al.*, 2024), an international collaboration of scholars and institutions, that aims to provide standardized assessments of urban sound environments across languages, countries and cultures with the ultimate goal of facilitating cross-cultural studies as well as the further expansion of the field. Building on the novel observation of previously undocumented interrelationships between soundscape attributes and sound categories, this study aims to fill a critical gap in the existing literature. To our knowledge, these specific relationships have not been explored before, making our findings a significant contribution to the field. By revealing these nuanced connections, our work challenges the common assumption that soundscape attributes are universally generalizable across different sound categories. This insight calls for more refined and context-sensitive approaches to soundscape assessment and interpretation. Ultimately, we believe our investigation not only advances theoretical understanding but also lays the groundwork for future research avenues in soundscape perception, thereby offering both practical and scholarly value.

II. METHODS

Listening tests were performed to evaluate the perceived affective quality of eight response scales according to Method A of ISO/TS 12913-2:2018 (ISO: Geneva, 2018). Details about translated attributes, audio stimuli, participants, test procedures, sound categorization and data analysis follow.

A. ISO/TS 12913-2:2018 attributes (Greek translation)

ISO/TS 12913-2:2018 (Method A) (ISO: Geneva, 2018) includes a list of eight response scales (pleasant, annoying, eventful, uneventful, vibrant, monotonous, calm, chaotic) with an affective attribute in the heading in English for the assessment of perceived affective quality. For the application of the method for Chania residents (Greece), Greek translations of the attributes were used (Papadakis *et al.*, 2022). Greek translations based on an translation approach of a combined technique of forward translation, synthesis, back translation, pre-test and a committee approach (Cha *et al.*, 2007). Additionally, the implementation of the method was carried out by bicultural translators, which is recommended to enhance the reliability of the results (Hambleton and Kanjee, 1995). This translation approach proved effective in avoiding translation issues that may arise (e.g., the paradox of equivalence), while within its application, challenges such as 'non-equivalence' were adequately addressed (Papadakis *et al.*, 2024).

B. Audio stimuli

The audio stimuli were recorded as part of the Soundscape Attributes Translation Project (SATP) (Aletta *et al.*, 2023b; Aletta *et al.*, 2024). They consist of 27 audio stimuli that were recorded in public areas by operators equipped with a binaural audio acquisition device. Operators conducted recordings while standing and maintaining a distance of at least 1m from reflecting surfaces, capturing sound indicative of a common usage scenario, as recommended by Mitchell et al. (Mitchell *et al.*, 2020). The recordings were made using the head-mounted binaural data acquisition device SQobold with BHSII by HEAD Acoustics, set at the resolution of 24 bit/44 kHz. Calibration was applied with the use of a calibration adapter and a sound level calibrator (¼") emitting a reference signal (1 kHz sine wave at 94 dB SPL) thereby ensuring consistent and comparable measurements. For the sake of the experiment, all the 27 audio samples were trimmed to be exactly 30-seconds long, and a 10 ms fades were applied at the start and the end, while exporting the recordings to the common audio format, using the ArtemiS SUITE (v. 12.6). No additional filtering or audio manipulations were conducted. The collection of audio samples displayed exposure conditions that extended between 44.9 dB(A) and 90.8 dB(A) L_{Aeq}, as measured by Bhan et al (Bhan, 2021). The selection of audio stimuli aimed to capture a broad range of typical urban sounds that are prevalent in cities across the world (i.e., not posing risks of sounding "unfamiliar"). This includes acoustic environments with varied sound sources compositions, which had the potential to elicit the full spectrum of assessments on either of the soundscape attributes scales scored by the participants.

C. Participants

Thirty residents of Chania, Greece took part in the listening tests (19 males, 11 females, M_{age}= 26.1 years, SD_{age}=3.6 years). All participants reported no hearing impairment. Chania, in the island of Crete, Greece has a population of 53.910 residents (Hellenic Statistical Authority, 2023). The majority of the population lives in dense urban clusters and some of the population in semi-dense urban clusters. According to (Eurostat, 2021), the degree of urbanization in Chania can be classified as a dense town (Papadakis *et al.*, 2023). Chania is a popular tourist destination, with a rich cultural heritage and a unique sound environment. The soundscape of Chania is influenced by various factors, including road traffic, tourist activities and natural sounds. The study was approved by the Committee on Ethics and Deontology of Research (C.E.D.R), Technical University of Crete (Project identification code: Protocol number 20/29.09.2020) in Greece.

D. Test procedures

During the experiments, the audio stimuli were presented to the participants through circumaural, acoustically open headphones (Sennheiser HD 650), at the original sound level as recorded on site. An external audio interface was utilized to deliver the playback controlled by a digital audio workstation running on a laptop. Experiments were conducted in a controlled sound-proof auditory environment, ensuring background noise stayed under 40 dB (A). All participants were tested individually. The experiment lasted an average of 50 minutes per participant, accounting for instructions and breaks. After their arrival, all participants were requested to sign the informed consent form. The participants were introduced to a training session that focused on familiarizing them with the experiment procedure and clarifying the soundscape attributes meanings. All participants individually experienced the 27 audio stimuli in varying sequences over consecutive sessions. Following a 30-second exposure, the participants were asked to evaluate the soundscapes. Each of the attributes was presented with a 100-step visual analogue scale (VAS) of 'attribute-soundscape match' (i.e., the Greek translations of the attributes: pleasant, calm, uneventful, monotonous, annoying, chaotic, eventful and vibrant). The scale ranged from 0 ('strongly disagree') to 100 ('strongly agree'). Each participant rated the soundscapes of the audio excerpts by placing a vertical mark on a scale, indicating the degree to which the attribute matched their perception of the soundscape.

E. Sound categorization according to ISO/TS 12913–2:2018

An important aspect of this research was the appropriate categorization of sound stimuli. The appropriate categorization was important to ensure methodological rigor and standardized data collection. In addition, appropriate categorization is important for future related research in order to achieve consistency and comparability, while facilitating interdisciplinary collaboration. The categorization was applied in accordance with ISO/TS 12913–2:2018 since, as stated in the standard, its purpose is to identify and harmonize the collection of data by which relevant information on the key components people, acoustic environment and context is obtained, measured and reported. In general, the ISO 12913 series on soundscape was developed in order to enable a broad international consensus and to provide a foundation for communication across disciplines and professions with an interest in soundscape.

For this study, the sound stimuli were categorized according to ISO/TS 12913–2:2018 based on their content and more specifically based on the dominance of sounds embedded in their natural context (3-fold categorization). Method A gives two options for the final categorization, a 3-fold one and a 4-fold one. In the categorizations it is stated that the term "noise" is used instead of "technological sounds". Also, that the term "noise" is not intended as a value judgment. The categorizations are presented in Table 1. Dominance was defined as sounds perceived as foreground during a large segment of the soundscape excerpts (Axelsson *et al.*, 2010). Foreground sound is also specified in ISO/TS 12913–2:2018 as the sound to which attention of a listener is particularly directed and which can be associated with a specific source. Members of the research team independently listened to all 27 soundscape excerpts and agreed on their categorization. Accordingly, sound stimuli were categorized as 'natural', 'human' and 'noise' (Appendix, Table III).

TABLE I. Sound categorization according to ISO/TS 12913–2:2018

Categorization according to ISO/TS 12913–2:2018			
3-fold Categorization	**Suggested Labeling (3-fold Categorization)**	**4-fold Categorization**	**Suggested Labeling (4-fold Categorization)**
Sounds from human beings (e.g., conversation, laughter, children at play, footsteps)	Human	Sounds from human beings (e.g., conversation, laughter, children at play, footsteps)	Human
Natural sounds (e.g., signing birds, flowing water, wind in vegetation)	Natural	Natural sounds (e.g., signing birds, flowing water, wind in vegetation)	Natural
Noise (e.g., traffic, construction, industry)	Noise	-	-
-	-	Traffic noise (e.g., cars, buses, trains, air planes)	Traffic
-	-	Other noise (e.g., sirens, construction, industry, loading of goods)	Other

F. Data analysis

For the investigation of meaningful interrelationships in the data, initially Spearman correlation coefficients were calculated among paired combinations of the eight attributes and different sound categories. For each pair of sound categories, the sum of the absolute differences of the Spearman correlation coefficients was calculated across all three possible combinations, and the combination with the largest sum was selected to be presented in the results.

In addition, to identify interrelationships between soundscape attributes and sound categories, VizRank method (Leban *et al.*, 2006) was applied. VizRank is a method which uses machine learning to automatically evaluate and rank possible data projections based on their ability to visually discriminate between different categories/classes. A new data set is constructed from the projection, containing the class value and two attributes: x and y positions of data points. Projection usefulness is estimated by inducing a classifier, the k-nearest neighbor (k-NN) classifier (Mucherino *et al.*, 2009) and evaluating its accuracy on this data set. Each projection is numerically evaluated with a value. Projections which provide perfect class separation receive higher value, while less informative projections receive lower values. k-NN is a machine learning method that predicts class value for an unlabeled example by analyzing its k neighboring examples. Each of the k neighbors votes for its class value and their vote is usually weighted according to the distance from the example. In VizRank method implementation, the votes are weighted using function e^{-t^2/s^2}, where t is the distance to the example and s is chosen so that the impact of the farthest of k examples is 0.001 (Leban *et al.*, 2006). The result of the voting is a probabilistic class prediction and the example can be labelled with the most probable class value. The method is used in various scientific fields (e.g. (Wang *et al.*, 2021)) and in this study was implemented with the 'Orange: data mining toolbox in Python' (Demšar *et al.*, 2013).

Finally, principal Components Analysis (PCA) was applied on the rating scale data for perceived affective quality, to assess the results from the participants. For each of the eight attributes of perceived affective quality, arithmetic mean values were calculated for the 27 locations across the participants. This resulted in a 27 locations × 8 adjectives data matrix, which was subjected to a PCA. To identify the optimized orthogonal components, varimax rotation with Kaiser

Normalization was applied (Kaiser, 1959). The statistical analysis was performed with the aid of SPSS 26 for Windows.

III. RESULTS

A. Relationships between attributes - Comparison per sound categories

Various approaches were followed for the assessment of the results and to investigate relationships between the attributes. The cumulative participant (n=30) ratings for each of the eight attributes are presented in figure 1 for all 27 sound stimuli (total), as well as differentiated by sound category (nature, human, noise) (figure 1). The overall results as well as the results per sound category are presented side by side for a common comparison as well as to avoid redundancy of data. For summarizing of the data, boxplots are included which present the median, minimum, first quartile, third quartile and maximum. In the same figure, violin plots are presented to compare the distribution of data between groups.

In order to assess the strength of the associations between the perceptual attributes as well as to find particular relationships between them, the Spearman correlation coefficients were calculated. The results are presented in a correlation matrix (figure 2) for the total sound stimuli and for the different sound categories (human, natural, noise).

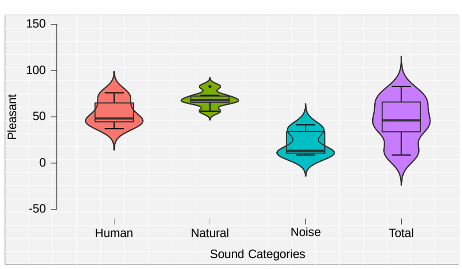
Figure 3 presents scatter plots that highlight relationships between attributes where there is a noticeable differentiation between the sound categories. These plots focus on the combinations that have the largest sum of the absolute differences of the Spearman correlation coefficients between the sound categories. This approach helps to visually identify how different sound categories behave in relation to specific attributes. The results reveals notable differences in sound categories correlate with attributes like monotonous, vibrant, and eventful. These correlations show nuanced patterns across different sound types, highlighting that sound perception is closely linked to contextual and categorical characteristics.

In figure 3(a), the variability explained in the monotonous-pleasant relationship shows a strong negative correlation for human sounds ($\rho = -0.74$) and a weak positive correlation for noise sounds ($\rho = 0.25$) (the following thresholds for interpretation are followed regarding the correlation coefficient: $|\rho| < 0.2$: negligible, $0.2 \leq |\rho| < 0.4$: weak, $0.4 \leq |\rho| < 0.6$: moderate, $0.6 \leq |\rho| < 0.8$: strong, $|\rho| \geq 0.8$: very strong). In figure 3(b), in the monotonous-chaotic relationship there is a strong negative correlation for noise sounds ($\rho = -0.76$) and a weak positive correlation for human sounds ($\rho = 0.21$). In figure 3(c), in the monotonous-pleasant relationship there is a positive correlation with noise and natural sounds ($\rho = 0.43$ and $\rho = 0.26$ respectfully) and a negative correlation with human sounds ($\rho = -0.23$). Regarding monotonous-annoying relationship (figure 3(d)), there is a positive correlation with human sounds ($\rho = 0.36$) and a negative with noise sounds ($\rho = -0.21$).

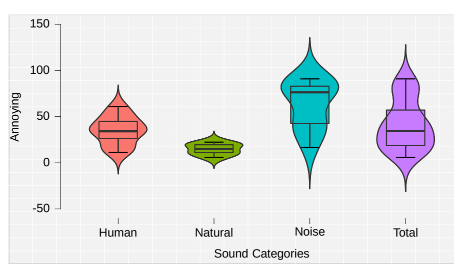
Regarding vibrant, in figure 3(e) it is shown that in the vibrant-pleasant relationship there is a moderate correlation with noise sounds ($\rho = -0.56$) and a positive correlation with human and natural sounds ($\rho = 0.39$ and $\rho = 0.26$ respectively). In figure 3(f), regarding vibrant-annoying relationship, there is a higher positive correlation for noise sounds ($\rho = 0.58$) in comparison to human ($\rho = 0.29$) and natural sounds ($\rho = 0.21$). The same applies in the vibrant-chaotic relationships where there is higher positive correlation for noise sounds ($\rho = 0.94$) in comparison to human ($\rho = 0.36$) and natural sounds ($\rho = 0.14$). Finally, in figure 3(h) regarding the eventful-pleasant relationship there is a negative correlation for noise and natural sounds while in the uneventful-pleasant relationship there is a positive correlation for noise and natural sounds.

Figure 4, on the other hand, displays scatter plots that show strong linear associations —either positive or negative—across all sound categories. Given the large number of possible attribute combinations (28 in total), not all combinations are included. For example, combinations of attributes like eventful-uneventful and pleasant-annoying represent opposing aspects of soundscapes and are expected to have linear associations (Axelsson *et al.*, 2010). The findings presented in figure 4 reveal linear associations across various sound categories.

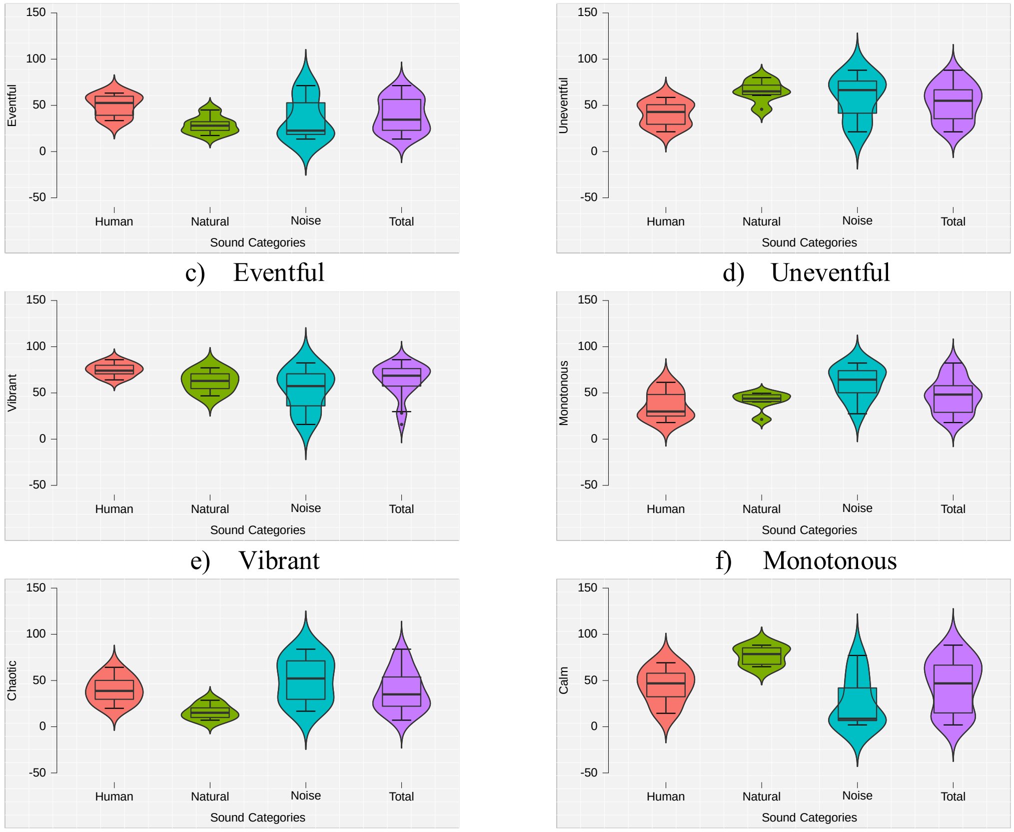
In figure 5, alternative 2-dimensional scatter plot visualizations are included. For each combination of attributes, the nearest neighbors in the projected 2D space were calculated as discussed in section 2.6 (VizRank method (Leban *et al.*, 2006)). The added value of the representation using VizRank methods lies in the fact that it provides an alternative approach for exploring informative two-dimensional projections of multidimensional data. While a scatter plot merely visualizes the relationship between two selected attributes, VizRank systematically evaluates numerous possible attribute pairs and ranks them according to their effectiveness in separating classes or revealing meaningful patterns. The total score of the projection is the average number of same-colored neighbors. Computation for numeric colors is similar, except that the coefficient of determination is used for measuring the local homogeneity of the projection. Scatter plots with the higher total scores are presented.



a) Pleasant

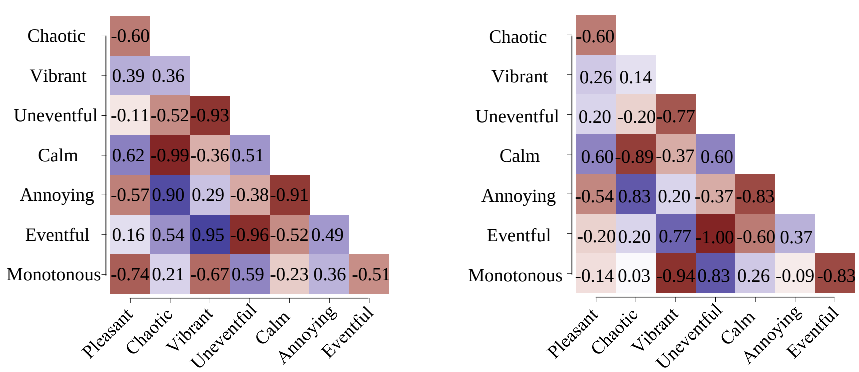


b) Annoying



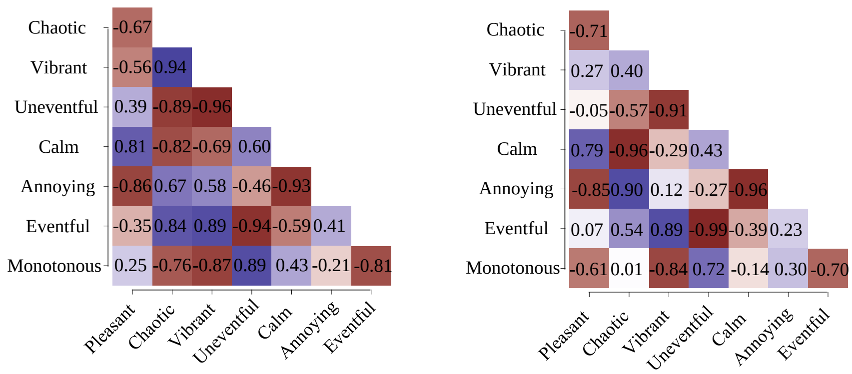
c) Eventful
d) Uneventful
e) Vibrant
f) Monotonous
g) Chaotic
h) Calm

FIG 1. Box plots including median, minimum, first quartile, third quartile and maximum and violin plots of the ratings of the eight attributes of ISO/TS 12913-2:2018 in the case of total sound stimuli and for different sound categories (human, natural, noise)



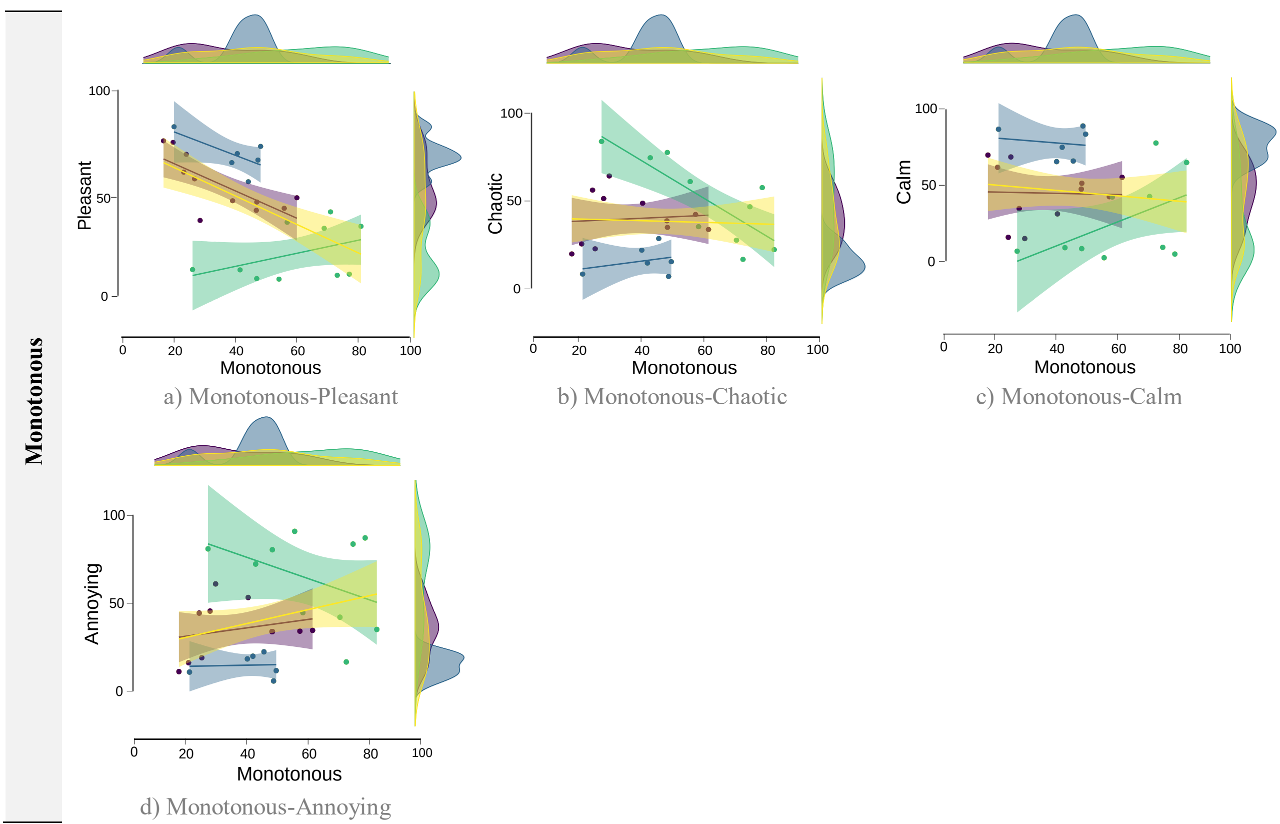
a) Human

b) Natural



c) Noise   d) Total

FIG.2. Spearman correlation coefficient matrix for ISO/TS 12913-2:2018 attributes in the case of total sound stimuli and for different sound categories (human, natural, noise)



a) Monotonous-Pleasant

b) Monotonous-Chaotic

c) Monotonous-Calm

d) Monotonous-Annoying

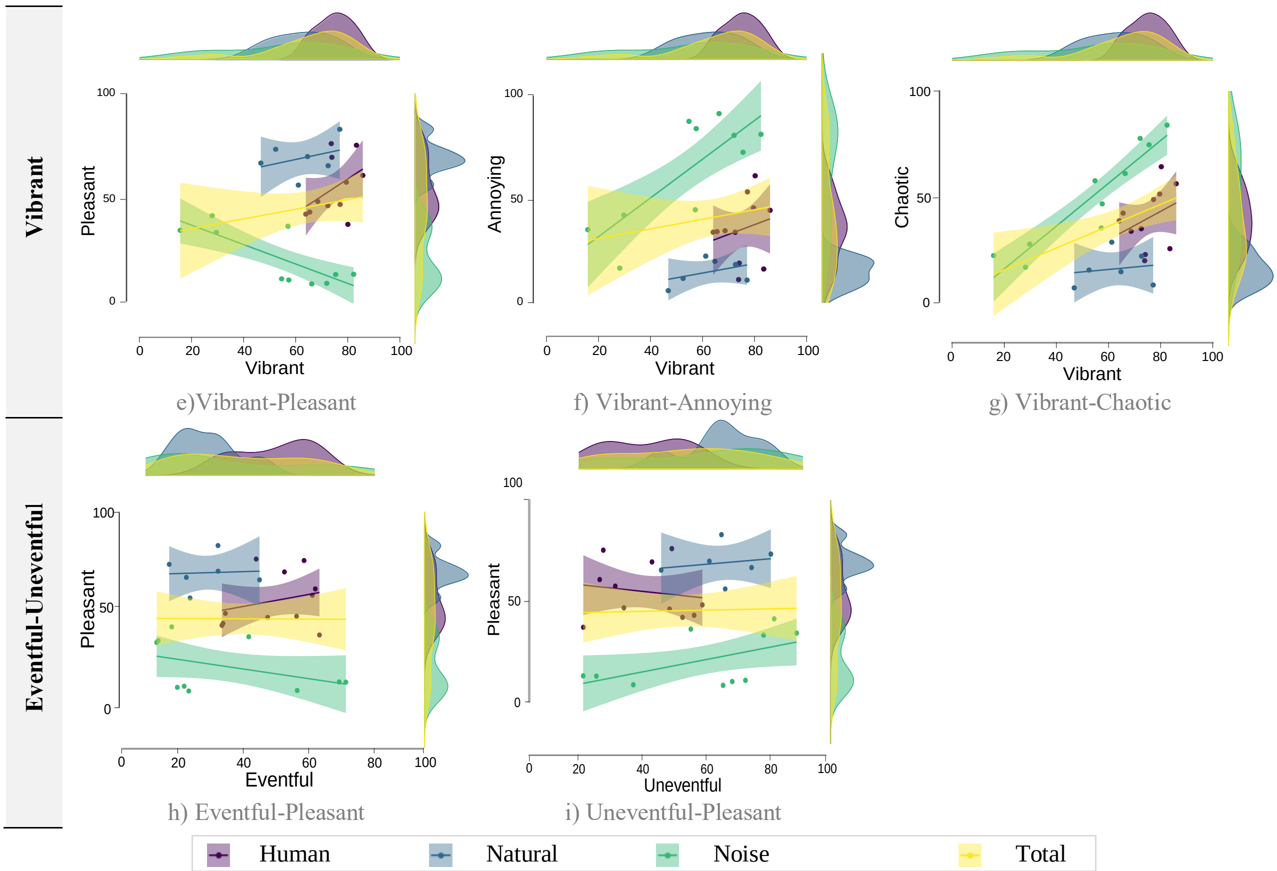
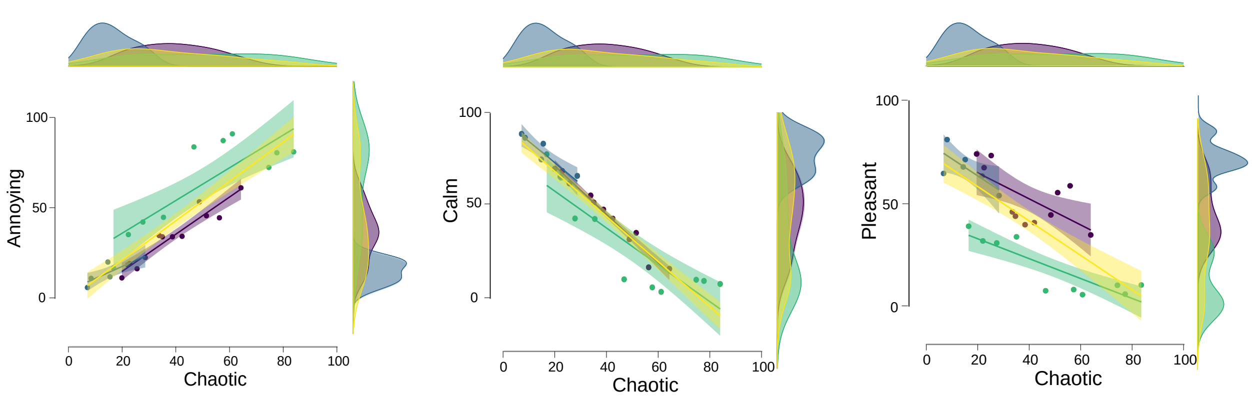


FIG.3. Scatter plots with noticeable differentiation between sound categories (human, natural, noise). R^2 values of attribute combinations for different sound categories are presented in the Appendix (Table IV). Data points represent the mean values of VAS for the sound stimuli among attribute combinations and different sound categories. Shaded areas represent regression lines with 95% confidence interval. Density plots shown on the margins represent distributions of each attribute involved in the scatter plot.



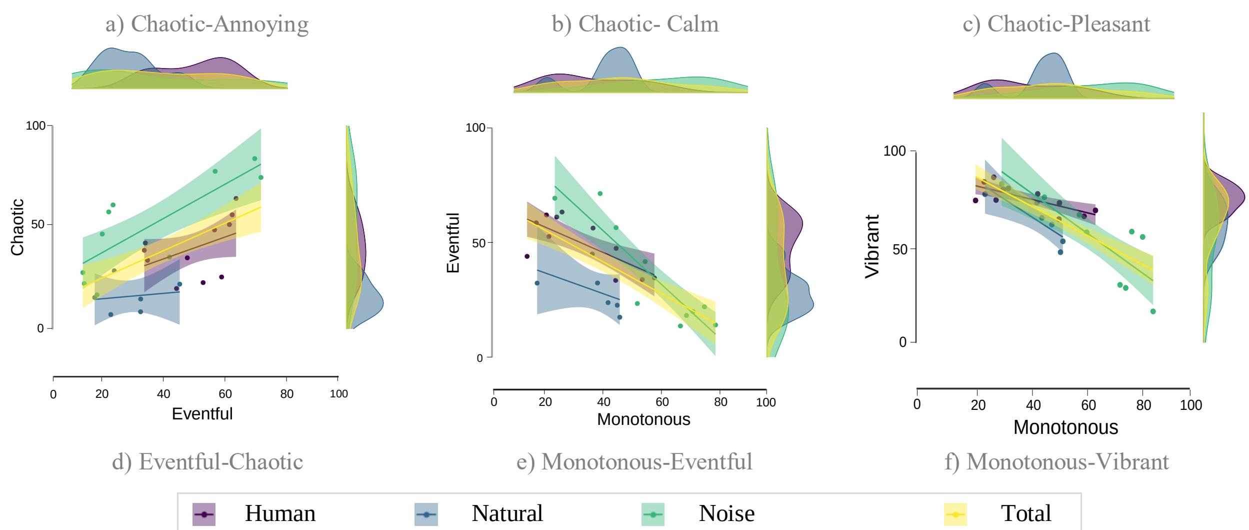
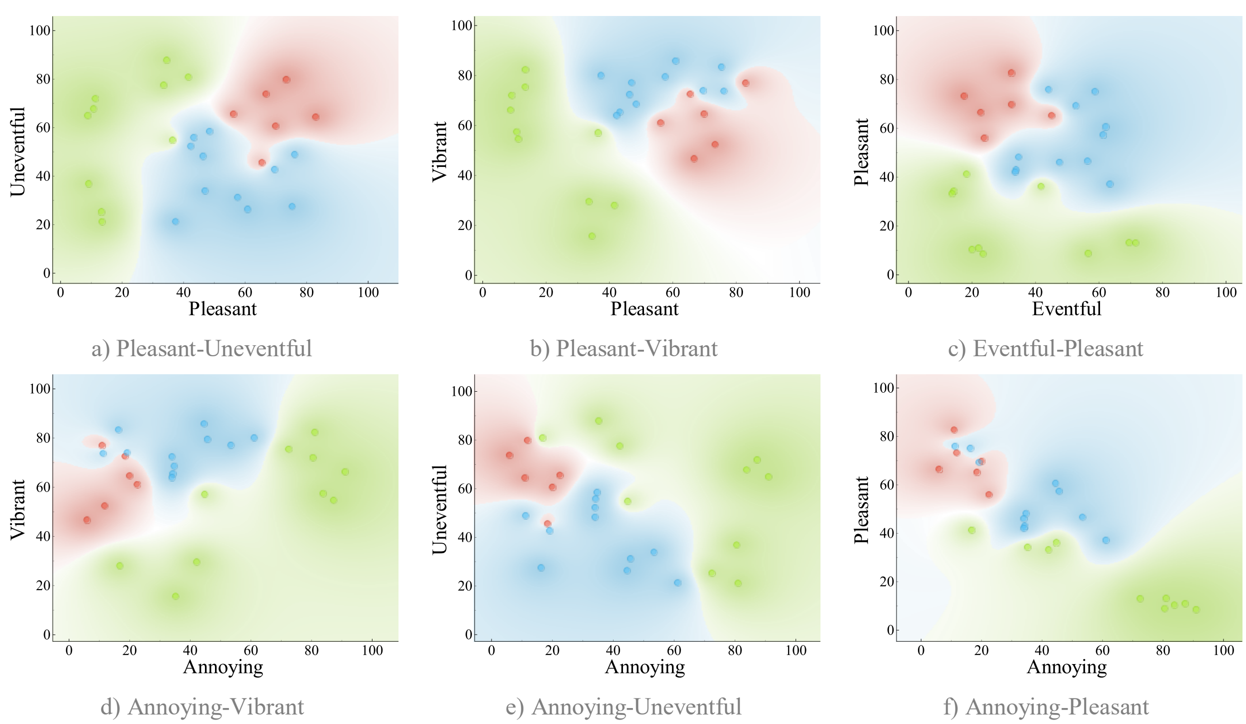


FIG.4. Scatter plots with a strong correlation (negative, positive) for all sound categories (human, natural, noise). Data points represent the mean values of VAS for the sound stimuli among attribute combinations and different sound categories. Shaded areas represent regression lines with 95% confidence interval. Density plots shown on the margins represent distributions of each attribute involved in the scatter plot.



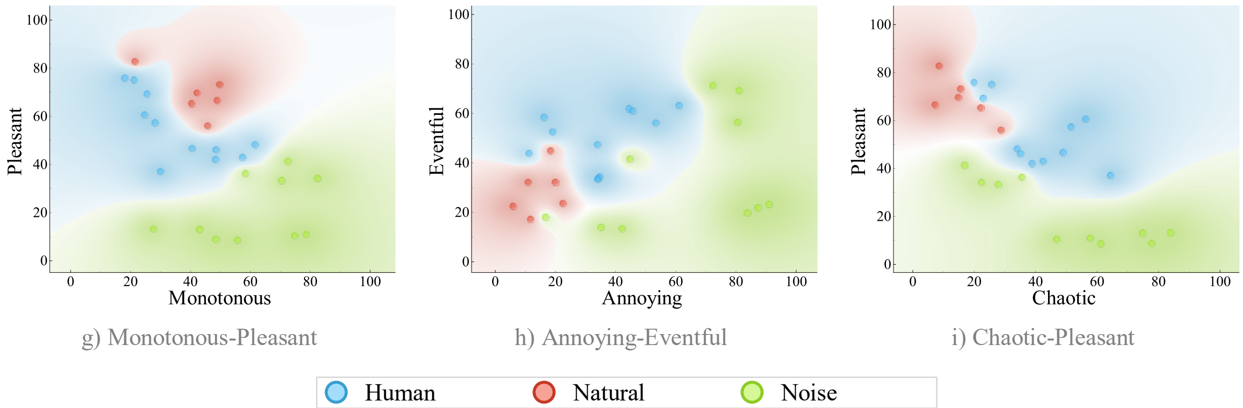


FIG.5. Scatter plot visualization where data points represent the mean values of VAS for the sound stimuli among attribute combinations and different sound categories (human, natural, noise). The numeric color score represents the local homogeneity of the projection measured by the coefficient of determination (R^2).

B. Principal Component Analysis

Principal component analysis was performed on the rating scale data for perceived affective quality. The Kaiser–Meyer–Olkin (KMO) test was applied to determine how suited the data is for factor analysis. The test measures sampling adequacy for each variable in the model and the complete model. KMO test had a value of 0.804 indicating the sampling is adequate. The recommended cut-off values for the KMO statistic vary across studies, but usually values below 0.50 are incompatible with analysis (Cureton and D'Agostino 2013). In addition, Bartlett's Test of Sphericity was applied, which provides information about whether the correlations in the data are strong enough to use a dimension-reduction technique such as principal components or common factor analysis. Bartlett's Test of Sphericity had a value less than 0.001, indicating that the factor analysis is appropriate. A commonly acknowledged cut-off value for determining the significance of the Sphericity Test is $p < 0.05$ (Field, 2024).After PCA, two components with Eigenvalues larger than 1 were obtained. Components 1 and 2 explained 48.14 % and 44.66 % of the variance in the data set, respectively. Figure 6 presents the uncorrected component loadings of the eight attribute scales.

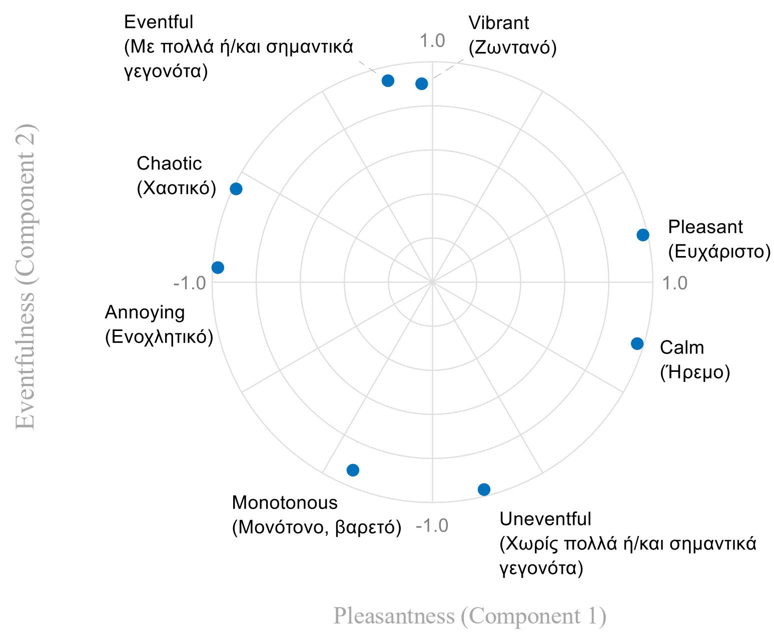


FIG.6. Component loading plots of the eight attributes of ISO/TS 12913-2:2018 (Greek translations of the attributes are also included)

IV. DISCUSSION

A. Relationships between attributes - Comparison per sound categories

1. Scatter plots with a noticeable differentiation between sound categories (human, natural, noise)

Perhaps the most novel and important finding of this research involves relationships of attributes in which there is a large differentiation between the sound categories. Figure 3 includes the scatter plots of attribute pairs with the largest sum of the absolute differences of the Spearman correlation coefficients between the sound categories. In addition, for an overall demonstration of these discrepancies, Table 2 includes the attribute combinations with the noticeable differentiations.

The results have been sorted into three categories: those related to the attribute monotonous, those related to the attribute vibrant and those related to the attributes eventful-uneventful.

The present study reveals distinct and meaningful relationships between soundscape attributes—such as monotonous, vibrant, and eventful—and different sound categories, including human, noise, and natural sounds. These relationships provide nuanced insights into how auditory perception varies depending on the type of sound and its contextual characteristics. For instance, pleasant human sounds are perceived as less monotonous, whereas this relationship is reversed for noise sounds, where pleasantness correlates with increased monotony. This diametrical pattern may be explained by the informational content embedded in human sounds. Human sounds often carry rich linguistic and paralinguistic cues that require active cognitive processing, thereby reducing the sense of monotony. Listeners engage with these sounds by interpreting speech, tone, and emotional nuances, which enhances their vibrancy and reduces boredom. In contrast, noise sounds—such as mechanical or environmental noise—lack this semantic richness and are often perceived as repetitive or unvarying, leading to a positive association between monotony and pleasantness only in specific contexts (e.g., steady white noise used for relaxation). Similarly, natural sounds like bird songs and rustling leaves are generally associated with higher pleasantness and eventfulness, reflecting their dynamic acoustic qualities and positive cultural schemata. The vibrant and eventful nature of these sounds aligns with listeners' expectations and prior experiences of natural environments, which are often linked to relaxation and well-being. These findings can be theoretically framed through Bartlett's schema theory (Bartlett, 1995), which posits that individuals interpret sensory information by actively reconstructing it using pre-existing mental frameworks or schemata. Applied to soundscape perception, listeners categorize sounds based on learned auditory schemata shaped by prior experience and cultural context. For example, a "natural" soundscape schema emphasizes dynamic, pleasant sounds like bird songs, while a "traffic" schema highlights mechanical noise and honking, often perceived as less pleasant and more monotonous. These schemata influence how attributes such as pleasantness and monotony are perceived and interrelated across sound categories. The approach used in this study—examining the interplay between soundscape attributes and sound categories—provides a valuable framework for future research. It enables a deeper understanding of how soundscapes are perceived in different contexts, such as urban versus rural environments, or across cultural boundaries. By verbalizing and interpreting these correlations, researchers can better identify the cognitive and emotional mechanisms underlying soundscape perception, which can inform soundscape design aimed at enhancing well-being or reducing auditory discomfort. In conclusion, the differentiated relationships observed between sound categories and soundscape attributes underscore the complexity of auditory perception. They highlight the importance of considering both the acoustic properties of sounds and the listener's cognitive schemata to fully understand how soundscapes are experienced. This enriched understanding lays a foundation for advancing research and practical applications in soundscape management and design.

TABLE II. Attribute combinations with noticeable differentiation between sound categories (human, natural, noise). Spearman correlations and colour maps of the combinations are included in the table.

		Noise	**Human**	**Natural**
Monotonous	Pleasant	0.25	-0.74	-0.14
	Chaotic	-0.76	0.21	0.03
	Calm	0.43	-0.23	0.26
	Annoying	-0.21	0.36	-0.09
Vibrant	Pleasant	-0.56	0.39	0.26
	Annoying	0.58	0.29	0.21
	Chaotic	0.94	0.36	0.14
Eventful	Pleasant	-0.35	0.16	-0.21
Uneventful	Pleasant	0.39	-0.11	0.21

2. *Descriptive statistics-Scatter plots with visualization-Scatter plots with strong correlation for all sound categories*

The descriptive statistics presented in figure 1 show in general that the noise sounds have the lowest values for the attribute pleasant and the highest in the attribute annoying, the human sounds have the highest values for the attributes eventful, vibrant and the lowest for the attributes uneventful, monotonous, while the nature sounds have the lowest value for the attribute chaotic and the highest for the attribute calm. Similar results were found in Axelsson et al. (Axelsson *et al.*, 2010) where 'soundscape excerpts dominated by technological (noise) sounds were found to be unpleasant, whereas soundscape excerpts dominated by natural sounds were pleasant and soundscape excerpts dominated by human sounds were eventful'. In this study it was also stated that 'these relationships remained after controlling for the overall soundscape loudness, which shows that 'informational' properties are substantial contributors to the perception of soundscape'. In a study about the role of Soundscape in Nature-Based Rehabilitation (Cerwén *et al.*, 2016), it was found that patients frequently referred to natural sounds as being part of a pleasant and 'quiet' experience that supported recovery and induced 'soft fascination'. Technological (noise) sounds were experienced as disturbing, while perception of human sounds varied depending on loudness and the social context. In addition, some universal associations were found in a study: natural sounds were primarily associated with positive emotions, whereas mechanical and industrial sounds were linked to negative emotions (Moscoso *et al.*, 2018).

In addition to the descriptive statistics (figure 2), the scatter plot visualizations presented in figure 5 are useful to make some generalizations about the relationships of the attributes for different sound categories. For example, in figure 5(a) it is shown that noise sounds have the lowest values for the attribute pleasant, with a wide range for the values of the attribute uneventful. Natural sounds have the highest values for the attribute pleasant and the attribute uneventful, while human sounds have medium to high values of the attribute pleasant and not high values for the attribute uneventful. Another typical example is in figure 5(i), in which noise sounds have a wide range for the attribute chaotic with generally low values for the attribute pleasant, natural sounds have low values for the attribute chaotic and high for the attribute pleasant, while human sounds have medium to high values for the attribute chaotic and attribute pleasant.

Finally, in figure 4, scatter plots with a strong correlation (negative, positive) for all sound categories (a general trend is observed for all categories) are presented. In figure 4(a), an increase in the attribute "chaotic" is observed to correspond with a heightened level of annoyance across all sound categories, including noise, natural, and human sounds. In addition, an increase for the attribute chaotic causes a decrease for calmness and pleasantness (figures 4(b) and 4(c), respectively). In figure 4(d) it is shown that an increase in eventfulness causes an increase for the attribute chaotic. In figures 4(e) and 4(f) it is shown that an increase for the attribute monotonous causes a decrease in eventfulness and vibrancy.

B. Principal Component Analysis

The affective responses, per ISO/TS 12913-3, can be represented in a two-dimensional model (the circumplex) with pleasantness and eventfulness on the x and y axis and with two alternative dimensions representing environments that are chaotic versus calm, and environments that are monotonous versus vibrant at a 45° rotation from the main dimensions. Results of this research, presented in figure 6, show that all vectors are long, with their endpoints located close to the periphery of the graphs, represented by unit circles that correspond to the maximum length of the vectors. This shows that the PCA solution is mainly a two-dimensional plane, with limited variance in any other dimension. Second, all the vectors are organized in the same and expected order along the circumplex. They are also largely organized as expected in the two varimax-rotated components, easily interpreted to represent Pleasantness (Component 1) and Eventfulness (Component 2).

An important observation is that the attribute *vibrant* is positioned very close to *eventful* in the circumplex for the examined Greek population. This pattern aligns with findings from a previous study comparing Greek and English residents (Papadakis *et al.*, 2023), where technological noise stimuli largely explained differences in the perception of *vibrant*. While the circumplex arrangement of vectors generally follows expected patterns, the notable deviation of *vibrant* from its anticipated diagonal position (45° between pleasantness and eventfulness) suggests a distinctive perceptual nuance. The possibility that semantic overlap in the Greek translations of *vibrant* and *eventful* might contribute to this pattern is acknowledged. However, to minimize such risks, a rigorous translation protocol was employed involving forward translation, synthesis, back-translation, pre-testing, and committee review (Cha *et al.*, 2007). All steps were conducted by bicultural translators to ensure semantic and conceptual equivalence (Hambleton and Kanjee, 1995). Given these stringent measures, it is more plausible that the observed deviations reflect genuine cross-cultural differences in how residents of Chania perceive *vibrant*, rather than translation artifacts. This interpretation is further supported by the consistency of these findings with prior cross-cultural research, highlighting the influence of culturally specific environmental factors—such as technological noise—on soundscape attribute perception. Thus, the relation analysis between *vibrant* and *eventful* offers valuable insight into culturally grounded variations in soundscape experience.

In studies, variations in the positions of perceptual attributes in the circumplex have been found (e.g. (Jeon *et al.*, 2018)). Although the circumplex model is very useful for representing the soundscape perception of a space as a whole, as it is stated in the ISO/TS 12913-3, the generality of the two-dimensional model is still under examination and requires further validation across languages and sites (Papadakis *et al.*, 2024). Assessing the differences in soundscape perception between cultures and countries is a very interesting area of research which is expected to be thoroughly explored in the coming years. The circumplex model will serve as a valuable tool for this purpose, providing a structured approach to understanding and evaluating the affective qualities of acoustic environments.

C. Limitations and future work

The results of this study shed new light especially on the interrelationships between soundscape attributes and sound categories. However, a limitation of this study lays in the fact that these results are based on the assessment of the perception of residents only in the case of Chania, Greece. This limitation means that study findings need to be interpreted cautiously. For the generalizability of the results, further data collection is required for the investigations of the interrelationships between soundscape attributes and sound categories.

However, this limitation also provides exciting possibilities for future research. Future studies could investigate the interrelationships between attributes for different sound categories in various cases such as different nationalities (Jeon *et al.*, 2018), different age groups, education level (Yu and Kang, 2010) and different kinds of settlements (Papadakis *et al.*, 2023). We hope that our study will serve as a framework for future research based on our approach and findings.

V. CONCLUSIONS

The aim of this study was to investigate the interrelationships between soundscape attributes and sound categories according to ISO/TS 12913-2:2018 and access the soundscape perception of residents of Chania, Greece. For this purpose listening tests were performed according to ISO/TS 12913-2:2018 (Method A). Sound stimuli were categorized according to the prevalence of sounds based in their context into ‘natural’, ‘human’ and ‘noise’ and statistical analysis was employed. Additionally, principal component analysis (PCA) was applied. The main conclusions of this study are:

1. The findings of this research reveal relationships of attributes in which there is a significant differentiation between the sound categories (natural, human, noise). The results have been sorted into three categories: related to the attribute monotonous, to the attribute vibrant and to the attributes eventful-uneventful.
2. Regarding monotonous, the variability explained in the monotonous-pleasant relationship shows a highly negative correlation for human sounds and a low positive correlation for noise sounds. In the monotonous-chaotic relationship there is a highly negative correlation for noise sounds and a low positive correlation for human sounds . In the monotonous-pleasant relationship there is a positive correlation with noise and natural sounds and a negative correlation with human sounds. Regarding monotonous-annoying relationship, there is a positive correlation with human sounds and a negative with noise sounds .
3. Regarding vibrant, in the vibrant-pleasant relationship there is a negative correlation with noise sounds and a low positive correlation with human and natural sounds. Regarding vibrant-annoying relationship there is a higher positive correlation for noise sounds in comparison to human and natural sounds. The same applies in the vibrant-chaotic relationships where there is higher positive correlation for noise sounds in comparison to human and natural sounds.
4. Regarding the eventful-pleasant relationship there is a low negative correlation for noise and natural sounds while in the uneventful-pleasant relationship there is a low positive correlation for noise and natural sounds.
5. Descriptive statistics showed in general that the noise sounds have the lowest values for the attribute pleasant and the highest in the attribute annoying, the human sounds have the highest values for the attributes eventful, vibrant and the lowest for the attributes

uneventful, monotonous, while the nature sounds have the lowest value for the attribute chaotic and the highest for the attribute calm.

Taken together, the findings of this study suggest that analysis based on categorization of sound stimuli (natural, human, noise) proves to be particularly useful for further accessing and understanding the perceived affective quality of soundscapes. We hope that our findings will serve as a foundation for future research endeavours exploring this significant topic.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors declare that they have no conflicts to disclose.

Ethics Approval

The study was approved by the Committee on Ethics and Deontology of Research (C.E.D.R), Technical University of Crete (Project identification code: Protocol number 20/29.09.2020) in Greece. All participants provided informed consent before taking part in the listening tests.

DATA AVAILABILITY

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

APPENDIX

TABLE III. Categorization of sound stimuli of the study according to ISO/TS 12913–2:2018. Sound stimuli can be found in a zenodo dataset (Oberman *et al.*, 2022).

Sound stimuli categorization			
Zenodo id	ISO/TS 12913–2:2018 Categorization	Foreground sound	Background sound
CT301	Noise	Technological	Inaudible
E01b	Noise	Technological	Technological
E11b	Noise	Technological	Technological
E12b	Noise	Technological	Technological
HR01	Noise	Technological	Technological
KT01	Noise	Technological	Technological
W01	Noise	Technological	Inaudible

W09	Noise	Technological	Inaudible
W15	Noise	Technological	Technological
W16	Noise	Technological	Technological-Human
E02	Natural sounds	Natural	Natural-Technological
N1	Natural sounds	Natural	Natural-Technological
RPJ01	Natural sounds	Natural	Human-Natural
VP01b	Natural sounds	Natural	Natural
W06	Natural sounds	Natural	Natural
W22	Natural sounds	Natural	Human-Natural
CG01	Sounds from human beings	Human*	Human
CG04	Sounds from human beings	Human	Human
CG07	Sounds from human beings	Human	Human
E05	Sounds from human beings	Human	Natural
E09	Sounds from human beings	Human	Human
E10	Sounds from human beings	Human	Natural
LS06	Sounds from human beings	Human*	Human
OS01c	Sounds from human beings	Human	Technological
OS01d	Sounds from human beings	Human*	Human
W11a	Sounds from human beings	Human	Technological
W23a	Sounds from human beings	Human	Human

*For these human sounds, also music is heard in the foreground.

TABLE IV. R^2 values of attribute combinations for different sound categories presented in FIG. 3.

Categories	Attribute Combinations (R^2)								
	Monotonous-Pleasant	Monotonous-Chaotic	Monotonous-Calm	Monotonous-Annoying	Vibrant-Pleasant	Vibrant-Annoying	Vibrant-Chaotic	Eventful-Pleasant	Uneventful-Pleasant
Noise	0.176	0.624	0.250	0.168	0.608	0.624	0.865	0.176	0.292
Human	0.533	0.008	0.001	0.058	0.176	0.048	0.109	0.068	0.026
Natural	0.449	0.090	0.026	0.003	0.123	0.168	0.026	0.003	0.032

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