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Determining factors for the appropriateness of soundscapes: A cross-sectional large-sample study in London (UK)[a)]

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ABSTRACT:
This study examines the association between appropriateness and the pleasantness-eventfulness circumplex model, as well as the influencing environmental and personal factors, in accordance with the recommended questionnaire of ISO/TS 12913-2 (2018). A database was used, containing over 1000 soundscape surveys collected across eleven locations in London. Confirmatory factor analysis and the structural summary method were applied to validate the relationship between appropriateness and the pleasantness-eventfulness circumplex model, while linear multilevel models were developed to investigate the effect of personal and environmental factors on appropriateness. The findings highlight varying relationship between appropriateness and the pleasantness-eventfulness dimensions of the soundscape circumplex model. The effect of personal factors on appropriateness is not negligible, accounting for approximately 2.1% of the variance. In contrast to the effects of the categories of landscape composition and acoustic metrics, dominant sound source type is the most influential category of environmental factors, with natural sounds explaining the most variance at 6%. Traffic noise is negatively associated with appropriateness which varies by location, while human sounds are negatively associated with appropriateness when respondents were Asian/Asian British. The findings provide empirical evidence of the relationship between appropriateness and the soundscape circumplex model and offer comprehensive insights into the affecting factors. *© 2024 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).* https://doi.org/10.1121/10.0034418

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I. INTRODUCTION

Within the soundscape community, "context" is considered crucial to soundscape, defined as "[the] acoustic environment as perceived or experienced and/or understood by a person or people, in context" [ISO 12913-1:2014: "Acoustics. Soundscape: Definition and conceptual framework" (ISO, 2014)]. The importance of contextual factors on soundscape is further emphasized in the ongoing ISO/AWI TS 16755-1 standard "Acoustics—Non acoustic factors influencing the perception, interpretation and response to environmental sounds" (ISO/AWI, 2024). The perception of acoustic environment exists in the given context and relates to visual identity of the city (Brown, 2012; Brown *et al.*, 2011; Southworth, 1969). Were a given acoustic environment placed into a different context, regardless of the new visual environment, people would perceive sound differently. When heavy traffic noise is present, it significantly reduces the pleasantness of an environment, even with natural views typically linked to more pleasant soundscapes in quieter settings (Tan *et al.*, 2022). This interaction between the context of a soundscape and its acoustic environment is central to the concept of soundscape perception.

In human geography, a distinction is made between "space" and "place"; a space only becomes a place when it is endowed with a higher or lesser value (Cresswell, 2015; Massey, 1994; Tuan, 1979). This differentiation can also be applied to soundscapes—an acoustic environment transforms into a soundscape when it is endowed with an attachment to a particular context (Mitchell *et al.*, 2024b). According to ISO 12913-1, an acoustic environment is a tangible entity; hence, when it is transported to a different context (e.g., a different location), it typically remains unchanged as long as the sound field remains consistent. The significance of non-acoustic factors on perception to environment sounds is reflected in endowing the acoustic environment with contextual identities that transform it into the soundscape. Conversely, when a soundscape linked to a particular context or location is moved to a new environment, the soundscape is inherently changed. Previous studies also suggested that geographical and cultural context influences the interpretation of soundscape perception (Aletta *et al.*, 2023). Therefore, a key aspect of the importance of context is whether a soundscape is perceived as appropriate for its context and its place (Brown, 2012; Brown *et al.*, 2011).

Although the importance of appropriateness has been recognized in soundscape studies, the literature review reported in part II suggests that previous research on this perceptual

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dimension remains inconclusive. In this study, first, we identify the relationship between soundscape appropriateness and the dimensions of the soundscape circumplex model, and then investigate the effect of personal and environmental factors on appropriateness across 11 locations in London.

II. LITERATURE REVIEW

Appropriateness of soundscape has been interpreted differently in previous studies. For instance, appropriateness is often seen as whether a sound environment meets participants' expectations and is crucial in determining the outcome of soundscape design experiments (Davies *et al.*, 2014; Larsson *et al.*, 2007). Moreover, soundscape appropriateness can be interpreted as the consistency of the visual and acoustic environments (Hong and Jeon, 2015), the relationship between activities and place (Nielbo *et al.*, 2013; Tarlao *et al.*, 2022), and the harmony between sound and context (Acun and Yilmazer, 2019). Historically in soundscape studies literature, the definition of soundscape appropriateness derives from familiarity, as one of the three dimensions of soundscape perception (Axelsson *et al.*, 2010), defined as "how usual or common a stimulus is in the subject's realm of experience" (Marcell *et al.*, 2000). Tables I and II report the theoretical paradigms of previous studies on the soundscape appropriateness.

Method A of ISO 12913-2, which is currently the most widely employed soundscape assessment method (Aletta and Torresin, 2023), includes a question asking participants to rate "Overall, to what extent is the present surrounding sound environment *appropriate* to the present place?" However, ISO does not clearly define what is meant by *appropriate*, leaving it ambiguous for both participants and practitioners. This review has underscored the diversity of understandings of what is meant by "soundscape appropriateness" and a lack of clarity for how the ISO 12913 question on appropriateness should be interpreted. In this study, we explore appropriateness of the soundscape based on responses to the method A questionnaire, using a working understanding of appropriateness as "the coherence between the acoustic environment and a person's expectations for the current place (i.e., based on activities, visual elements, context)."

A. Appropriateness in relation to the soundscape circumplex model

The soundscape circumplex model, derived from Russell's circumplex model (Russell, 1980), was justified by Västfjäll *et al.* (2003) to describe soundscape perception. Axelsson suggested that soundscape appropriateness is statistically orthogonal to the soundscape circumplex model consisting of pleasantness and eventfulness, but should be used as a complementary descriptor (Axelsson, 2015). However, subsequent studies suggested the association between appropriateness and pleasantness is complex and context dependent.

Some studies have found a correlation between soundscape appropriateness and pleasantness (Tarlao *et al.*, 2021). For instance, appropriateness for indoor soundscape is associated with pleasantness (Lu *et al.*, 2023), and appropriateness in residential soundscapes enhances pleasantness, as matching landscape elements with residents' expectations increases both appropriateness and pleasantness (Tan *et al.*, 2021). Similarly, when appropriateness of a soundscape increases, in forested areas, the presence of appropriate soundscape elements has a positive impact on the perception of pleasantness (Hong *et al.*, 2019).

Conversely, while no studies explicitly state that appropriateness is not related to pleasantness, one previous study demonstrated that vehicle driving sounds, which are appropriate and the dominant sound in traffic areas, are not associated with soundscape satisfaction, suggesting that appropriateness can be independent of pleasantness in certain contexts (Li *et al.*, 2022). Therefore, a comprehensive study is needed to validate the relationship between appropriateness and the soundscape circumplex model and to explore differences across locations.

B. Contextual factors which affect soundscape appropriateness

According to ISO/TS 12913-2 (2018), the context refers to "the interrelationship between person, activities, and place" influencing auditory sensation, its interpretation, and the responses to the acoustic environment. In this research, we focus on personal factors and environmental factors and their relationship with the soundscape, through the lens of the ISO 12913-2 question on appropriateness. In this study, personal factors are defined as the demographics, psychological well-being and cognitive aspects (e.g., needs and expectations, preference) (Bild *et al.*, 2016), which influence the relationship between people and the soundscape (Truax, 2001). Environmental factors refer to visual environment factors and sound environment factors, where the visual environment factors are interpreted as permanent elements (e.g., buildings, landscapes, streets) and dynamic elements (e.g., people, vehicles), while sound environment factors are interpreted as psychoacoustics (e.g., sound pressure levels, loudness, sharpness, roughness) and dominant sound sources, which together describe the overall environment.

1. Environmental factors

Table I demonstrates the influence of environmental factors on the appropriateness of soundscape. Tarlao *et al.* (2022) investigated the impact of spatiotemporal factors, such as the time of day and specific locations, on soundscapes appropriateness. They found that soundscape was rated more appropriate in quiet environments compared to noisy ones, and higher in the afternoon than in the evening. Moreover, acoustic factors significantly impact the appropriateness of a soundscape (Aletta *et al.*, 2016). Traffic noise negatively affects the soundscape appropriateness (Nielbo *et al.*, 2013), whereas natural sounds enhance it (Jeon and

TABLE I. Summary of the literature review of the affecting environmental factors for appropriateness of soundscape. Paradigm refers to the understanding of the appropriateness of soundscape in previous studies.

Reference	Paradigm	Environmental factors	Location	Sample size	Statistical testing	Findings
Tarlao *et al.*, 2022	Appropriateness of soundscape for the activities	Different time, quiet or noisy environment	A small public square in Montreal	185 participants (102 women, 76 men)	ANOVA-type statistics: -time and appropriateness (ATS = 16.67, p = 0.004) - time * location and appropriateness (ATS = 14.60, p = 0.001)	- The rating of appropriateness in the quiet environment (location) or in the afternoon (time) is higher than appropriateness in the noisy environment (location) or in the evening (time). -Location and its interaction effect are the significant factor in explaining appropriateness
Nielbo *et al.*, 2013		Sound sources	Sound recordings without context	15 participants (8 women, 7 men, 18–63 age range)	ANOVA-type statistics: - sound source and appropriateness (F(7, 952) = 38.8, p < 0.001)	Traffic noises have a great impact on appropriateness, while human sounds, birds, music also influence appropriateness for activities.
Lu *et al.*, 2023	Appropriateness of soundscape to a place	Visual elements, sound sources	17 indoor environments	32 participants (19 women, 13 men)	1. MLM model testing (y=pleasantness): - heavy traffic* natural features (beta = −0.40, t = −4.80) - light traffic* natural features (beta = −0.12, t = −1.90) 2. Correlation coefficient between appropriateness and pleasantness: r = 0.544, p < 0.001	In areas with less traffic sound, natural window view enhances appropriateness of indoor soundscape, but not in areas where traffic sound is dominant
Axelsson, 2015		Urban environment, social environment	25 urban locations in London	50 participants (25 female, 25 male)	$R^2 = 0.57$	Urban environment and social environment explain 57% of variance of appropriateness for soundscape
Jeon and Jo, 2020	Expectation of sound sources in a place	Sound sources	Six locations in Seoul (Street, public square, recreation space)	20 participants (10 women, 20 men, 22-29 age range)	(Traffic noise: r = 0.59, p < 0.01; human sounds: r = −0.38, p < 0.01; birdsongs: r = 0.40, p < 0.01)	Linear correlation was found between sound sources and appropriateness.
Tan *et al.*, 2021		Visual elements, sound sources	Urban residential environment	11 participants	Spearman's partial correlation coefficient between visual Road and appropriateness when controlling traffic sounds: r = 0.019, p > 0.05	Specific aural sound sources are found to correlate uniquely to appropriateness while controlling for relevant visual elements, whereas visual elements became redundant in its partial correlation to appropriateness.
Abdul Hamid *et al.*, 2023	Accordance between individual expectation and soundscape	Noise sensitivity, Contextual characteristic, sound source	Urban shopping streets	411 participants	$R^2 = 0.454$	Perceived sound source, urban sound environment, visual quality and visual perception explained 45.4% of the variance in appropriateness.

Jo, 2020). Interestingly, Lu *et al.* (2023) found that the effect of traffic sounds on appropriateness varies between areas with heavy traffic and light traffic. Further exploration is needed to determine if sound sources influence appropriateness differently across various locations.

Previous studies have also examined the influence of visual elements on soundscape appropriateness in various scenarios. In commercial areas, both visual quality and perception significantly affect soundscape appropriateness (Abdul Hamid *et al.*, 2023). Not only do individual visual or

TABLE II. Summary of the literature review of the affecting personal factors for appropriateness of soundscape. Paradigm refers to the understanding of the appropriateness of soundscape in previous studies.

Reference	Paradigm	Personal factors/ interaction effect	Location	Sample size	Statistical testing	Findings
Aletta *et al.*, 2023	Appropriateness of soundscape in a place	Cross-cultural difference (China and Europe)	London, China	2000 participants	Mantel-Haenszel linear-by-linear association Chi-squared test: Loudness ∼ appropriateness (Europe): −0.109, $p < 0.001$; Loudness ∼ appropriateness (China): −0.342, $p < 0.001$	The Chinese sample found it less appropriate in the loud sound environment, compared with the Europe sample
Ma *et al.*, 2021		Visit frequency	Sha Tin Park of Hong Kong	150 participants (71.3% women, 28.7% men)	Linear regression model (y = soundscape preference): - visit frequency (beta = 0.17, $p < 0.05$)	Daily user of the park expresses greater overall preference for a good soundscape
Acun and Yilmazer, 2019		Individual preference	Historical museum	113 participants (66 women, 47 men)	Structural equation model: The association between preference and expectation shows the positive path coefficient (0.288)	Preference is positively correlated with the expectation of sound
Ren *et al.*, 2018	Expectation of general soundscape	Psychological perceptions	Historical districts	302 participants (153 Chinese students, 149 English students)	Factor analysis: psychological perception (Chinese: 12.03%, English: 13.69%) as one of the factors of expectation	Psychological perception influences people's expectation of soundscape
Jeon and Jo, 2020	Expectation of sound sources in a place	Expectation	Six locations in Seoul (Street, public square, recreation space)	20 participants (10 women, 20 men, 22–29 age range)	—	Appropriateness is synonymous with the expectations of the sound sources
Tarlao *et al.*, 2021		Noise sensitivity, Social interaction[a]Age	Public square, park in Montreal	1429 participants	Structural equation model: - Noise sensitivity∼pleasantness (b = −0.117, SE = 0.042, $p < 0.005$) - Age ∼ social interaction∼pleasantness (b1,[a] b2 = 0.001, SE = 0.001, $p < 0.05$) - Pleasantnesss ∼ appropriateness (b = 0.093, SE = 0.023, $p < 0.001$)	-An increase in noise sensitivity correlated to a decrease in appropriateness. -Indirect influence of age on appropriateness is mediated through the effect of social interaction.
Bild *et al.*, 2016	Appropriateness of soundscape for the activities	Social interaction	Two large parks and one square in Netherland	208 participants	Mann–Whitney U test: Social interaction∼suitability: U = 34.500, $p < 0.05$	Social interaction is associated with suitability ratings

[a]The indirect effect calculated in the structural equation modeling (SEM) analysis.

auditory sensations affect appropriateness, but the interaction between audio and visual elements also contributes to soundscape appropriateness. The relationship between visual elements and appropriateness is influenced by dominant sound sources. For instance, in areas with less traffic sound, a natural window view enhances appropriateness of indoor soundscape, but this is not the case in areas dominated by traffic sounds (Lu *et al.*, 2023). Additionally, specific auditory sources are uniquely correlated with appropriateness when controlling for visual elements, whereas visual elements alone become redundant (Tan *et al.*, 2021).

It can be found that visual and acoustic factors, or their interaction effect, explain the variance of appropriateness to some extent. Given the complexity of the composition of environmental factors (including acoustic elements, visual elements, etc.) and the location-specific differences in the relationship between environmental factors and appropriateness, it becomes necessary to derive conclusive findings on how different categories of environmental factors affect appropriateness. Previous studies have provided insights into the influence of environmental factors on soundscape perception by categorizing locations based on landscape composition, dominant sound sources, and psychoacoustic metrics (Huang, 2022; Mitchell *et al.*, 2021).

2. Personal factors

Table II illustrates the impact of personal factors (e.g., demographics, psychological well-being) on the appropriateness of soundscape. Previous studies have highlighted how these factors influence soundscape appropriateness (Erfanian *et al.*, 2021; Ren *et al.*, 2018). Aletta *et al.* (2023) found that Chinese participants consider the soundscape less appropriate in louder sound environments, compared with the Europe samples. Acun and Yilmazer (2019) suggested a correlation between individual preference and expectations of sound environment. Moreover, daily users familiar with a context exhibit higher expectations of the soundscape (Ma *et al.*, 2021). When appropriateness is defined as the expectation of a sound source within a visually perceived environment, participants expectations of specific sound sources (e.g., traffic noise and natural sound) directly derives the degree of soundscape appropriateness (Jo and Jeon, 2020). Demographic factors and social behaviors also play a role in affecting soundscape assessment (Erfanian *et al.*, 2021; Yu and Kang, 2008). Previous research indicated a direct influence of noise sensitivity on appropriateness and an indirect influence of age on appropriateness, mediated through social interaction (Tarlao *et al.*, 2021).

Interestingly, Bild *et al.* (2016) provided a critical framework that emphasizes how contextual factors, including environmental conditions, spatiotemporal aspects, and the amenities in the space, shape the relationship between users and their perception of auditory environments. However, the extent to which environmental factors mediate the relationship between personal factors and appropriateness remains unclear. Given that adequate data on individual and environmental factors are available in this study, it is worth considering the interactions between environmental and personal factors in addition to their effects on appropriateness separately.

C. Objectives

This review of previous literature indicated that findings about associations between soundscape appropriateness and the soundscape circumplex model remain inconclusive. However, the impact of context on appropriateness has not been adequately quantified in the context of the circumplex model. Different locations include, but are not limited to, pedestrian-dominated areas (e.g., parks, plazas, and waterfronts) and traffic-dominated areas (e.g., streets, transportation hubs). We then propose RQ1: What is the relationship between soundscape appropriateness and the dimensions of the soundscape circumplex model, and does the relationship vary across different locations?

Given our working definition of appropriateness as the "coherence between the acoustic environment and a person's expectations for the current place (i.e., based on activities, visual elements, context)," it is worthwhile to investigate the impact of personal factors that influence these expectations. While studies have highlighted the relationships between specific personal factors and soundscape perception, there remains a gap in conclusive research regarding the impact of personal factors on soundscape appropriateness as suggested by ISO/TS 12913-2 (2018). Then RQ2 is, to what extent can personal factors explain the variance in soundscape appropriateness?

Previous studies on the effect of environmental factors (i.e., visual and acoustic environment) on appropriateness have typically focused on one type of location, or one type of environmental factor (i.e., acoustic, visual). Few studies have systematically compared the effects of different categories of environmental factors on appropriateness in diverse urban environment (Kang, 2023). In this study, we first examine the effects of different categories of environmental factors on appropriateness. After identifying the most influential category, we explore how its relevant elements (e.g., natural sounds within the sound source type category) contribute to variations in soundscape appropriateness across different locations. Thus, RQ3 is: Which category of environmental factors and its relevant elements contribute the most to the variation in soundscape appropriateness? Does the contribution vary across different locations?

III. METHODS

A. Data collection protocol

We are using the soundscape data from the International Soundscape Database v1.0.1-alpha.1 (Mitchell *et al.*, 2024a), which encompasses over 3500 participants from Europe and China. This study focuses specifically on data collected from eleven locations in London (N = 1016) between 28th February 2019 and 18th October 2019, under favorable weather conditions [see Erfanian *et al.* (2021) for more details]. Details of the number of participants at each location are provided in Table XI (see the Appendix). These locations were selected to represent a diverse range of usage types, as well as visual and acoustic environments in London. For the sake of brevity, interested readers may find details of the selection of the locations in the Appendix. The soundscape survey process was conducted within the framework of the soundscape indices (SSID) project (Kang *et al.*, 2019), adhering to its data collection protocol (Mitchell *et al.*, 2020). Table III presents eight commonly used descriptors of perceived affective quality, appropriateness, dominant sound source, and visit frequency as outlined in method A of ISO/TS 12913:2018. The question "How often would you like to visit this place again?" related to revisit intention was excluded as a factor influencing appropriateness, as we interpreted revisit intention as a reflection of the overall

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TABLE III. Items of the SSID protocol for soundscape data collection in this study.

Variables	Question	Scale
Pleasant Vibrant Eventful Chaotic Annoying Monotonous Uneventful Calm	For each of the 8 scales below, to what extent do you agree or disagree that the surrounding sound environment you just experienced was… • Pleasant • Vibrant • Eventful • Chaotic • Annoying • Monotonous • Uneventful • Calm	Likert scale: Totally disagree (1) – Totally agree (5)
Appropriateness	Overall, to what extent is the present surrounding sound environment appropriate to the present place?	Likert scale: Not at all (1) – Perfectly (5)
Traffic noise Other noise Natural sounds Human sounds	To what extent do you presently hear the following four types of sounds?	Likert scale: Not at all (1) – Dominates completely (5)
Visit frequency	How often do you visit this place?	Likert scale (1–5): Never/This is my first time here; Rarely; Sometimes; Often; Very often
WHO-5	Please indicate for each of the 5 statements which is closest to how you have been feeling over the past 2 weeks, • I have felt cheerful and in good spirits. • I have felt calm and relaxed. • I have felt active and vigorous. • I woke up feeling fresh and rested. • My daily life has been filled with things that interest me.	Composite index: sum of responses to each of the questions (at no time (0)- all of the time (5), then multiply by 4 to get a score from 0 to 100

soundscape evaluation rather than an input variable that directly affects it.

Table IV presents psychological well-being and demographic factors, including age group, education, occupation, and ethnicity. Psychological well-being, characterized by WHO-5 well-being index [*Quality Control Methods for Medicinal Plant Materials* (WHO, 1998)], was used to assess the mental health of participants (Table III). The WHO-5 well-being index is a psychometrically reliable questionnaire assessing well-being based on five non-invasive questions, asking participants how they feel over the last two week across five questions regarding positive mood, vitality, social relationships, personal autonomy, and environmental mastery (Topp *et al.*, 2015). Responses range from 0 "at no time" to 5 "all of the time," and the scores for the five questions are summed and multiplied by 4 to obtain a total score from 0 to 100 (Blom *et al.*, 2012; Topp *et al.*, 2015).

B. Participants

In the ISD data collection used for this study, researchers randomly selected participants from 11 sites in London and invited them to take part in the study. The goal was to include as broad a spectrum of participants as possible to gain insights from different perspectives within an urban soundscape context. Passersby were invited to participate in the survey if they were older than 18 years old. Once the survey process and data privacy information were explained

TABLE IV. Demographic factors reported in the questionnaires section.

Personal factors	N = 1016	N(%) Age mean = 33.7
Age group	Age Group_1 (18–24)	331(32.6%)
	Age Group_2 (25–34)	310(30.5%)
	Age Group_3 (35–44)	137(13.5%)
	Age Group_4 (45–54)	82(8.1%)
	Age Group_5 (55+)	126(12.4%)
Education	Some high school	19(1.9%)
	High school graduate	156(15.4%)
	Some college	127(12.5%)
	Trade/Technical/Vocational training	41(4.0%)
	University graduate	370(36.4%)
	Some postgraduate work	53(5.2%)
	Postgraduate degree (master)	242(23.8%)
Occupation	Employed	586(57.7%)
	Unemployed	23(2.3%)
	Retired	59(5.8%)
	Student	303(29.8%)
	Other	26(2.6%)
	Rather not say	16(2.6%)
Ethnicity	White	710(69.9%)
	Mixed/Multiple ethnic groups	58(5.7%)
	Asian/Asian British	148(14.6%)
	Black/African/Caribbean/Black British	27(2.7%)
	Middle Eastern	18(1.8%)
	Rather not say	30(3.0%)
	Other ethnic group	15(1.5%)

and consent was obtained, the participants completed the survey provided in the SSID Protocol (Mitchell *et al.*, 2020), including demographics information, summarized in Table III. Specifically, the dataset included 1016 valid responses, with 44.88% of participants identifying as male and 52.85% as female. The mean age of the respondents was 33.72 years (Mage = 33.72), with a standard deviation of 14.53 years (SDage = 14.53), indicating the typical variation in ages across the sample. To better reflect the age distribution of the participants, we subdivided the age range into five age groups: 18–24 (32.6%), 25–34 (30.5%), 35–44 (13.5%), 45–54 (8.1%), and 55+ (12.4%).

Table IV presents the participants' demographic data including age group, education, occupation, ethnicity. Previous research by Aletta *et al.* (2023) demonstrated differences in soundscape experience between Chinese and European samples, highlighting the importance of exploring whether different ethnicities assess soundscape appropriateness differently, at least within the London context. The ethnic breakdown of the database is as follows: White (69.9%), Mixed/Multiple ethnic groups (5.7%), Asian/Asian British (14.6%), Black/African/Caribbean/Black British (2.7%), Middle Eastern (1.8%), Rather not say (3%), and Other ethnic group (1.5%).

C. Data analysis

Structural equation modelling (SEM), correlation analysis, structural summary method (SSM), and linear mixed effects regression (LMER) are employed to address the proposed research questions. For RQ1, we first validate the reliability of previous findings on the complex relationship between appropriateness and soundscape descriptors by performing a confirmatory factor analysis using SEM. Correlation analysis and SSM are then used to further explore how appropriateness relates to the primary dimensions of the circumplex model. For RQ2 and RQ3, LMER, using intraclass correlation coefficient (ICC) was selected as the appropriate method to (a) examine the association between personal factors and soundscape appropriateness while accounting for location-based differences, (b) determine the extent to which different categories of environmental factors explain appropriateness, and (c) assess the variability of environmental factor impacts on appropriateness across various locations.

1. Confirmatory factor analysis (CFA)

The CFA, as a subset of SEM (Kline, 2023), employs a hypothesis-testing approach. Initially, relationships between factors are hypothesized based on theoretical assumptions. The model's fit is then evaluated using various fit indices, such as Chi-square, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR).

In this study, CFA was applied to validate the orthogonality hypothesis (Axelsson, 2015) by further exploring how appropriateness relates to eight soundscape descriptors. We first construct an uncorrelated factors model based Axelsson's hypothesis on the assumption that appropriateness was orthogonal to the pleasantness-eventfulness circumplex model, i.e., as the third factor, appropriateness is uncorrelated with the other two factors (pleasantness and eventfulness). For this model, the covariances between "appropriateness" and the other two latent variables ("pleasantness" and "eventfulness") were constrained to be zero, while "pleasantness" and "eventfulness" were allowed to covary using the marker method, enabling free estimation of factor variances. Appropriateness was measured by one indicator, based on Axelsson's hypothesis of its independence from the eight soundscape descriptors. To ensure the reliability of the appropriateness factor with only one indicator (Kline, 2023), the error variance of the indicator was fixed to a small non-zero value.

Model fit was assessed using multiple indicators, with adequacy thresholds set as follows: CFI ($0.90 < \text{CFI} < 1$), TLI ($0.90 < \text{TLI} < 1$), RMSEA ($0 < \text{RMSEA} < 0.08$), SRMR ($0 < \text{SRMR} < 0.08$). The Chi-square ($\chi 2$) test is very sensitive to large samples and is always significant ($p < 0.001$) when the sample size exceeds 400 (Barrett, 2007). If the uncorrelated factor hypothesis shows poor model fit, a correlated factors model—where the covariance between appropriateness and the other factors is not constrained to zero—is constructed and assessed according to the fit index. A significantly better fit for the correlated model will refute the orthogonality assumption. We performed confirmatory factor analysis using "lavaan" (version 0.6–17) in R statistical software (R Core Team, 2024; Rosseel, 2012).

2. Correlation analysis

Associations between all pairs of variables were explored by calculating Spearman correlation coefficient and Chi-square. Three sets of correlation analysis were conducted: (a) the association between appropriateness and eight soundscape descriptors, (b) the association between appropriateness and personal factors, (c) the association between appropriateness and environmental factors. Additionally, a Bonferroni correction was applied to adjust for potential family-wise type I errors that may arise from multiple comparisons. In the correlation analysis between appropriateness and the pleasantness-eventfulness circumplex model reported in Table VI, it was hypothesized that eight variables with a target value of $p = 0.05$, as a baseline, and a Bonferroni correction is required to test each hypothesis at a significance level of $p = 0.05/8 = 0.00625$. The Bonferroni correction was also applied to the analysis of the correlation between appropriateness and environmental factors, more details of which can be found in the Appendix. We conducted Correlation analysis using "correlation" (version 0.8.4) (Makowski *et al.*, 2020).

3. SSM

The SSM is a technique for analyzing circumplex data which makes use of the theoretical relationships between the

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factors of a circumplex. For factors which align with a circumplex arrangement, when the response values are plotted according to their corresponding angle in the circumplex on the *x* axis and their score on the *y* axis, they should trace out a cosine curve. By fitting a cosine curve with the following equation Eq. (1) (Gurtman, 1992):

$$S_i = e + a \times \cos(\theta_i - d), \quad (1)$$

where e is the elevation, a is the amplitude of the curve, S_i and θ_i are the variable's score and angle, and d is the angular displacement that highlights the highest point of the curve and represents the variable's location within the circumplex space. Moreover, model fit, denoted as R^2, is used to describe how well the observed data fits the cosine curve. If the model fit is less than 0.7, the model is unacceptable. If the model fit is between 0.7 and 0.8, the model is appropriate but not quite good enough. But if it is above 0.8, the model is considered a good fit (Zimmermann and Wright, 2017).

For this analysis, we use SSM to locate an external variable (i.e., appropriateness) within the circumplex space by calculating the Spearman correlation coefficient between appropriateness and each circumplex attribute, then fitting the cosine curve to these coefficient scores. This allows us to extract the above parameters, representing elevation (e)—the mean correlation score between the external variable and the circumplex variables; amplitude (a)—the distinctiveness of the curve profile and the distance from the origin in the circumplex space; displacement (d)—the angle of the external variable in the circumplex space; and the model fit R^2.

The reasons to choose SSM as the suitable technique of analyzing soundscape circumplex model are (1) SSM is designed to capture data in a circular space, fitting the data structure of soundscape circumplex model. (2) SSM is able to model the complex factors (i.e., interacting factors) in soundscape studies by capturing the association between external variables and circumplex data. (3) SSM ensures robust validation to assessing model fit using R^2. If the model fit/R^2 is acceptable (>0.7), it is assumed that there is no orthogonality between the external measurements and the circumplex variables, i.e., the external variables are not independent of the variables within the circumplex model, possibly where the external variables are in a two-dimensional plane, or in a plane in three-dimensional space (except for a plane that is orthogonal to the two-dimensional plane of the circumplex model). (4) SSM allows for comparison of external measures within the circumplex model across different environments.

In this study, following the CFA results testing the orthogonality hypothesis, we further explored the relationship between appropriateness and the main dimensions of the Circumplex model by applying the SSM through the CIRCUMPLEX package (version 0.3.10) (Girard *et al.*, 2024). SSM locates appropriateness as the external measure within the two-dimensional (2D) plane of circumplex model by capturing the correlation between the external measure and mean scores on circumplex scales (Gurtman and Pincus, 2003; Wright *et al.*, 2009). Given that previous studies indicate the relationship between appropriateness and the soundscape circumplex model varies across locations, SSM can summarize appropriateness at different locations within the circumplex model to compare parameter differences.

4. LMER

LMER (Gelman and Hill, 2007), also known as multilevel modelling, is applied to the hierarchical data structure, incorporating both individual-level (fixed effects) and group-level (random effects) variables. The coefficients and intercepts in LMER model are allowed to vary depending on different groups, and group differences are represented in three forms: (1) Varying intercepts, (2) varying slopes, (3) varying intercept and slopes (Gelman and Hill, 2007). Moreover, ICC ranging from 0 to 1 quantifies the correlation between observations within the cluster and provides the criteria for interpreting the LMER model and selecting the optimal clusters as the random effect (Hox *et al.*, 2017; Koo and Li, 2016). High values of ICC suggest a significant proportion of variance can be attributed to clusters, highlighting a strong association between the clustered variables and dependent variables. An ICC threshold of 0.1 or higher suggests that an LMER model is appropriate, indicating the significance of the data's hierarchical structure in explaining the dependent variable's variation (Bliese, 1998).

In this study, given the complex relationship among the affecting factors (i.e., environmental, personal factors) of appropriateness, the first step was to include only the personal factors as independent variables of the model to reduce the complexity. Building on the previous study (Erfanian *et al.*, 2021), which demonstrated the validity of applying LMER to examine the impact of personal factors on soundscape, we first employ LMER to explore the effect of personal factors on appropriateness. If personal factors significantly explain the variance in appropriateness, it is necessary to model their interaction with environmental factors (Bild *et al.*, 2016), as this interaction may reveal additional effects that are not captured when analyzing these factors independently. This sequential approach ensures that the individual contributions of personal factors are first understood before investigating potential interaction effects.

For RQ2, the LMER model was built in two levels: personal factors as the fixed effects and the location categorization as the random effects. To explore suitable random effects between random intercept only and both random intercept and slope, the random-intercept only model given in Eq. (2), was selected as the appropriate model in the model comparison, in line with previous research that personal factors consistently affect how people perceive sound environment regardless of locations (Erfanian *et al.*, 2021).

For RQ3, the model ICC was first calculated and compared for different environmental factor clustering approaches to select the best location clusters as random

TABLE V. Goodness of fit indicators of CFA models for soundscape assessment.

Model	χ^2(df)	SRMR	RMSEA	CFI	TLI
Uncorrelated factors	306.098 (23), $p < 0.001$	0.104	0.110	0.890	0.836
Correlated factors	150.357 (21), $p < 0.001$	0.041	0.078	0.952	0.918

effects, and the relevant environmental factors within the cluster as fixed effects. Given that relationship between environmental factors and appropriateness varies by location (Lu *et al.*, 2023; Tarlao *et al.*, 2022), we then build the LMER model with random slopes and intercepts [Eq. (3)] to analyze the differences in the impacts of environmental factors on appropriateness across locations:

$$Apprp \sim pf + (1|locationID), \quad (2)$$

$$Apprp \sim ef + (ef|locationID), \quad (3)$$

where *Apprp* is appropriateness, *pf* is the set of personal factors, and *ef* is the set of environmental factors.

We use backward stepwise feature selection for the fixed effects in the LMER model. An initial model comprising all potential variables was created, and each feature was incrementally removed until no further improvements in the model were observed. To avoid the multicollinearity among the selected variables, we set a variance inflation factor threshold of less than 5, features that exceed the threshold are removed from the model. The random slope in the random effect was selected based on model convergence and avoiding overfitting. The baseline model with random slopes and intercepts was simplified by removing overfitting slopes (proportion of variance = 0). The analysis of variance (ANOVA) function tests for significant differences between the simplified and baseline model. If no significant difference exists ($p > 0.05$), the final model with fixed and random effects is obtained.

The Linear mixed-effects regression model was implemented using "lmer4" (version 1.1–35.1) (Bates *et al.*, 2015). The "lmerTest" package (version 3.1–3) (Kuznetsova *et al.*, 2017) was used for feature selection and overfitting testing, with the "step" function was used for feature selection of fixed effects, and the "VarCorr" and "rePCA" functions selected for random effects. Plots were created using "sjPlot" (version 2.8.15) packages (Lüdecke, 2018).

IV. RESULTS

A. Association between appropriateness and the pleasantness-eventfulness circumplex model

Building on the approach used by (Tarlao *et al.*, 2021) to examine the relationship between soundscape descriptors and appropriateness using SEM, we applied the same approach to our database, performing CFA to validate the reliability of the relationship between appropriateness and soundscape circumplex model. As shown in Table V, the uncorrelated factors solution (Fig. 1) results in a poorer fit to the data [χ^2 (df) = 306.098 (23), $p < 0.001$, SRMR = 0.104, RMSEA = 0.110, CFI = 0.895, TLI = 0.836]. This result refutes the original hypothesis and suggests the need for an alternative approach using a correlated (oblique) three-factor model. Compared to the uncorrelated three-factor analysis, the correlated factor solution in the Fig. 1 shows good model fit values [χ^2 (df) = 150.307 (21), $p < 0.001$, SRMR = 0.041, RMSEA = 0.078, CFI = 0.952, TLI = 0.918] (reported in Table V), suggesting that soundscape appropriateness can be located within the two-dimensional space of the soundscape circumplex model. The improved correlated factor model is more accurate and representative of the data, suggesting that appropriateness is correlated with the pleasantness-eventfulness dimensions of the circumplex, in line with recent literature (Tarlao *et al.*, 2021).

Based on the CFA results, we continue to explore further the ways in which appropriateness is related to the primary dimensions of the circumplex. Spearman's rank correlation was first computed to assess the association between soundscape appropriateness and eight soundscape descriptors. To validate the robustness of the association between the external measurements and the circumplex variables and compare the differences in correlations across

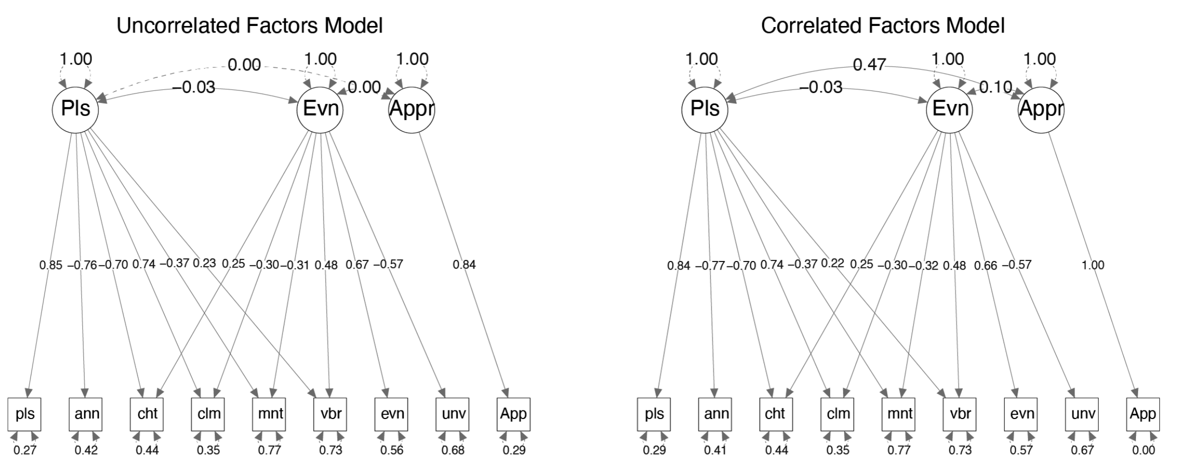

FIG. 1. Comparison of uncorrelated and correlated factors CFA model.

locations, SSM was then applied to locate soundscape appropriateness as an external measure within the 2D plane of the soundscape circumplex model.

Table VI reports spearman correlation coefficients and correlation-based structural summary statistics with 95% confidence intervals (CIs). Since Tarlao *et al.* (2021) and Jeon *et al.* (2018) reported that the two-dimensional structure of soundscape assessment (pleasantness-eventfulness) was influenced by contextual factors, correlation analysis was performed separately for the each of the 11 different locations as well as for all locations combined. In general, soundscape appropriateness was positively correlated with soundscape descriptors "pleasant," "vibrant," "calm," and negatively correlated with descriptors "chaotic," "uneventful," "annoying," "monotonous." The model fit (R^2) in the SSM analysis was 0.958, indicating a strong fit to the observed data. The amplitude or the peak correlation of the appropriateness, was 0.32, which is notable as it is higher than 0.15. The angular displacement, i.e., the angular position in the circumferential model, is 359 degrees, aligning nearly perfectly with pleasantness (0°/360°). Overall, soundscape appropriateness was closely correlated with pleasantness in all eleven locations, as it shown in Fig. 2(a).

At the location level, it should be noted that appropriateness demonstrates no correlation with eight soundscape descriptors in Camden Town and Euston Tap, which was confirmed by the model fits ($R^2 < 0.7$) for these locations (Table VI), as well as the dashed line indicating wide CIs in Fig. 2(b). The model fits for other locations were adequate or good ($R^2 > 0.7$) with peak correlations above 0.25 (see Table VI). Specifically, in Fig. 2(c), appropriateness for soundscape in Marchmont Garden and Regent's Park Japanese Garden was correlated with "calm" indicators, while appropriateness in Russell Square and Tate Modern [see Fig. 2(d)] was correlated closely with "vibrant" indicators. Appropriateness in other locations, including St. Pancras Lock, Regent's Park Broadwalk, St. Paul's Churchyard, St. Paul's row, Torrington Square, was closely correlated with pleasantness.

B. Effect of personal factors on appropriateness

To address RQ2 "To what extent can personal factors explain the variance in soundscape appropriateness?", correlation analysis was first performed to establish the relationship between all pairs of variables, including the predictors

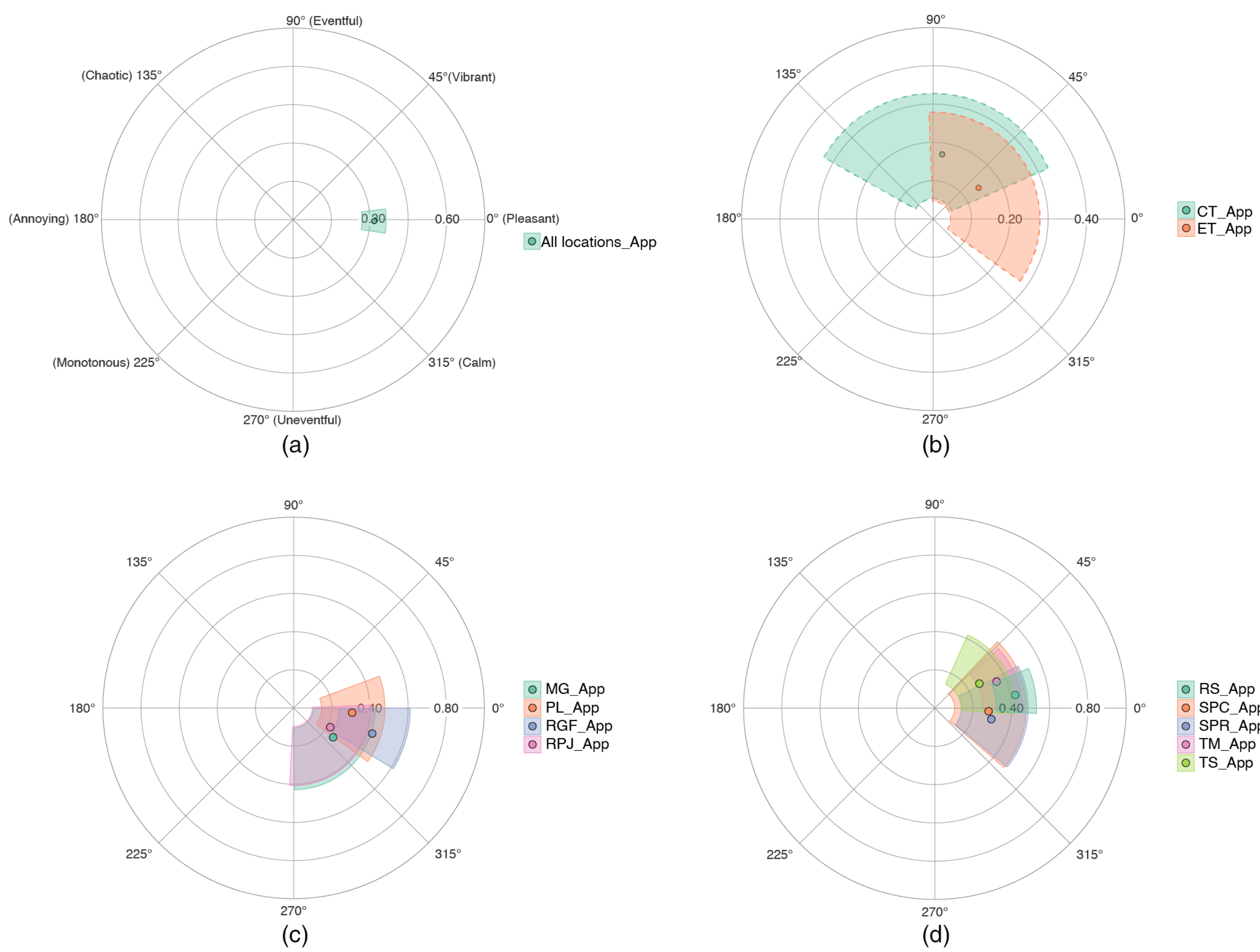

FIG. 2. (Color online) SSM analysis for the correlation between soundscape descriptors and appropriateness, (a) all locations; (b), (c), (d) eleven London locations (for location IDs, see the Appendix).

TABLE VI. Spearman correlation coefficients and correlation-based Structural summary statistics with 95% CIs in all locations and eleven groups by locations (for location IDs, see the Appendix).

		Correlation analysis								SSM		
Factors		Pleasant	Chaotic	Vibrant	Uneventful	Calm	Annoying	Eventful	Monotonous	Amplitude	Displacement	Model fit/R^2
Appropriateness	All sites	0.337[a]	−0.251[a]	0.163[a]	−0.090[a]	0.282[a]	−0.366[a]	0.013	−0.236[a]	0.32 (0.27,0.37)	359 (351.7,7.1)	0.958
	CT	−0.123	0.190	0.255	−0.158	−0.074	−0.152	0.178	−0.062	0.17 (0.05, 0.33)	82.1 (26.7,154.1)	0.591
	ET	0.010	−0.060	−0.117	−0.283	0.047	−0.294	0.101	−0.168	0.14 (0.05, 0.28)	34.5 (330.8, 89.6)	0.425
	MG	0.319[a]	−0.173	0.066	0.214	0.281[a]	−0.212	−0.104	−0.085	0.26 (0.11, 0.44)	323.3 (269.9, 358.5)	0.975
	PL	0.235[a]	−0.319[a]	0.214	−0.029	0.298[a]	−0.208	−0.007	−0.282	0.31 (0.15, 0.48)	355.5 (321.9, 19.1)	0.902
	RGF	0.516[a]	−0.371[a]	0.072	−0.041	0.382[a]	−0.418[a]	−0.054	−0.107	0.43 (0.24, 0.60)	342.0 (328.9, 358.4)	0.922
	RPJ	0.267	−0.325[a]	0.211	−0.054	0.309	−0.200	−0.003	−0.257	0.22 (0.09, 0.41)	332.3 (267.4, 3.6)	0.777
	RS	0.460[a]	−0.291[a]	0.200	−0.185	0.307[a]	−0.431[a]	0.034	−0.403[a]	0.43 (0.32, 0.52)	9.3 (357.0, 22.4)	0.943
	SPC	0.299	−0.098	0.237	0.137	0.256	−0.357[a]	0.175	−0.054	0.28 (0.12, 0.48)	356.7 (322.0, 42.7)	0.847
	SPR	0.300	−0.271	0.003	−0.039	0.203	−0.439[a]	—0.072	−0.110	0.30 (0.14, 0.49)	348.9 (321.0, 23.6)	0.906
	TM	0.353[a]	−0.163	0.370[a]	−0.167	0.094	−0.392[a]	0.119	−0.320[a]	0.35 (0.26, 0.46)	23.2 (359.7, 43.6)	0.977
	TS	0.186	−0.075	0.201	−0.204	0.134	−0.234	0.151	−0.268[a]	0.27 (0.14, 0.42)	28.9 (356.0, 67.9)	0.948

[a]Correlation is significant at the 0.006 25 level (2-tailed).

(personal factors) and outcome variables (appropriateness). Given the different types of variables (ordinal, categorical), Spearman correlation analysis and Chi-square were performed separately to explore the association between appropriateness and personal factors at different locations. According to the correlation matrix for appropriateness and personal factors in Table VII, appropriateness is positively correlated with age group, and negatively correlated with visit frequency and ethnicity. Psychological well-being, education, gender, and occupation are not significantly correlated with appropriateness.

Linear mixed-effect modelling was then performed to explore the extent of the variance in appropriateness explained by personal factors. If personal factors explain only a slight variance in appropriateness, interactions between personal and environmental factors can be ignored. However, if personal factors significantly explain the variance of appropriateness, these factors should be considered while exploring RQ3 "environmental factors affecting appropriateness."

A random intercept (location ID) and a fixed slope (predictor) were applied to account for the differences in soundscape appropriateness across different locations. Independent variables in the model were reduced by applying backward stepwise feature selection. Psychological well-being, education, and gender were not significant variables after feature selection. Given the high correlation between age group and occupation, including both would result in one feature failing to meet the selection threshold. Therefore, either one of the age group or occupation was selected for the final model, along with the significantly correlated variables: visit frequency and ethnicity.

According to the results of the final model (see Table VIII), soundscape appropriateness is positively correlated with the over-55 age group, and negatively correlated with the Visit frequency and ethnicity (Asian/Asian British). Part R^2, marginal R^2, and conditional R^2 values are calculated for the soundscape appropriateness model. Part R^2 represents the reduction of fixed-effect variance caused by removing a specific variable, measuring each variable's contribution in explaining the variance of the dependent variable. Marginal R^2 refers to the variance explained by fixed effects, while conditional R^2 refers to the variance explained by both fixed and random effects (Nakagawa and Schielzeth, 2013).

TABLE VII. Correlation coefficients for appropriateness and all personal factors.

	Psychological well-being	Education	Gender	Age group	Occupation	Visit frequency	Ethnicity
Psychological well-being							
Education	0.019						
Gender	0.002	0.008					
Age group	0.084[a]	0.061	−0.110[a]				
Occupation	−0.065[b]	−0.248[a]	0.151[a]	−0.417[a]			
Visit frequency	0.079[b]	−0.014	0.014	0.095[a]	−0.100[a]		
Ethnicity	−0.043	0.042	0.096[a]	−0.198[a]	0.195[a]	−0.062	
Appropriateness	0.046	0.009	0.017	0.114[a]	−0.023	−0.068[b]	−0.115[a]

[a]$p < 0.01$.
[b]$p < 0.05$.

https://doi.org/10.1121/10.0034418

TABLE VIII. Fixed and random effects in a linear mixed model using personal factors as candidate variables to explain variations in soundscape appropriateness.

Fixed effects				
	Soundscape appropriateness			
Predictors	Estimate	Std.Error	95%CI	Part R^2 (95%CI)
Intercept	3.62[a]	0.12	3.38, 3.85	
Visit frequency	−0.06[b]	0.03	−0.13, −0.03	0.004 (0, 0.02)
Ethnicity (Asian /Asian British)	−0.32[a]	0.09	−0.50, −0.15	0.012 (0.01, 0.03)
Age group (55+)	0.28[b]	0.13	0.03, 0.54	0.005 (0, 0.02)
Random effects				
LocationID (intercept)	0.11	0.33		
ICC	0.103			
Marginal R^2/ conditional R^2	0.021/ 0.121			
AIC	2734			

[a] $p < 0.001$.
[b] $p < 0.05$.

Specifically, the conditional R^2 indicates that the model explains 12.1% of the variance in soundscape appropriateness. According to the marginal R^2, location-level differences explain approximately 10% variance in soundscape appropriateness, while personal factors explain 2.1% variance in soundscape appropriateness. Compared with the previous research, where 1.4% of variance in pleasantness and 3.9% of variance in eventfulness were explained by personal factors, it is evident that personal factors explain the variance in appropriateness to a moderate extent and should therefore be considered when exploring the influential environmental factors in RQ3. Ethnicity (Asian/Asian British) accounts for the largest portion of the variance attributable to fixed effects, approximately 1.2%, followed by visit frequency (0.4%) and over-55 age group (0.5%).

C. Contribution of environmental factors to appropriateness

1. Comparison of different categories of environmental factors

To sort out RQ3 "Which category of environmental factors and its relevant elements contribute significantly to soundscape appropriateness? Does the contribution vary in different locations?" We first conducted a correlation analysis between appropriateness and environmental factors across all locations (see the Appendix). Generally, soundscape appropriateness is significantly correlated with sound sources compared to acoustic metrics and landscape composition. Specifically, appropriateness is positively correlated with natural sounds and negatively correlated with traffic and other noise.

To further explore the contributions of different categories of environmental factors to soundscape appropriateness, we developed a baseline model with only intercepts and computed the ICC using various clustering approaches. Previous studies have clustered and analyzed the ISD database by different categorization methods, including landscape composition, dominant sound source, and acoustic category factors (Huang, 2022; Mitchell *et al.*, 2021). By comparing ICCs in different baseline models, we determined the contribution of various group clustering approaches to soundscape appropriateness.

Table IX presents the clustering of locations and their ICCs based on landscape composition, acoustic features, and dominant sound source. In this study, we used the clusters results from the previous studies for the same dataset (Aletta *et al.*, 2020; Huang, 2022; Mitchell, 2022). The soundscape data were first categorized by proportions of landscape composition, with Huang (2022) identifying four principal components using K-Means clustering by calculating the mean values of visual elements, including permanent components (sky, buildings, roads, greenery, water) and dynamic components (people, bicycles, cars, motorcycles, buses). The acoustic features were categorized by Aletta *et al.* (2020) into three types of zones: traffic/noise-dominated, active, and quiet, based on psychoacoustic measurements (L_{Aeq}, L_{A10}, L_{A90}, Loudness, Roughness). Mitchell (2022) categorized locations into three types: natural sounds-dominated, human sounds-dominated and traffic and other noise-dominated based on the mean highest scores of the dominant sound source type. When comparing the ICCs of the different clusters (landscape ID, acoustic ID, and dominant sound source ID), the difference in dominant sound source across clusters explained the most variance in appropriateness, about 7.2%. This suggests that dominant sound source type is the most influential environmental category in soundscape appropriateness, compared to landscape composition and the acoustics features.

Although previous studies identified the impact of various environmental factors on soundscape appropriateness, the relative importance of these factors has not been fully explored. This study, utilizing the extensive ISD database, which encompasses diverse contexts and acoustic environments across London, demonstrates that dominant sound sources are the most significant contributors to soundscape

TABLE IX. Details of the three types of clustering (landscape composition, acoustic features, and dominant sound sources) and their corresponding ICCs.

	Description	Location	ICC Random Intercept only (y ~ (1 | Cluster))
Landscape ID	Green urban trails and plazas	Marchmont Garden, St. Pancras Lock; Regents' Park Japanese Garden _2, Russel Square_3;	0.034
	Enclosed urban parks with a high degree of greenery	Regents' Park Japanese Garden _1, Regents Park Broadwalk, St Paul's Cross, Russel Square (1,2)	
	Urban transport roads and pedestrian with sparse greenery (Few vehicles)	Camden Town (1,3,4), St Paul's Row, Tate Modern, Torrington Square	
	Close to busy traffic roads, sparse greenery	Camden Town _2, Euston Tap	
Acoustic ID	Active areas	Regents Park Japan, Russell Square, St Paul's Row, St Paul's Churchyard, Tate Modern, Torrington Square	0.029
	Quiet areas	Marchmont Garden, St. Pancras Lock, Regent's Park Broadwalk	
	Traffic/noise-dominated areas	Camden Town, Euston Tap	
Dominant sound source ID	Natural sounds dominated	Regents' Park Japanese Garden, Regent's Park Broadwalk, Russell Square	0.072
	Human sounds dominated	Tate Modern, St Paul's Row, St Paul's Churchyard	
	Traffic noiseand other noise dominated	Camden Town, Euston Tap, Torrington Square, St. Pancras Lock	
Location ID	All locations	—	0.112

appropriateness within environmental factors. The highest ICC value of 0.10 for Location ID indicates that 10% of the variance in soundscape appropriateness can be attributed to differences between locations. This represents a substantial clustering effect, implying that location is a significant factor influencing soundscape appropriateness.

2. Contribution of the specific elements within the most influential environmental category

In the LMER model, dominant sound sources were included in the fixed effects as the most influential environmental category, while the random effects clustering used location IDs with the highest ICC. The selected personal factors from RQ2 were also included in the new LMER model for two reasons: (1) The RQ2 results showed that personal factors significantly affect appropriateness, (2) the literature review indicated that the interrelationship between personal and environmental factors on appropriateness is unclear and needs further explored.

During the process of feature selection of the fixed effects, visit frequency and age group (55+) did not meet the threshold of significance and thus was removed from the variables in the model. Sound source and ethnicity (Asian/Asian British) were selected as fixed effects, with traffic noise as a random slope and Location ID clusters as the random intercept (see Table X). The model found that appropriateness was positively correlated with natural sounds, and the interaction between traffic noise and other noise, but negatively correlated with traffic noise and other noise. Human sounds were negatively associated with soundscape appropriateness when respondents were Asian/British Asian.

To assess the impact of input variables, fixed effects, and random effects on soundscape appropriateness, we calculated the part R^2, marginal R^2, and conditional R^2. The comprehensive model accounted for 22.3% of the variance in soundscape appropriateness. Specifically, fixed effects at the individual level explained 17.5% of the variance, while random effects at the location level accounted for 4.8%. Among the variables, natural sounds contributed 6% to the variance in soundscape appropriateness, followed by other noise (2%), the interaction between ethnicity (Asian/Asian British) and human sounds (1.9%), traffic noise (1.2%), and the interaction between traffic noise and other noise (0.6%). In the varying-intercept and varying-slope model, Fig. 3 presents the random effects with location (i.e., location ID) as the random intercept and with traffic noise as the random slope. This finding highlights that the impact of traffic noise on soundscape appropriateness varies depending on the location.

V. DISCUSSION

Soundscape appropriateness has been emphasized as a key dimension in soundscape design evaluation. This study provides empirical evidence that the relationship between soundscape appropriateness and the pleasantness-eventfulness circumplex is context-dependent, guiding designers on when to adopt appropriateness as an independent or complementary descriptor in soundscape evaluations. Additionally, this research contributes to the development of soundscape design frameworks that integrate both acoustic and non-acoustic factors, assessing the extent to which the sound environment aligns with its context. By applying these findings, designers can better understand how to evaluate soundscapes in various urban settings

TABLE X. Fixed and random effects in a linear mixed model using dominant sound sources and personal factors as candidate variables to explain variations in soundscape appropriateness.

Fixed effects				
	Soundscape appropriateness			
Predictors	Estimate	Std. Error	95%CI	Part R^2 (95%CI)
Intercept	4.07[a]	0.22	3.63, 4.5	
Traffic noise	−0.25[b]	0.08	−0.39, −0.10	0.012 (0.00, 0.03)
Other noise	−0.35[a]	0.08	−0.50, −0.19	0.020 (0.01, 0.04)
Natural sounds	0.21[a]	0.03	0.15, 0.27	0.060 (0.04, 0.10)
Traffic noise x Other noise	0.06[c]	0.03	0.01, 0.11	0.006 (0.00, 0.02)
Ethnicity (Asian /Asian British) × Human sounds	−0.12[a]	0.03	−0.169, −0.065	0.019 (0.01, 0.04)
Random effects				
LocationID (Intercept)	0.00	0.02		
Traffic noise	0.01	0.08		
ICC	0.058			
Marginal R^2/ Conditional R^2	0.175/0.223			
AIC	2737			

[a]$p< 0.001$.
[b]$p< 0.01$.
[c]$p< 0.05$.

and make contextually informed decisions to enhance overall soundscape quality.

A. Appropriateness in the two-dimensional plane of the pleasantness-eventfulness circumplex

Following the discussion on the nuanced relationship between appropriateness and soundscape circumplex model in previous studies (see Sec. II A), a three-factor CFA analysis confirms that appropriateness correlates with the pleasant-eventful dimensions of the circumplex model. This aligns to some extent with the CFA results of Tarlao *et al.* (2021), where "appropriateness" could be loaded onto the latent variable "pleasantness," although their understanding of appropriateness was whether it is appropriate for activities to occur in a place. Further SSM analysis captures the association between appropriateness and primary dimensions of soundscape circumplex model, validating the correlation model in general and across all locations in London. The result suggested that appropriateness is significantly correlated with pleasantness at all locations in London, except for locations dominated by traffic or other noise (e.g., Euston Tap, Camden Town). The varying relationship between soundscape appropriateness and the soundscape circumplex model might be due to the distorted correlation with appropriateness across different locations. Different

FIG. 3. (Color online) Location-level scaled coefficients of the random effects for the soundscape appropriateness model.

interpretations of appropriateness in questionnaires lead participants to understand it differently (see Sec. II B). When appropriateness is perceived as the alignment between activities and soundscape, people might rate activities as appropriate without necessarily finding the soundscape pleasant.

The selection of locations also contributes to varying locations of appropriateness within soundscape circumplex model. The park locations (Monumento Garibaldi, Pancras Lock, Regents Park Fields, and Regents Park Japan) appropriateness is generally located in the calm quadrant (323.3° to 355.5°), while in the urban squares (Russell Square, Tate Modern and Torrington Square) appropriateness is located in the vibrant quadrant (9.3° to 28.9°). The diverse association between appropriateness and the soundscape circumplex model may be attributed to the complexity of understanding auditory environment. Activities are key factors that influence how people perceive sound environments (Nielbo *et al.*, 2013). Activities occurring in a space transform it into a place, playing a crucial role in sound perception. Differences in expectations of activities among participants, and variations in activities at different times, can affect the assessment of soundscape appropriateness. While more appropriate soundscapes are universally more pleasant, the activities and expectations for a space can shift the exact type of soundscape which is considered more appropriate; in parks where relaxation and restoration can be expected to be the primary activities, a calm soundscape is considered more appropriate, while in urban squares where socialization and recreation are more common, a vibrant soundscape is more appropriate.

B. Personal factor and its association with appropriateness

A linear mixed-effects model was used to investigate the influence of personal factors on appropriateness for soundscape. Psychological well-being demonstrated no correlation with soundscape appropriateness, whereas age group (55+), visit frequency, and ethnicity (Asian/Asian British) were correlated with soundscape appropriateness. First, individuals over 55 years old were positively correlated with soundscape appropriateness, suggesting older people express a higher level of soundscape appropriateness. This aligns with research suggesting older people, who are more sensitive to high-frequency noise, tend to select more appropriate soundscapes that match their expectations. Visit frequency was negatively correlated with soundscape appropriateness, consistent with previous findings that first-time visitors rated soundscape appropriateness higher compared to frequent visitors (Bild *et al.*, 2016). Interestingly, ethnicity (Asian/Asian British) was negatively correlated with appropriateness, in line with Aletta *et al.* (2023), where the Chinese sample perceived soundscape less appropriate compared with the Europe sample. One of the possible explanation is that participants from Asian backgrounds are more sensitive to noisy urban sound environment, and therefore gave lower appropriateness scores (Aletta *et al.*, 2023). Another possible explanation is that listeners experience soundscapes differently when they associate them with cultural meanings, leading to variations in listeners' evaluations of soundscapes from different cultural backgrounds, suggested by ISO/TS (2014) (ISO 12913-1:2014: "Acoustics. Soundscape: Definition and conceptual framework").

In combination with Erfanian *et al.* (2021), the significant influence of personal factors on soundscape cannot be neglected (e.g., appropriateness, pleasantness, and eventfulness), which highlights the importance of an inclusive soundscape approach in both soundscape assessment and design stage, such as public participation (Xiao *et al.*, 2018). Joynt and Kang (2010) suggested that soundscape perception is enhanced when people can participate in the design process and have some control over the sound environment. Satisfaction with soundscape design interventions increases when participants are involved in the design process, indicating that soundscape design is not just an outcome but a comprehensive process from design to implementation. As a next step in the participatory soundscape planning framework, participatory soundscape design methods are highly recommended for future soundscape studies.

C. Sound source as an influential environmental factor for appropriateness

Regarding the association between environmental factors and soundscape appropriateness, dominant sound sources primarily contribute to the variance of appropriateness. Previous research highlights the significance of sound sources in soundscape classification and the intermediate effect between visual elements and appropriateness. Specifically, Erfanian *et al.* (2019) stated that sound sources were the categorization of soundscape perception, including natural sounds, non-human sound sources, and environmental sounds created by humans. The visual elements of traffic became irrelevant and lose their unique correlation to appropriateness when traffic sound was not considered (Tan *et al.*, 2021). Moreover, the importance of sound sources in assessing soundscape appropriateness was also highlighted at public transportation hubs (Puyana-Romero *et al.*, 2022).

In general, soundscape appropriateness was positively correlated with natural sound, and negatively correlated with traffic noise and other noise. The effect of traffic noise on appropriateness varied across different locations. In the traffic noise-dominated areas (e.g., Torrington Square, Camden Town), traffic noise was weakly correlated with appropriateness (see the Appendix). Participants were more tolerant towards the louder traffic noise in the traffic noise-dominated areas when traffic noise was in the expected range. Conversely, in locations where dominant sounds (natural or human sounds) are pleasing, the soundscape quality and overall impression improve as the dominant sound increases (Pérez-Martínez *et al.*, 2018). The effect of location on the interaction between sound sources and appropriateness is further validated by previous research (Tarlao *et al.*, 2022). Quiet streets were more appropriate on weekends compared to weekdays, even as they became more crowded and noisier due to increased activities. Conversely, busy streets, while less crowded on weekends, were considered less appropriate than on weekdays.

When traffic noise coexisted with other environmental noise, their interaction enhanced soundscape appropriateness. One possibility was that when other noise acted as foreground sounds, relegating traffic noise to the background, and providing relevant environmental context (Zhang *et al.*, 2019). It is also worthwhile highlighting the interaction between sound sources and personal factors. The findings suggested a negative correlation between soundscape appropriateness and human sounds when the participants were Asian/Asian British. Yu and Kang (2014) explored the potential influence of cultural differences on sound source preference, discovering that insect sounds were preferred in Taiwan, while church bells were preferred in the UK. Other studies confirmed the cultural-social aspects played a significant role in individual assessments of soundscapes. Deng *et al.* (2020) compared sound source preference between China and Croatia, while Hermida *et al.* (2019) pointed out that cultural and social experience affect soundscape meaning of a place. Beyond cultural aspects, individual expectations also mediated the effect of human sounds on appropriateness. Previous research indicated that expectations influenced people's behaviors and activities in a place (Davies *et al.*, 2014). Specifically, those who were willing to revisit a location anticipated more activities or human sounds in the same context (Kang, 2017). Overall, the role of human sounds in appropriateness is changeable and needs to be considered alongside other factors in soundscape practices (e.g., social-cultural aspects, individual expectation).

D. Limitations

While SSM analysis provided valuable insight on the relationship between appropriateness and soundscape circumplex model, it might not adequately capture the high variability in contextual factors across different locations. Additionally, SSM analysis relied heavily on the quality and consistency of soundscape circumplex data based on the ISO/TS 12913-3:2019 standard. The assumption that all perceptual attributes contribute equally to the model might not be applicable in some environments, as different contexts might emphasize certain attributes over others.

CFA revealed that soundscape appropriateness was correlated with the primary dimensions of the soundscape circumplex model across all locations. However, the SSM indicates that appropriateness functions as an independent soundscape descriptor in traffic/noise-dominated areas (e.g., Camden Town, Euston Tap). The use of soundscape data collection based on method A of ISO/TS (2018) has limitations, as it may ignore other acoustic features that could better characterize a soundscape. Future soundscape studies in traffic/noise-dominated areas are highly recommended to incorporate appropriateness into the assessment of soundscape. Additionally, the limited data (approximately 200 samples) available for these traffic noise-dominated areas hinders further exploration, necessitating additional data collection to clarify the relationship between appropriateness and soundscape circumplex model in future studies.

The ongoing ISO/AWI TS 16755-1 standard suggests that contextual factors significantly impact soundscape perception. In this study, although the validity of LocationID as an environmental variable and its integration into soundscape predictive modeling has been tested in previous research (Mitchell *et al.*, 2021), this was due to the lack of a generalizable spatial variable to measure influences of contextual factors on different measurement points with sufficient precision. Future research needs to introduce a set of operationalized spatial metrics to define environmental units of soundscape, especially in high-density urban areas, and to investigate the effects of contextual factors on soundscape perception.

Further, this study's interpretation of appropriateness was derived from the International Organization for Standardization standard ISO/TS 12913-2 (2018). Readers may be interested in different interpretations of appropriateness and their relationship with soundscape circumplex models and influencing factors. However, due to the complexity of appropriateness, it is challenging to compare different interpretations of appropriateness and to clarify the relationship with the circumplex model and the influencing factors. Future research might explore other interpretations of appropriateness, comparing their differences in relation to the soundscape circumplex model.

VI. CONCLUSION

Appropriateness for soundscape has been acknowledged as an important descriptor in soundscape assessment. However, due to the complexity of appropriateness and its interpretation, few studies have comprehensively explored soundscape appropriateness and its relationship with the soundscape circumplex model, nor have they provided an overall assessment of its affecting factors and their interactions (both individual and environmental factors). This study aims to offer insights and conclusive findings on the affecting factors (personal and environmental factors) of appropriateness for soundscape, as suggested by ISO/TS 12913-2 (2018), and its relationship with the soundscape circumplex model. The main findings of this research are:

- Soundscape appropriateness was correlated with the two primary dimensions: pleasantness and eventfulness of the soundscape circumplex model, except for the locations where traffic noise is dominant (e.g., Camden Town, Euston Tap), which appropriateness demonstrated no correlation with the dimensions of the soundscape circumplex model.
- Personal factors explained 2.1% of the variance in appropriateness for soundscape while location-level differences explained approximately 10.0% variance. Specifically, appropriateness was positively associated with over 55 years old age group, and negatively associated with visit frequency and ethnicity (Asian/Asian British).

- Among the different categories of environmental factors, the difference in dominant sound source across clusters explained 7.2% of the variance in soundscape appropriateness, which was the most influential category of environmental factors. This was followed by differences in landscape composition and acoustic metrics explaining 3.4% and 2.9% of the variance in appropriateness.
- Within the most influential category of environmental factors, natural sounds positively correlated with appropriateness and explained the most variance at 6%. Soundscape appropriateness was negatively associated with traffic noise and other noise, but positively associated with their interaction effect. Notably, the impact of traffic noise on appropriateness varied across locations. Additionally, the relationship between human sounds and appropriateness varied by different ethnicity. For the participants who were Asian/ Asian British, human sounds were negatively correlated with appropriateness.

These findings shed light on the relationship between appropriateness and the soundscape circumplex model and elucidate why appropriateness cannot serve as an independent metric. This insight is crucial for a more comprehensive assessment of soundscape perception. Additionally, the appropriateness of soundscape underscores the importance of context in soundscape perception. Future studies should aim to quantify the effects of non-acoustic factors, integrate them into soundscape prediction models, and validate their effectiveness through virtual reality or onsite experiments.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors declare that they have no conflicts to disclose.

Ethics Approval

Ethical approval for the study was obtained via the low-risk research departmental route at UCL Bartlett School of Environment, Energy and Resources—Research Ethics Committee (UCL BSEER REC) (approval letter, 14 October 2019), and all participants approached on site at the different public spaces provided informed consent before taking part in the survey.

DATA AVAILABILITY

The database of this study are available in Mitchell *et al.* (2024a). The International Soundscape Database: An integrated multimedia database of urban soundscape surveys—questionnaires with acoustical and contextual information (version 1.0.1-alpha.1), accessed at https://zenodo.org/records/10639661.

APPENDIX

1. Selection of the soundscape sites

The data were collected from the public in eleven locations in London based on the aim of the large-scale study. Table XI reports the basic description of the contextual and acoustic features of eleven locations from the SSID database. The rationale for site selection was to cover as many different usage types, visual and acoustic environment in London as possible. The assessment process of the dominant sound source was to qualitatively describe the site's acoustic environment by listening to playback of recordings and examining 360 panoramic photographs (Mitchell *et al.*, 2020)

2. Environmental factors

To capture acoustic and visual metrics during the soundscape survey process, audio-video recordings were performed in the study by using binaural measurement and 360° video based on of the ISO 12913-2: 2018 Technical Specifications. Acoustic metrics (L_{Aeq}, L_{Ceq}-L_{Aeq}, L_{A10}-L_{A90}),

TABLE XI. The 11 locations included in the measurements campaign in London. The dominant sound sources were qualitatively derived from the recordings.

ID	Location ID	Description	Dominant sound sources	Number of participants
CT	Camden Town	Entrance to train underground station	Traffic noise and other noise	89
ET	Euston Tap	Public transport	Traffic noise	93
MG	Marchmont Garden	Park	No dominant sounds	90
PL	St. Pancras Lock	Canal green	Human and water sounds	75
RPF	Regent's Park Broadwalk	Park	Natural and Human sounds	106
RPJ	Regent's Park Japanese Garden	Garden	Natural sounds	77
RS	Russel Square	Square, green	Natural sounds, traffic noise, human sounds	144
SPC	St. Paul's Churchyard	Church courtyard	Traffic noise, human sounds	60
SPR	St. Paul's Row	Small square, paved	Traffic noise, human sounds	52
TM	Tate Modern	Waterfront, paved	Human sounds	127
TS	Torrington Square	Square, paved	Traffic noise, human sounds	103

TABLE XII. Acoustic measurement and visual factors.

(Psycho)acoustic metrics		Unit	Description
(Psycho)acoustic	L_{Aeq}	dB	IEC 61672-1:2013 (2013)
	$L_{Ceq} - L_{Aeq}$		ISO 1996-1:2016 (2016)
	$L_{A10} - L_{A90}$		ISO 1996-1:2016 (2016)
	Roughness (R)	asper	ECMA-418-2 (2020)
	Sharpness (S)	acum	ISO 532-1:2017 (2017)
	Loudness (N5)	sones	ISO 532-1:2017 (2017)
	Impulsiveness (I)	Iu	ECMA-418-2 (2020)
	Fluctuation strength (FS)	Vacil	ECMA-418-2 (2020)
	Tonality (T)	tuHMS	Sottek (2016)
Landscape composition metrics		Unit	Description
Permanent landscape elements	Sky	Percentage (%)	the percentage of permanent landscape elements in the panoramic image
	Buildings		
	Road		
	Greenery		
	Water		
Dynamic landscape elements	People	Number	the average number of dynamic landscape elements in the panoramic image
	Bicycle		
	Car		
	Motorcycle		
	Bus		

psychoacoustic metrics (Roughness, Sharpness, Loudness, Impulsiveness, Fluctuation strength, and Tonality) are reported in Table XII. Moreover, for the landscape composition (see Table XII), by processing 360 video into a single panoramic image, the presence of permanent landscape elements (sky, buildings, street, greenery, water) was computed by the proportion of pixels in the landscape layer to the overall pixels, while the dynamic landscape elements (people, bicycle, bus, car, motorcycle) was performed using the algorithm, according to Joglekar *et al*. (2020). For the sake of brevity of the text, details of data collection process can be referred to Mitchell *et al*. (2020) while the identification of landscape elements can be found in Huang (2022).

TABLE XIII. Correlation coefficients for studied variables across different locations (CT: Camden Town, ET: Euston Tap, MG: Marchmont Garden, PL: St. Pancras Lock, RGF: Regent's Park Broadwalk, RGJ: Regent's Park Japanese Garden, RS: Russel Square, SPC: St. Paul's Churchyard, SPR: St. Paul's row, TM: Tate Modern, TS: Torrington Square). Some correlation coefficients are not shown in the Table XIII because the landscape elements in one location is missing or only one video recording session in one location.

		Soundscape appropriateness											
Group variables	Factors	All locations	MG	RGJ	PL	RGJ	RS	SPC	SPR	TM	TS	CT	ET
Sound source	Traffic noise	−0.202[a]	−0.192	−0.296[a]	−0.139	−0.242	−0.214	−0.421[a]	−0.117	−0.190	0.002	0.043	−0.051
	Other noise	−0.289[a]	−0.390	−0.229	−0.146	−0.024	−0.160	−0.268	−0.385	−0.288[a]	−0.282[a]	−0.050	−0.135
	Human sounds	0.047	−0.027	0.119	0.030	−0.061	0.075	0.057	0.114	0.209[a]	0.145	−0.022	−0.087
	Natural sounds	0.291[a]	0.187	0.421[a]	0.232	0.146	0.330[a]	0.218	0.330	0.223	0.014	−0.078	0.087
Psychoacoustic metrics	Roughness (R)	−0.171[a]	−0.100	−0.333[a]	−0.054	−0.236	−0.139	−0.266	−0.136	0.082	−0.136	−0.120	0.041
	Sharpness (S)	0.079	0.152	−0.045	0.141	−0.245	0.024	−0.030	−0.041	0.128	−0.252	−0.258	0.020
	Loudness (N5)	−0.103[a]	−0.026	−0.304[a]	0.082	−0.239	0.059	−0.005	−0.082	0.128	−0.185	−0.169	0.112
	Impulsiveness (I)	−0.041	0.109	0.033	−0.078	0.162	−0.128	−0.211	−0.251	0.063	−0.003	0.030	0.103
	Fluctuation strength (Fls)	−0.023	0.206	0.221	−0.150	0.217	−0.139	−0.141	−0.112	0.069	−0.228	−0.089	0.209[a]
	Tonality (T)	−0.054	0.225	−0.102	−0.055	0.187	−0.133	0.080	−0.029	0.169	−0.212	−0.225[a]	0.086
	L_{Aeq}	−0.109[a]	0.015	−0.262[a]	0.089	−0.220	0.041	−0.121	−0.045	0.130	−0.202	−0.197	0.053
	$L_{Ceq} - L_{Aeq}$	−0.013	0.053	−0.219	−0.143	0.223	0.055	−0.121	0.018	−0.114	0.183	0.184	0.140
	$L_{A10} - L_{A90}$	−0.019	−0.060	0.148	0.030	0.175	−0.079	−0.223	−0.080	0.065	−0.065	0.030	0.056
Landscape composition	Sky	−0.145[a]	0.145		0.254[a]	0.238	0.075			0.006	−0.241	−0.016	−0.008
	Buildings	0.188[a]	−0.151		−0.254[a]	0.179	−0.168			−0.006	0.240	−0.113	−0.025
	Road	−0.175[a]	−0.064		−0.254[a]	0.238	0.046			−0.006	−0.012	0.016	0.058
	Greenery	0.153[a]	0.097		−0.254[a]	−0.238	−0.056			−0.006	−0.240	0.084	0.017
	Water	0.119[a]			0.254[a]	0.238	0.193			−0.006			

[a]Correlations are significant at the 0.0125 level for sound source, 0.0056 level for psychoacoustic metrics, 0.01 level for landscape composition.

3. Correlation coefficients for appropriateness and environmental factors across different locations

The correlation analysis between soundscape appropriateness and each category of environmental variables was performed separately. Bonferroni corrections were applied to test the assumptions for each category at significance levels of $a = 0.05/4 = 0.0125$, $a = 0.05/9 = 0.0056$, $a = 0.05/5 = 0.01$, and $a = 0.05/7 = 0.00714$, respectively.

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