Office soundscape assessment: A model of acoustic environment perception in open-plan offices[1]

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The soundscape approach has been utilised in recent research for residential environments, but applications to indoor working environments remain limited. This study investigated the suitability of affective quality evaluations of open-plan office acoustics. Perceptual assessments were completed by occupants of eight open-plan office floorplates, using affective dimensions outlined in PD ISO/TS 12913-3:2019 and indoor soundscape studies. Participant demographic, contextual, work-related quality, and psychological well-being data was collected. Workstation noise levels were measured following BS ISO 22955:2021. Principal component analysis identified *Pleasantness*, *Eventfulness*, and *Emptiness* as the main perceptual dimensions, cumulatively explaining 56% of the total variance. Results indicate the suitability of the PD ISO/TS 12913-3:2019 two-dimensional model for open-plan offices. The perceived presence of human sounds negatively correlated with ISO *Pleasantness* yet positively correlated with ISO *Eventfulness*. Participant gender and aural diversity mediated ISO *Pleasantness*. Psychological well-being and work-related quality correlated positively with soundscape pleasantness. No correlations were found between level-based acoustical indicators—equivalent continuous sound level (L_{Aeq}), level exceeded 10% (L_{A10}) and 90% (L_{A90}) of the time, level variability (L_{A10}-L_{A90}) and *Liveliness*—and perceptual scores. A conceptual representation of open-plan office soundscape perception is presented, offering a framework for evaluating and designing workspaces to enhance well-being.

I. INTRODUCTION

The significance of sound in open-plan offices has been extensively studied, with research showing relationships between acoustical characteristics and job satisfaction (Park *et al.*, 2020), productivity (Felipe Contin de Oliveira *et al.*, 2023), and well-being (Di Blasio *et al.*, 2019). The international standards BS ISO 22955:2021 and BS EN ISO 3382-3:2022 detail the measurement and calculation procedures for acoustical indicators such as spatial decay rate of speech ($D_{2,\mathrm{S}}$), speech level at four-metre distance ($L_{p,\mathrm{A,S,4m}}$) and in-situ acoustic attenuation of speech ($D_{\mathrm{A,S}}$) (ISO, 2021, 2022). BS ISO 22955:2021 defines the measurement of equivalent continuous workstation noise level ($L_{\mathrm{Aeq},T}$), and percentile indices such as level exceeded 10% (L_{A10}) and 90% (L_{A90}) of the time; representing peak and background levels respectively (Yadav *et al.*, 2021). Vellenga *et al.* (2017) propose the indicator *Liveliness*, calculated using a mapping between equivalent continuous workstation noise level and level exceeded 5% of the time (L_{A5}).

The appropriate methodology for the perceptual assessment of open-plan office acoustics is less clear: BS ISO 22955:2021 provides an example of a user survey on open-plan office acoustics but does not specify analysis procedures (ISO, 2021). In research literature, a variety of subjective assessment methodologies can be found: Hongisto *et al.* (2015) developed the "acoustic satisfaction" measure, calculated from a combination of affective and sound quality ratings; Chen and Ma (2022) propose a questionnaire to measure the health level of acoustic environments for occupants completing complex cognitive tasks; and Vellenga *et al.*

(2017) utilised a one-dimensional assessment of “liveliness”, where “quiet” was assumed to oppose “turbulent”.

In contrast, the perceptual assessment of outdoor soundscapes is standardised in the ISO 12913 series (ISO, 2014, 2018, 2019). These guidelines define a “soundscape” as the “acoustic environment as perceived or experienced and/or understood by a person or people, in context” and utilise the two-dimensional “pleasantness” and “eventfulness” perceptual assessment framework. Two-dimensional coordinates are calculated from subjective evaluation of the eight perceived affective qualities shown in Fig. 1. The two-dimensional model for soundscape perception was informed by exploratory studies, in which participants were asked to assess outdoor soundscapes using a large number of attributes (Axelsson *et al.*, 2010; Cain *et al.*, 2011). Principal component analysis (PCA) was used to reduce the original attributes to a smaller number of key components, and similarities to Russell’s circumplex model of affect were identified (Axelsson *et al.*, 2010; Russell, 1980). Useful correlations have been found between soundscape pleasantness and eventfulness dimensions and the acoustical indicators: equivalent continuous sound level ($L_{\mathrm{Aeq,30s}}$), loudness exceeded 10% of the time (N_{10}) and loudness variability (N_{10}-N_{90}) (Axelsson *et al.*, 2010).

The resultant two-dimensional model of soundscape perception has been subsequently employed to identify associations between outdoor soundscape perception and: psychological well-being, sound source type and dominance (Erfanian *et al.*, 2020), environmental usage context and aesthetics (Hong *et al.*, 2020). Demographic factors such as age and gender have been shown to mediate soundscape perception (Erfanian *et al.*, 2020), and tools have been developed for the probabilistic representation of soundscape perception—enabling recog-

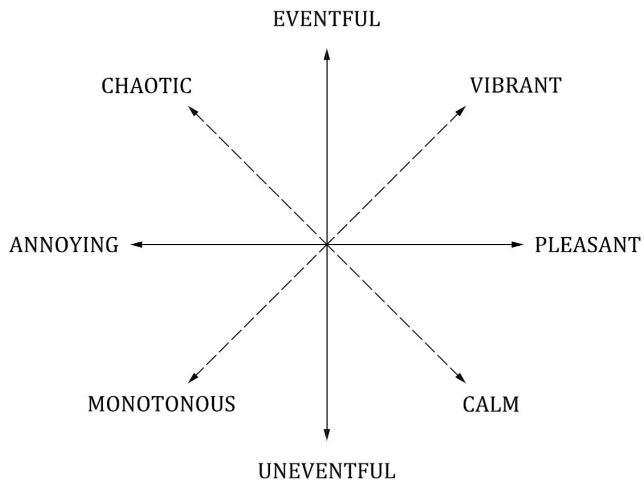

FIG. 1. Graphical representation of the two-dimensional model of soundscape perception presented in PD ISO/TS 12913-3:2019 (ISO, 2019). Permission to reproduce extracts from British Standards is granted by BSI Standards Limited (BSI). No other use of this material is permitted. British Standards can be obtained from BSI Knowledge knowledge.bsigroup.com.

nition of the perceptual variances possible between occupants of an environment (Mitchell *et al.*, 2022). Mitchell *et al.* (2021) demonstrate the ability to predict soundscape perception using acoustical indicators including $L_{\mathrm{Aeq},T}$ and loudness exceeded 5% of the time (N_5).

By utilising an approach similar to the initial outdoor soundscape studies (Axelsson *et al.*, 2010; Cain *et al.*, 2011), the perceptual dimensions for indoor environments have been explored. Torresin *et al.* (2020) propose a "comfort" and "content" two-dimensional framework for use in residential settings; also calculated from assessment of a set of eight perceived affective qualities. By directly applying this model to open-plan offices, Jo and Jeon (2022) identified a relationship between work-related quality and open-plan office soundscape perception, yet the suitability of perceptual dimensions developed for residential settings—using a virtual environment and stimuli designed to replicate a living room—in open-plan offices is unclear. Jo and Jeon (2022) reproduced audio-visual stimuli virtually; the correlation of which to in-situ soundscape assessment by real office occupants is also uncertain. Jo and Jeon (2022) found $L_{\mathrm{Aeq},T}$ and L_{A10}-L_{A90}—the range between L_{A10} and L_{A90}—to be useful indicators of soundscape subjective response. Acun and Yilmazer (2018) completed a qualitative study of open-plan office soundscape perception using the Grounded Theory approach. This study indicated the importance of affective qualities such as "promoting motivation" and "promoting concentration".

To confirm the key components of open-plan office soundscape perception, a study following similar methodologies to those employed by Axelsson *et al.* (2010) and Torresin *et al.* (2020) is required. Development of a perceptual assessment methodology for open-plan offices, similar to the PD ISO/TS 12913-3:2019 two-dimensional model (ISO, 2019), will enable quantification of how occupants perceive the workplace acoustical environment. Consequently, providing a lexicon describing human experience to be used as a design tool. Applying such an experiential approach will ultimately enable workplace designers, and building users, to tailor the environment to better suit the conditions for intended activities (Acun and Yilmazer, 2018).

The primary aims of this study were to investigate the applicability of soundscape perceptual assessment methodologies to the open-plan office environment and to confirm the key components of open-plan office soundscape perception. This study expands on the work previously presented by West *et al.* (2023), comprising a significantly larger dataset, and providing a more comprehensive analysis and discussion.

FIG. 2. Images of three example floorplates for which office soundscape assessments were completed.

II. METHODOLOGY

A. Office Soundscape Assessments

TABLE I. Summary of floorplate conditions during the office soundscape assessments. "Survey n" indicates the number of completed participant questionnaires.

Floorplate	Area (m^2)	Ceiling height (m)	Capacity	Density (m^2/p)	Occupancy (%)	$L_{Aeq,9h}$ (dB)	Survey n
1.1	1008	2.9	132	7.6	16.7	44.6	8
1.2	1008	2.9	132	7.6	31.8	48.2	9
2	1086	2.9	121	9.0	50.4	48.2	21
3	478	3.0	76	6.3	25.0	50.8	11
4	435	2.9	56	7.8	52.8	48.5	12
5	768	2.9	124	6.2	62.1	47.8	24
6	1033	2.9	146	7.1	58.9	50.4	18
7	647	3.5	72	9.0	70.8	52.6	28
8	673	3.5	100	6.7	43.3	50.6	7
						Total	**138**

Office soundscape assessments were conducted in eight floorplate configurations across three buildings of two organisations—a university and a multidisciplinary consultancy—in the centre of Birmingham, United Kingdom (UK). An in-situ experimental design was elected to ensure results are representative of real workplace occupants and environments. All selected floorplates were fully open-plan—designed to accommodate multiple persons working without separation (Fayard *et al.*, 2021; ISO, 2021)—and contained no fully enclosed workstations. All floorplates operated a hybrid working model, where colleagues move between the office building and a home workspace throughout the working week (Oygür *et al.*, 2022). The floorplates comprised colleagues from a variety of disciplines including human resources, engineering, planning, information technology, finance, estates, marketing, legal and academic services. An assortment of floorplate areas (435–1086m^2), peak occupancy (16.7–70.8%) and densities (6.2–9.0m^2/p) were captured. Table I displays the full range of floorplate conditions and associated participant survey responses. The surface materials in all floorplates were comparable and considered typical (Yadav *et al.*, 2021), comprising: absorptive ceiling tiles or panels, painted plaster walls with windows, and carpet flooring. Floorplates both with and without desk dividers were included in the study. Images of example floorplates are shown in Fig. 2. Floorplate layouts can be viewed in the supplementary material for publication.

The variance in peak occupancy between floorplates was dictated by the natural working requirements of the occupants based on each floorplate. Days with anticipated occupancy considered typical for each floorplate were selected for assessment. The range of included floorplate densities is in line with the UK average (British Council for Offices, 2022). Floorplates 2 and 7 had the most spacious density (9m^2/p), with Floorplate 5 being the most crowded (6.2m^2/p). Floorplate 2 had a similar area to Floorplate 1, but a more spacious density due to a greater provision of open meeting areas between desks. Floorplate 3 observed the second lowest peak occupancy and yet the second highest floorplate $L_{\mathrm{Aeq,9h}}$; this is attributed to the observed collaborative nature of the tasks completed by occupants on this floorplate.

1. Questionnaire

An online questionnaire was developed to identify the important factors of open-plan office soundscape perception. Colleagues located within the floorplates on assessment days were asked to rate the soundscape, using a five-point Likert scale, against 26 unidirectional attributes. The attributes used were taken from PD ISO/TS 12913-2:2018 (ISO, 2018), the residential "comfort" and "content" framework proposed by Torresin *et al.* (2020), the affective qualities of office soundscape described by Acun and Yilmazer (2018) and an interpretation of the residential soundscape dimensions used by Jo and Jeon (2022) for office soundscape study. The number of initial attributes in this study was deliberately less than those used by Axelsson *et al.* (2010) and Torresin *et al.* (2020) for two reasons. First, the participants in the assessed office environments were at work; a short questionnaire duration was therefore deemed important. Second, the aforementioned studies provided a more concise starting point for this study (Acun and Yilmazer, 2018; Axelsson *et al.*, 2010; Jo and Jeon, 2022; Torresin *et al.*, 2020).

Participants were asked to assess the soundscape overall, its appropriateness, and identify the presence of four classes of sound source using the methodology outlined in the PD ISO/TS 12913-2:2018 Method A questionnaire (ISO, 2018). The sound source classes were modified for appropriateness to the office environment based on the qualitative research completed by Acun and Yilmazer (2018), to: "Sounds from human beings", "Mechanical and electronic sounds", "Outdoor sounds" and "Music".

Demographic data was collected by asking participants to self-report age, gender and whether they would describe themselves as being aurally diverse. Contextual information was gathered, including self-assessment of the "operational requirement" for spending the day in the office, and "task type" was recorded using the activity categories defined in BS ISO 22955:2021 (ISO, 2021). Work-related quality was self-reported following the methodology applied by Jo and Jeon (2022)—participants rated their work-related "satisfaction", "willingness to work" and "productivity". Participant psychological well-being was indicated using the World Health Organisation-Five Well-Being Index (WHO-5) which has seen success in other soundscape studies (Erfanian *et al.*, 2020). Using this indicator, a score out of 100 is calculated based on participant responses to five statements describing how they have felt over the previous two weeks (Psykiatric Center North Zealand, 1998). The full participant questionnaire can be viewed in the supplementary material for publication.

On the morning of each test day, all floorplate occupants were invited to participate in the study by email. The email included participant consent and information documents and a link to the questionnaire; presented via Microsoft Forms (Microsoft, 2024). Ethical approval was provided by the Faculty Academic Ethics Committee in advance of the study.

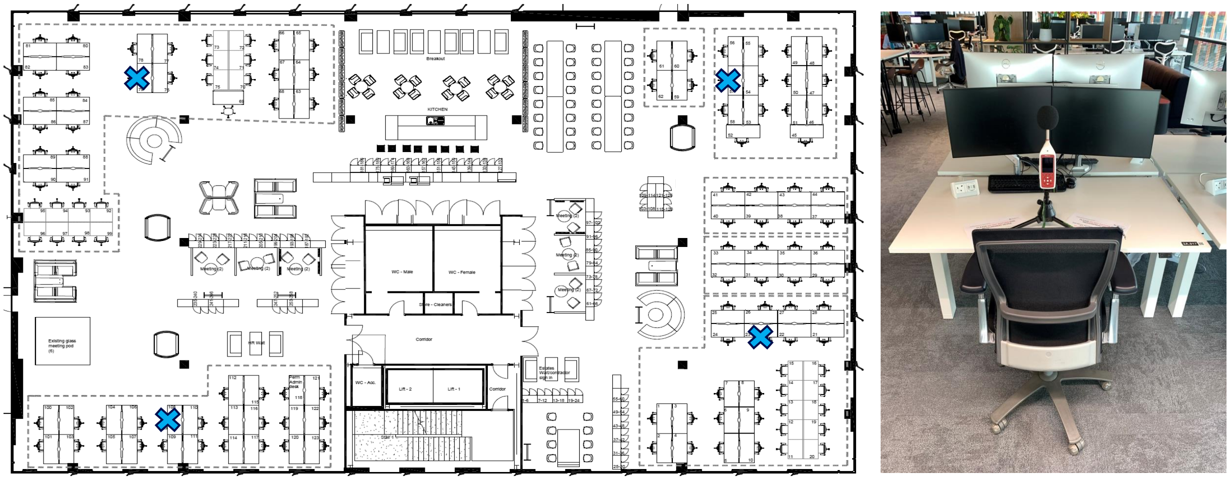

FIG. 3. Indicative schematic of floorplate measurement locations denoted with crosses (left), and an image of an example workstation measurement setup (right).

Participation was voluntary with no compensation provided, resulting in a range of questionnaire responses per floorplate (n). Across the nine test days, 138 occupants elected to complete the study comprising 68 female, 61 male, four non-binary and five preferring not to specify gender. The mean participant age was 40, with a range of 21–68 years and SD = 12.1. 19 participants self-reported as aurally diverse, with a range of hearing differences described including autism, noise sensitivity, hearing loss and the use of hearing aids (Drever and Hugill, 2023).

2. Workstation Noise Levels

On each assessment day, workstation noise levels were acquired in accordance with BS ISO 22955:2021 Annex E (ISO, 2021). Cirrus Optimus+ Red sound level meters were positioned at unoccupied workstations in different working zones within each floorplate; for example, a floorplate with four distinct teams working in four corners of the floorplate would have comprised four measurement locations. The microphone tip was positioned 1.2m from the floor, on unoccupied desks representative of the rest of the zone; for instance, if the zone comprised desks without partitions the sound level meter was positioned on a desk without partitions. An example workstation measurement setup and floorplate measurement locations can be seen in Fig. 3. Measurements were completed for approximately nine hours, ensuring the start and end of the working day was captured. The "fast" time weighting was used (0.125s), and time history was recorded every second.

For comparison to the perceptual data collected with the questionnaire, the acoustical indicators L_{Aeq}, L_{A10}, L_{A90}, L_{A10}-L_{A90} and *Liveliness* were calculated for each floorplate measurement zone, for both nine-hour and 15-minute windows. An average floorplate $L_{\mathrm{Aeq,9h}}$ was also calculated. The calculated indicators were selected based on findings from other office acoustic or soundscape research (Axelsson *et al.*, 2010; Torresin *et al.*, 2020; Vellenga *et al.*, 2017). The nine-hour window was included to represent the full working day, while the 15-minute window represents the survey completion period; based on the average participant survey completion duration. Each participant's online questionnaire completion time was used to determine the closest 15-minute measurement interval to utilise for analysis. Due to privacy concerns raised by office occupants audio was not captured, limiting the psychoacoustic indicators calculable to the level-based metrics discussed.

B. Data Analysis

Statistical analyses were completed using the software environment R (Version 4.2.1) (R Core Team, 2022). Principal component analysis was completed to reduce the 26 attributes to several principal components (PC) explaining most of the data variance. To ensure the appropriateness of PCA, the dataset was tested using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (0.87) and Bartlett's test of sphericity ($p < 0.001$) (Bartlett, 1937; Kaiser, 1960). As interpretation of the initial components was intuitive, no rotation was required (Torresin *et al.*, 2020).

For comparison to the calculated participant scores for the extracted principal components (cf. Section III A), the two-dimensional pleasantness P and eventfulness E coordinates were calculated in accordance with PD ISO/TS 12913-3:2019 (ISO, 2019):

$$P = (p - a) + \cos 45^\circ \cdot (ca - ch) + \cos 45^\circ \cdot (v - m) \tag{1}$$

$$E = (e - u) + \cos 45^\circ \cdot (ch - ca) + \cos 45^\circ \cdot (v - m) \tag{2}$$

where a, ca, ch, e, m, p, u and v respectively represent the eight perceived affective qualities: annoying, calm, chaotic, eventful, monotonous, pleasant, uneventful and vibrant. Pearson correlation coefficients were calculated for interval and continuous variables. Spearman's rank correlation coefficients were calculated for ordinal variables. One-way analysis of variance (ANOVA) was calculated for categorical variables except aural diversity, for which Welch's t-tests were performed due to the unequal sample size between groups (ISO, 2019).

III. RESULTS

A. Principal Component Analysis

The first three components respectively explained 34%, 16% and 6% of the total vari-

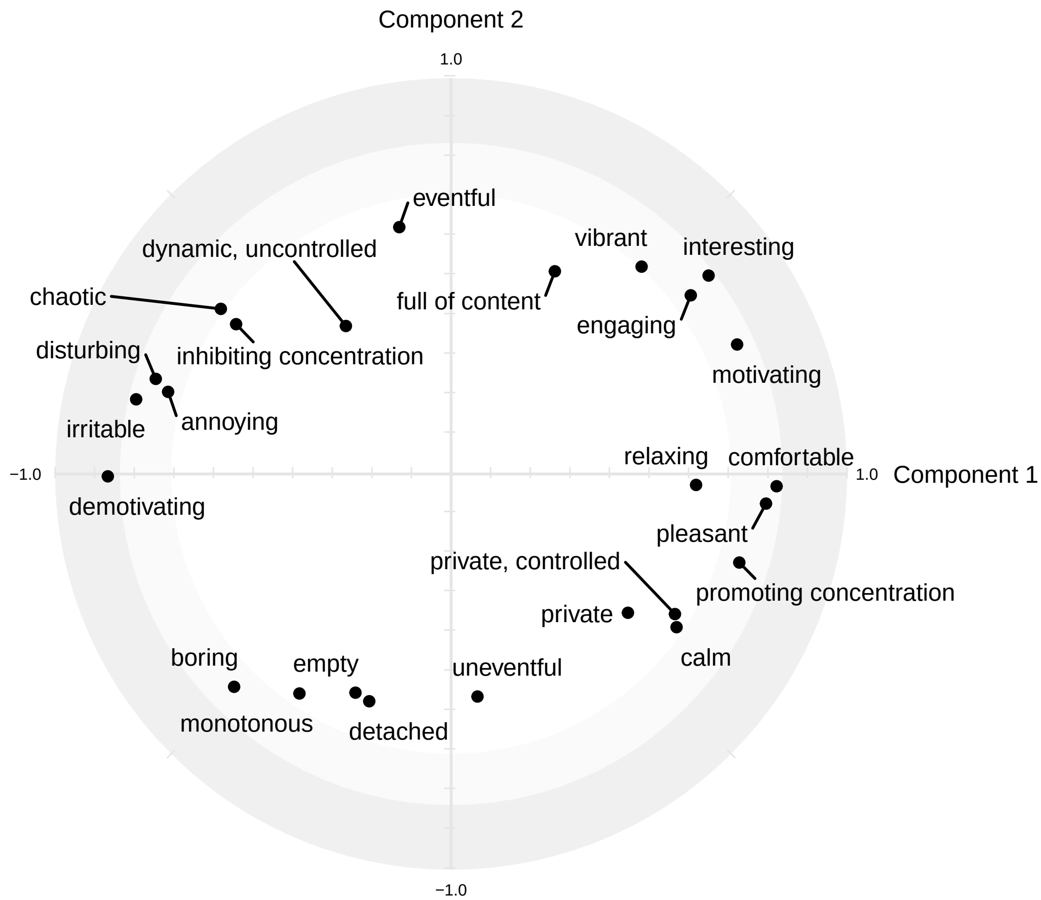

FIG. 4. Loadings of the 26 attribute scales to PC1 and PC2. Three areas are indicated according to the distance between the attribute vectors (v_a) and the origin: Zone 1, ${v_a}^2<0.50$ (white); Zone 2, $0.50\leq{v_a}^2<0.70$ (light grey); Zone 3, ${v_a}^2\geq0.70$ (dark grey), where ${v_a}^2$ represents the amount of attribute variance explained by the plotted PCs.

ance and were directly interpreted. Two additional components satisfied the Kaiser criterion (eigenvalue >1.0)—cumulatively explaining 9% additional variance—but could not be meaningfully interpreted (Axelsson *et al.*, 2010; Torresin *et al.*, 2020). The following results concern the first three components only.

Fig. 4 shows the component loading plot for PC1 and PC2, displaying the contributions of the original 26 attributes to the first two components. Fig. 5 shows the component loading

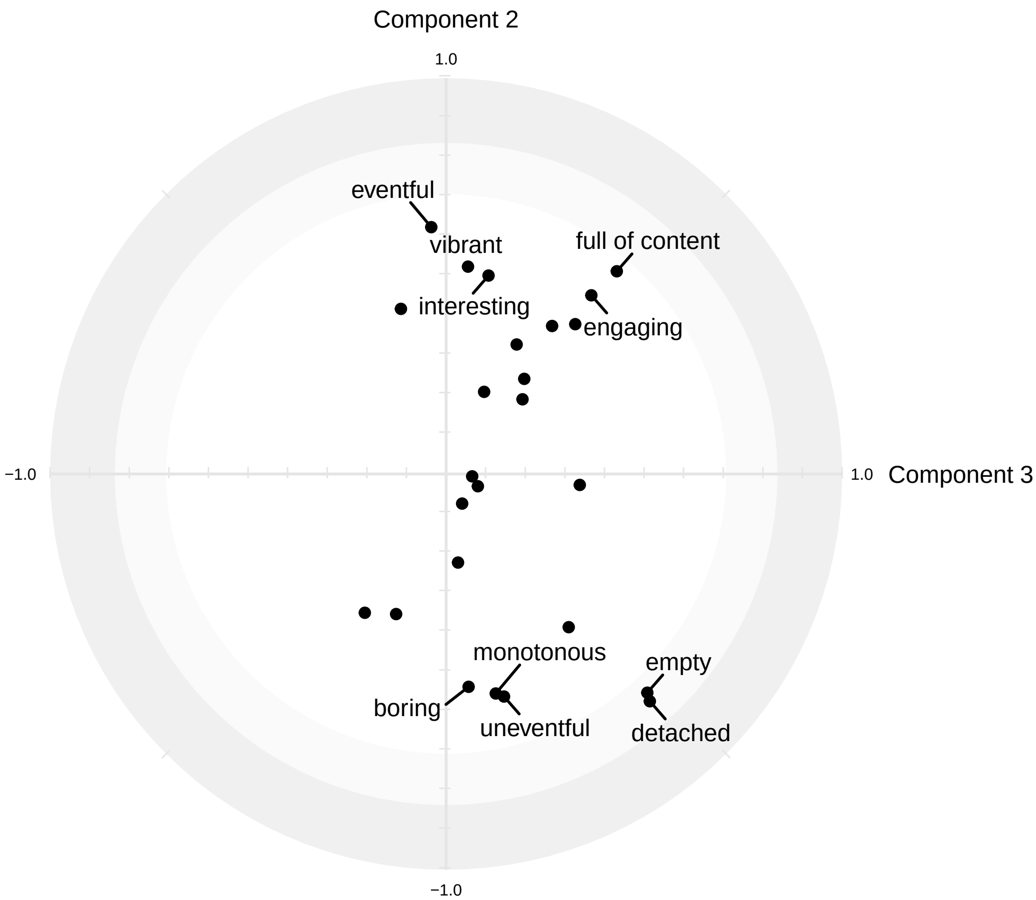

FIG. 5. Loadings of the 26 attribute scales to PC2 and PC3. Three areas are indicated according to the distance between the attribute vectors (v_a) and the origin: Zone 1, ${v_a}^2$<0.50 (white); Zone 2, 0.50≤${v_a}^2$<0.70 (light grey); Zone 3, ${v_a}^2$≥0.70 (dark grey), where ${v_a}^2$ represents the amount of attribute variance explained by the plotted PCs. Variables with v_a<0.5 are not labelled.

plot for PC2 and PC3. To enable direct comparison to previous soundscape studies, three areas are indicated according to the distance between the attribute vectors (v_a) and the origin: Zone 1, ${v_a}^2$<0.50 (white); Zone 2, 0.50≤${v_a}^2$<0.70 (light grey); Zone 3, ${v_a}^2$≥0.70 (dark grey), where ${v_a}^2$ represents the amount of attribute variance explained by the plotted PCs (Axelsson *et al.*, 2010; Torresin *et al.*, 2020). The components were interpreted by identifying the most correlated variables, both positively and negatively (Axelsson *et al.*, 2010; Torresin *et al.*, 2020).

The first component was best explained by "comfortable", "pleasant" and "promoting concentration" in the positive direction; "demotivating", "irritable" and "disturbing" in the negative direction, and was subsequently labelled *Pleasantness*. The second component was best explained positively by "eventful", "vibrant" and "full of content", and negatively by "detached", "uneventful" and "empty", and was labelled *Eventfulness*. The third component was best explained by "empty" and "detached" in the positive direction and was labelled *Emptiness*.

B. Relationships Between Variables

Table II shows the Pearson correlation coefficients between the PC scores, the PD ISO/TS 12913-3:2019 two-dimensional coordinates: ISO *Pleasantness* and ISO *Eventfulness*, and the nine-hour and 15-minute level-based acoustical indicators. PC1 *Pleasantness* scores were very strongly positively correlated with ISO *Pleasantness* coordinates, as were PC2 *Eventfulness* scores with ISO *Eventfulness*. No significant correlations were found between the level-based acoustical indicators calculated and the perceptual scores.

Spearman's rank correlation coefficients are displayed in Table III for the PC scores, PD ISO/TS 12913-3:2019 coordinates, soundscape assessment and appropriateness, sound source dominance, operational requirement, work-related quality and WHO-5 Well-being Index scores. PC1 *Pleasantness* scores and ISO *Pleasantness* coordinates were strongly positively correlated with overall soundscape assessment scores. PC1 *Pleasantness* scores and ISO *Pleasantness* coordinates were strongly and moderately positively correlated with

TABLE II. Pearson correlation coefficients between the PC scores, PD ISO/TS 12913-3:2019 two-dimensional coordinates and acoustical indicators.

	PC1 *Pleasantness*	PC2 *Eventfulness*	PC3 *Emptiness*	ISO *Pleasantness*	ISO *Eventfulness*
PC2 *Eventfulness*	−0.02				
PC3 *Emptiness*	0.01	0.00			
ISO *Pleasantness*	0.91 ***	−0.07	0.05		
ISO *Eventfulness*	−0.16 .	0.83 ***	−0.18 *	−0.21 *	
Zonal $L_{\mathrm{Aeq,9h}}$	0.14	0.10	−0.30	0.04	0.19
Average Floorplate $L_{\mathrm{Aeq,9h}}$	0.14	−0.04	−0.25	0.02	0.06
$L_{\mathrm{A10,9h}}$	0.16	0.09	−0.30	0.07	0.18
$L_{\mathrm{A90,9h}}$	0.17	0.05	−0.28	0.07	0.11
$L_{\mathrm{A10,9h}}$-$L_{\mathrm{A90,9h}}$	−0.13	0.01	0.19	−0.05	−0.02
$Liveliness_{\mathrm{9h}}$	0.21	0.11	−0.19	0.15	0.10
Zonal $L_{\mathrm{Aeq,15min}}$	0.11	0.17	−0.21	0.03	0.22
$L_{\mathrm{A10,15min}}$	0.15	0.16	−0.16	0.07	0.19
$L_{\mathrm{A90,15min}}$	0.20	0.09	−0.26	0.08	0.14
$L_{\mathrm{A10,15min}}$-$L_{\mathrm{A90,15min}}$	−0.15	0.07	0.24	−0.04	0.03
$Liveliness_{\mathrm{15min}}$	0.10	0.20	−0.02	0.05	0.16

. $p \leq 0.10$, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

soundscape appropriateness scores respectively. PC1 *Pleasantness* scores and ISO *Pleasantness* coordinates were moderately negatively correlated with sounds from human beings scores. A moderate negative correlation was also observed between PC1 *Pleasantness* scores and ISO *Pleasantness* coordinates with mechanical and electronic sounds scores. PC2 *Eventfulness* scores and ISO *Eventfulness* coordinates were moderately positively correlated with sounds from human beings scores. PC1 *Pleasantness* scores and ISO *Pleasantness* coordi-

TABLE III. Spearman's rank correlation coefficients for the PC scores, PD ISO/TS 12913-3:2019 two-dimensional coordinates, soundscape assessment and appropriateness, sound source dominance, operational requirement, WHO-5 Well-Being Index and work-related quality scores.

	PC1 *Pleasantness*	PC2 *Eventfulness*	PC3 *Emptiness*	ISO *Pleasantness*	ISO *Eventfulness*
Soundscape assessment	0.74 ***	0.05	−0.08	0.62 ***	−0.09
Soundscape appropriateness	0.55 ***	−0.05	−0.07	0.47 ***	−0.15
Sounds from human beings	−0.34 *	0.39 **	−0.14	−0.34 *	0.43 ***
Mechanical and electronic sounds	−0.36 **	0.07	−0.15	−0.42 ***	0.22
Outdoor sounds	−0.15	−0.05	0.12	−0.16	0.02
Music	0.04	−0.02	0.12	−0.03	0.04
Operational requirement	0.09	0.03	0.10	0.10	−0.07
Work-related satisfaction	0.56 ***	0.05	−0.06	0.52 ***	−0.04
Willingness to work	0.35 *	0.13	0.02	0.31 .	0.08
Perceived productivity	0.40 ***	0.00	−0.02	0.36 **	−0.07
WHO-5	0.43 ***	0.00	−0.05	0.40 ***	−0.05

. $p \leq 0.10$, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

nates were strongly positively correlated with overall work-related satisfaction. PC1 *Pleasantness* scores and ISO *Pleasantness* were moderately positively correlated with perceived productivity and willingness to work scores; although the correlation between ISO *Pleasantness* coordinates and willingness to work scores is at the 90% confidence level. Both PC1 *Pleasantness* scores and ISO *Pleasantness* coordinates were moderately positively correlated with WHO-5 Well-Being Index scores.

Table IV shows the one-way analysis of variance results for ISO *Pleasantness* and ISO

TABLE IV. One-way ANOVA results for ISO *Pleasantness* and ISO *Eventfulness* according to self-reported gender and task type.

		df	*SS*	*MS*	*F*	*p*
ISO *Pleasantness*	Gender	3	1.198	0.3993	4.453	$p = 0.005$ **
	Residuals	132	11.836	0.0897		
	Task type	4	0.727	0.18164	1.952	$p = 0.105$
	Residuals	133	12.374	0.9304		
ISO *Eventfulness*	Gender	3	0.012	0.00390	0.051	$p = 0.985$
	Residuals	132	10.108	0.07658		
	Task type	4	0.066	0.01642	0.215	$p = 0.929$
	Residuals	133	10.137	0.07622		

. $p \leq 0.10$, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

Eventfulness, by gender and task type. A statistically significant difference was found in ISO *Pleasantness* score according to gender; graphically displayed in Fig. 6. Welch's t-tests were performed to compare ISO *Pleasantness* and ISO *Eventfulness* in self-reported aural diversity. There was a significant difference in ISO *Pleasantness* between participants who self-identified as aurally diverse ($M = -0.031, SD = 0.42$) and those who did not ($M = 0.171, SD = 0.28$); $t(20) = 2.005$, $p = 0.058$, albeit at the 90% confidence level. A significant difference was also observed in ISO *Eventfulness* between participants who self-identified as aurally diverse ($M = 0.158, SD = 0.25$) and those who did not ($M = -0.081, SD = 0.27$); $t(25) = -3.828$, $p \leq 0.001$.

IV. DISCUSSION

The PCA results demonstrate the affective response to office soundscapes can largely

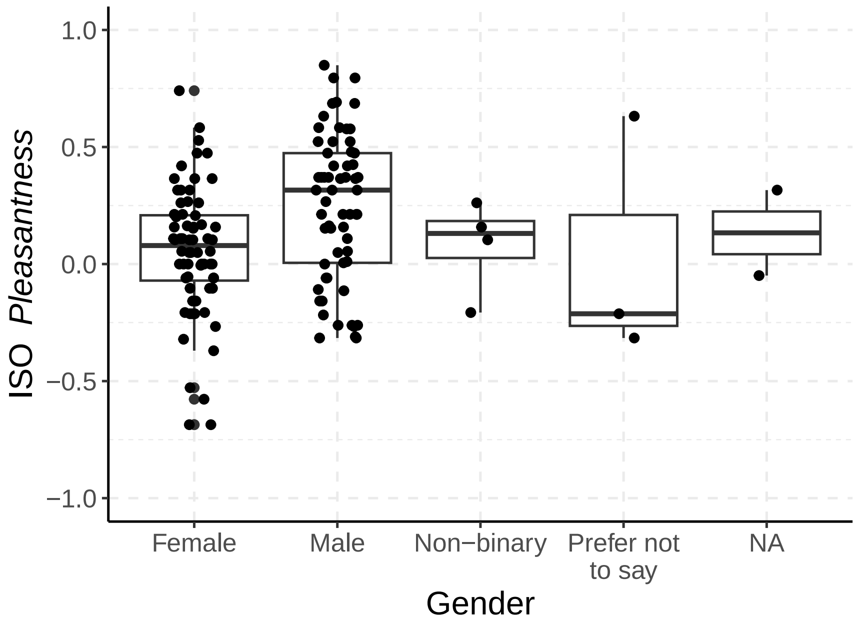

FIG. 6. Boxplot of ISO *Pleasantness* by self-reported gender. The central line within the boxes indicates the statistical median.

be described by three main components: *Pleasantness*, *Eventfulness* and *Emptiness*. Comparison of Fig. 4 to Fig. 1—the graphical representation of the two-dimensional model of soundscape perception presented in PD ISO/TS 12913-3:2019 (ISO, 2019)—identifies clear similarities. Loadings for the first component show a cluster of variables akin to "pleasant": "comfortable", "promoting concentration" and "relaxing" in the positive direction, and a group of variables similar to "annoying" in the negative direction: "demotivating", "irritable" and "disturbing". The second component observes "eventful" in the positive direction and "uneventful" in the negative direction, acting approximately perpendicular to the PC1 axis.

A cluster of variables with positive loadings for both PC1 *Pleasantness* and PC2 *Eventfulness* are similar to "vibrant": "interesting" and "engaging". Conversely, variables with negative loadings for both PC1 *Pleasantness* and PC2 *Eventfulness* include “boring” and “monotonous”. The variable “chaotic” has a negative loading for PC1 *Pleasantness* and a positive loading for PC2 *Eventfulness*, whilst “calm” observes a positive loading for PC1 *Pleasantness* and a negative loading for PC2 *Eventfulness*. This distribution of variables is comparable to the proposed relationship of the eight attributes contributing to the PD ISO/TS 12913-3:2019 two-dimensional model (ISO, 2019). The described behaviour of PC1 *Pleasantness* and PC2 *Eventfulness* component loadings—further supported by the very strong correlations between PC1 *Pleasantness* and ISO *Pleasantness*, PC2 *Eventfulness* and ISO *Eventfulness*—indicates the applicability of the two-dimensional soundscape model to open-plan offices.

Due to the strong negative loading from “demotivating” on PC1 *Pleasantness*, and the partial loading of “annoying” on PC2 *Eventfulness*—resulting in subtle differences between PC score and ISO coordinate correlations with other variables—it could be argued use of an amended version of the PD ISO/TS 12913-3:2019 two-dimensional model would be more appropriate in open-plan office environments, with “annoying” replaced by “demotivating”. The very strong correlations between PC1 *Pleasantness* and ISO *Pleasantness*; and PC2 *Eventfulness* and ISO *Eventfulness*, and the practicality of expecting practitioners to use a different two-dimensional model per environment—outdoor, residential and open-plan-offices—supports the conclusion that the PD ISO/TS 12913-3:2019 two-dimensional model is suitable for soundscape assessment of open-plan office environments.

The third component: PC3 *Emptiness* observed positive loadings from “empty” and “detached”, but also “full of content”. The variables “empty” and “detached” loaded negatively on PC2 *Eventfuless*, whereas “full of content” loaded PC2 *Eventfuless* positively. This behaviour may be explained by circumstances where the immediate physical environment is “empty” but the acoustical environment is eventful, or “full of content”, for example when sound is audible from distant office occupants but the desks around the participant are vacant (Haapakangas *et al.*, 2017). The value of PC3 *Emptiness* for office soundscape assessment should be further explored in future studies.

A strong positive correlation between ISO *Pleasantness* and overall soundscape assessment scores confirms increased perceptions of pleasantness are associated with increased overall office soundscape assessment; a similar effect has been observed in outdoor environments (Axelsson, 2015). A moderate correlation indicates a similar relationship between perceptions of pleasantness and office soundscape appropriateness. While these findings may appear axiomatic, it does not necessarily hold true that increased soundscape pleasantness should lead to increased perceived appropriateness; in an exterior context, high levels of traffic noise may be deemed unpleasant and yet appropriate if the assessment environment is a roadside. Such divergence between soundscape appropriateness and overall assessment has been observed in outdoor studies (Axelsson, 2015).

Sounds from human beings were found to contribute negatively to office soundscape pleasantness, indicating the importance of reducing the perceived presence of human generated sounds—speech, conversation, laughter—for improving office soundscape pleasantness. This is consistent with findings from studies using both qualitative and quantitative methods, where speech related noise has been identified as a key issue in open-plan offices (Acun and Yilmazer, 2018; Haapakangas *et al.*, 2017; Roskams *et al.*, 2019). Sounds from human beings were found to contribute positively to ISO *Eventfulness* scores, corresponding with outdoor soundscape studies (Axelsson *et al.*, 2010; Erfanian *et al.*, 2020). These findings imply disparity between sound source compositions leading to increased office soundscape pleasantness and eventfulness perception. The moderate negative correlation between ISO *Pleasantness* and mechanical and electronic sounds—keyboard, printer, call alerts, ventilation—indicates control of these sound sources is also important.

Gender was associated with changes in ISO *Pleasantness* score, with male participants observing a higher median than females. This is in contradiction with outdoor soundscape study (Erfanian *et al.*, 2020), where males scored soundscape pleasantness more negatively than females and it was argued variance in soundscape perception by gender may be caused by emotional (Yang and Kang, 2005) or auditory processing differences (Simon-Dack *et al.*, 2009). Kim *et al.* (2013) concluded female office occupants' satisfaction levels were consistently lower than male occupants for 15 indoor environmental quality indicators—including noise levels and sound privacy. The cause of these deviations should be further explored, with other sources citing office design as being conceptualised based on masculine behaviours (Hirst and Schwabenland, 2018).

Aural diversity was also found to mediate ISO *Pleasantness*, with those self-identifying as being aurally diverse yielding a lower mean score than participants who did not. The opposite effect was observed for ISO *Eventfulness*. This highlights the necessity for further discussion: should office environments be designed for aural-typical occupants or those with the most sensitive needs (Drever and Hugill, 2023; Roskams *et al.*, 2019)? Drever and Hugill (2023) encourage acknowledgement of the "complexities of lived and embodied experience

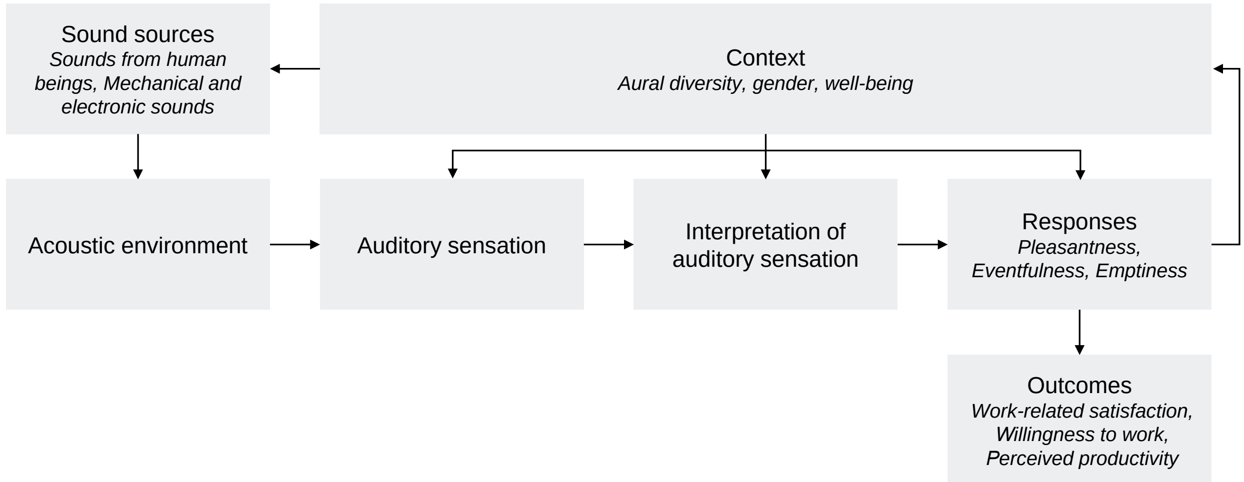

FIG. 7. A conceptual representation of open-plan office soundscape perception, adapted from the perceptual construct of soundscape perception presented in BS ISO 12913-1:2014 (ISO, 2014). Permission to reproduce extracts from British Standards is granted by BSI Standards Limited (BSI). No other use of this material is permitted. British Standards can be obtained from BSI Knowledge knowledge.bsigroup.com.

in all its diversity and fluctuation"; a sentiment this evidence suggests should be applied to open-plan office soundscape design. It should also be noted approximately one-sixth of the study participants self-identified as aurally diverse—a figure in line with global population estimates (Drever and Hugill, 2023).

No statistically significant relationship was found between soundscape scores and participant task type. This contradicts other studies, where it was concluded soundscape preference depended on task type, mood and personal preference (Acun and Yilmazer, 2018). This effect should be explored further, using cognitive tests to understand participants' ability to perform a variety of tasks in varying open-plan office soundscapes (Yadav *et al.*, 2023).

The moderate positive correlation between ISO *Pleasantness* and the WHO-5 Well-Being Index indicates a relationship between office occupant psychological well-being and soundscape pleasantness perception. Similar effects have been observed in exterior soundscape studies and were attributed to the concept that well-being underlies perception of the external world (Erfanian *et al.*, 2020). Sander *et al.* (2021) identified office noise as a cause of stress using physiological measures, and as such, the possibility of office soundscapes negatively impacting occupant well-being should not be rejected. The positive correlations between ISO *Pleasantness* and: work-related satisfaction, willingness to work and perceived productivity may also be explained by underlying participant well-being. However, studies have shown the negative impacts of noise on cognitive performance and disturbance—particularly meaningful speech (Renz *et al.*, 2018; Yadav *et al.*, 2023)—indicating the likelihood of a link between office soundscape perception and work performance. It should be highlighted the measures of well-being and work-related quality used in this study were self-reported. Future research should investigate whether the perception of office soundscapes mediates well-being, using psycho-physiological indicators such as heart rate or skin conductance, and productivity, using cognitive performance tests such as serial recall tasks, to confirm the validity of the self-reported measures (Medvedev *et al.*, 2015; Yadav *et al.*, 2023). The use of virtual assessment environments would enable the collection of such data (Yadav *et al.*, 2023). While causality has not been proven in this study, these findings reiterate the important relationship between the office acoustical environment, employee well-being and productivity (Bergefurt *et al.*, 2022; Yadav *et al.*, 2023).

The lack of correlation between the level-based nine-hour and 15-minute acoustical indicators calculated and the perceptual scores, necessitates investigation of alternative acoustical indicators for objective quantification of office soundscape perception. In residential environments, the most strongly correlated indicators for soundscape comfort and content were N_{10} and L_{A10}-L_{A90} respectively (Torresin *et al.*, 2020). A limitation of the current study is the inability to calculate loudness indicators such as N_{10}—due to the privacy concerns raised by office occupants preventing audio capture. Future studies should investigate appropriate indicators using virtual evaluation environments where privacy is not a concern (Jeon *et al.*, 2022).

The usefulness of room acoustic indicators—particularly those outlined in BS ISO 22955:2021 and BS EN ISO 3382-3:2022—should also be explored (ISO, 2021, 2022). Reverberation time (T) and distraction distance (r_D) have been shown to successfully indicate changes in cognitive performance and disturbance by noise respectively (Haapakangas *et al.*, 2017; Yadav *et al.*, 2023), implying the potential for application in the quantification of office soundscape perception. Virtual evaluation environments should be utilised in any future study exploring interactions between room acoustic indicators and office soundscape perception, providing the ability to vary room acoustic properties in a controlled manner (Jeon *et al.*, 2022). This in-situ study naturally includes a limited range of floorplate densities, ceiling heights and materials; virtual evaluation will enable the assessment of a wider range of office designs. It is not expected that assessment of a larger range of office configurations would change the concluded suitability of the PD ISO/TS 12913-3:2019 two-dimensional model, but quantifying the effect of varying common design parameters on soundscape perception would help inform practitioner design decisions. The study is also limited to fully hybrid workplaces located in Birmingham, UK. In 2023, 83% of organisations in the UK had hybrid working in place (CIPD, 2023), however, the ability to generalise the conclusions made in this study to other regions and languages should be explored in future studies (Puglisi *et al.*, 2024).

A conceptual representation of open-plan office soundscape perception, adapted from the perceptual construct of soundscape perception presented in BS ISO 12913-1:2014 (ISO, 2014), is shown in Fig. 7. The proposed framework enhances the BS ISO 12913-1:2014 model with the evidence obtained through this research for use in open-plan office environments.

V. CONCLUSIONS

The primary aims of this study were to investigate the applicability of soundscape perceptual assessment methodologies to the open-plan office environment and confirm the key components of open-plan office soundscape perception. The main conclusions are:

- Three principal perceptual dimensions: *Pleasantness*, *Eventfulness* and *Emptiness*, were found to explain 56% of the variance within 26 attribute rating scales;
- Similarities between the first two dimensions—*Pleasantness* and *Eventfulness*—and the PD ISO/TS 12913-3:2019 two-dimensional model suggest the applicability of the PD ISO/TS 12913-3:2019 two-dimensional model to open-plan office soundscape assessment (ISO, 2019);
- ISO *Pleasantness* scores were positively correlated with overall office soundscape assessment and appropriateness;
- The perceived presence of sounds from human beings was negatively correlated with ISO *Pleasantness* scores but positively correlated with ISO *Eventfulness* scores.

Additional findings include:

- Participant gender and self-reported aural diversity were shown to mediate ISO *Pleasantness* scores;
- Psychological well-being and overall work-related satisfaction, willingness to work and perceived productivity were correlated with soundscape pleasantness scores;
- No correlation was evident between the calculated, level-based, nine-hour or 15-minute acoustical indicators and perceptual scores.

Future work will expand on the conclusions and limitations of this study by utilising virtual evaluation environments. Exploration of the influence of office design parameters on soundscape perception will ultimately identify appropriate room acoustic and psychoacoustic indicators for predicting open-plan office soundscape perceptual performance.

SUPPLEMENTARY MATERIAL

See supplementary material at [URL will be inserted by AIP] for floorplate layouts and the full participant questionnaire.

AUTHOR DECLARATIONS

The data supporting this study's findings are available from the corresponding author upon reasonable request in line with research ethical approval. Informed consent was obtained from all study participants. The authors have no conflicts of interest to disclose.

[1]An earlier version of this work was presented at the UK's Institute of Acoustics conference, ACOUSTICS 2023, doi: 10.25144/16577

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