AN IN-SITU INVESTIGATION OF OFFICE SOUNDSCAPE PERCEPTUAL EVALUATION METHODOLOGIES

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1 INTRODUCTION

The importance of acoustics in open-plan offices is well documented, with studies highlighting associations between acoustical characteristics and job satisfaction, productivity, and well-being.[1–3] The international standards BS EN ISO 3382-3:2022 and BS ISO 22955:2021 detail the measurement and calculation procedures for acoustical indicators such as: spatial decay rate of speech ($D_{2,S}$), speech level at a four metre distance ($L_{p,A,S,4m}$), in-situ acoustic attenuation of speech ($D_{A,S}$) and workstation noise level ($L_{Aeq,T}$).[4,5]

Perceptual assessment of open-plan offices is less standardised. BS ISO 22955:2021 provides an example user survey but does not specify analysis procedures.[5] In research literature, numerous subjective assessment methodologies can be found including quantification of “acoustic satisfaction”, “acoustical quality”, “perceived disturbance by noise”, “comfortableness” and “liveliness”.[6–10]

Following initial exploratory work, the perceptual assessment of external soundscapes is now standardised in the ISO 12913 series.[11–14] This methodology utilises the two-dimensional pleasantness and eventfulness perceptual assessment framework. Recent studies have developed similar perceptual dimensions in residential environments, however, the suitability of such an approach in open-plan offices remains scarcely explored.[15,16]

Development of a perceptual assessment methodology for open-plan offices will enable prediction of how occupants perceive their sonic environment. In turn, providing a lexicon describing human experience to be used as a design tool. Applying such an experiential approach should enable workplace designers, and building users, to tailor the environment to better suit the conditions for the intended activities: improving user comfort and giving greater certainties in creating healthy and productive environments.[17] Consequently, the primary aim of this study was to investigate the applicability of soundscape perceptual assessment methodologies to the open-plan office environment.

2 METHODOLOGY

2.1 Office Soundscape Assessments

Office soundscape assessments were conducted in five floorplate configurations across two university buildings in Birmingham city centre. All floorplates were open-plan and hybrid: designed to accommodate multiple persons working without separation, and accommodating colleagues who move between the office building and a home work space.[5,18,19] The floorplates comprised colleagues from a variety of disciplines including human resources, information technology, finance, estates, marketing, legal and academic services. An assortment of floorplate areas (435-1086m^2) and occupancies (16.7-62.1%) were captured. Table 1 displays the range of floorplate areas, capacities, workstation noise levels and associated participant survey responses. Images of example floorplates are shown in Figure 1.

Floorplate	Floorplate Area [m²]	Floorplate Capacity	Peak Floorplate Occupancy Ratio [%]	Average Floorplate $L_{\mathrm{Aeq,\,9\,hour}}$ [dB]	**Survey *n***
1.1	1008	132	16.7	44.2	**8**
1.2	1008	132	31.8	46.8	**9**
2	1086	121	50.4	48.1	**21**
3	478	76	25.0	50.8	**11**
4	435	56	52.8	48.3	**12**
5	768	124	62.1	47.8	**24**
				Total	**85**

Table 1: Summary of floorplate conditions during the office soundscape assessments. "Survey *n*" indicates the number of completed participant questionnaires.

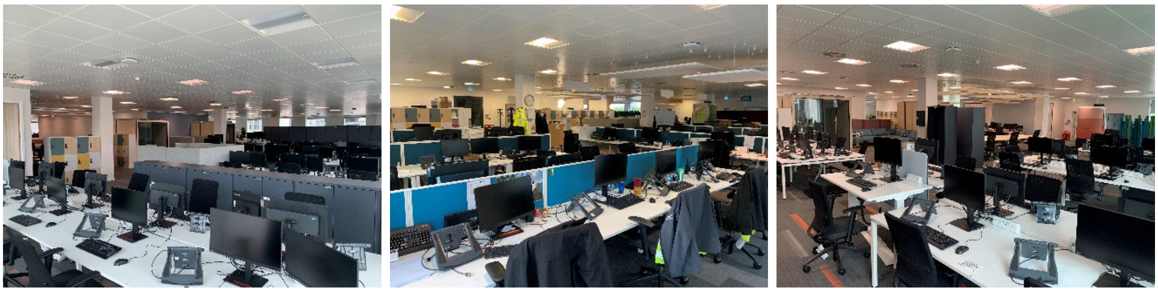

Figure 1: Images of example floorplates for which office soundscape assessments were completed.

2.1.1 Questionnaire

A 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, residential soundscape research, office soundscape qualitative research and an interpretation of the indoor soundscape dimensions used for a recent office study.[13,15–17]

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.[13] The sound source classes were modified for appropriateness to the office environment based on prior qualitative research.[17] Participant demographic and contextual data was collected, including self-assessment of the "operational requirement" for spending the day in the office, and "task type" using the activity categories defined in BS ISO 22955:2021.[5] Work-related quality was assessed equivalently to previous office soundscape research, and participant well-being indicated using the World Health Organisation-Five Well-Being Index (WHO-5).[16,20]

2.1.2 Workstation Noise Levels

On each assessment day, workstation noise levels were acquired in accordance with BS ISO 22955:2021 Annex E.[5] Sound level meters were positioned at unoccupied workstations in acoustically different zones within each floorplate. Measurements were completed for approximately nine hours, ensuring the start and end of the working day was captured. The "fast" time weighting was used, and time history recorded every second. The microphone tip was positioned 1.2m from the floor. An example workstation setup and measurement locations can be seen in Figure 2.

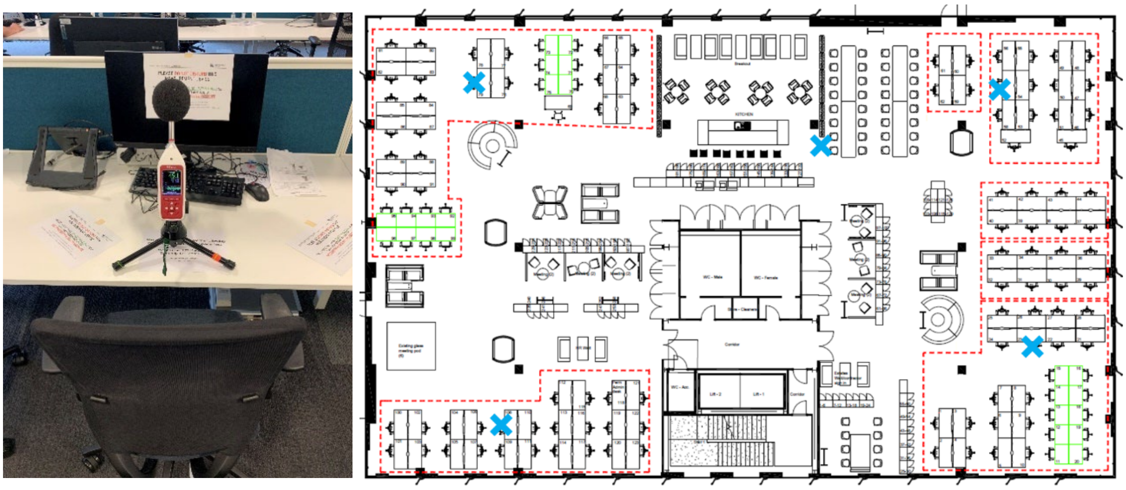

Figure 2: Indicative image of a workstation measurement setup (left) and plan of floorplate measurement locations (right), denoted by blue crosses.

2.2 Data Analysis

Statistical analyses were completed using the software environment R (Version 4.2.1).[21] Principal component analysis (PCA) 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 and Bartlett's test of sphericity.[22,23] As interpretation of the initial components was intuitive, no rotation was required.[15]

For comparison to the calculated participant scores for the extracted principal components (cf. Section 3.1), the two-dimensional pleasantness and eventfulness coordinates were calculated in accordance with PD ISO/TS 12913-3:2019.[14] Subsequent Pearson correlation coefficients were calculated for interval and continuous variables. Spearman's rank correlation coefficients were calculated for ordinal variables.[14] One-way analysis of variance (ANOVA) was calculated for categorical variables.[14]

3 RESULTS

3.1 Principal Component Analysis

The first three components respectively explained 38%, 16% and 6% of the total variance 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.[11,15] The following results concern the first three components only.

Figure 3 shows the component loading plot for PC1 and PC2, displaying the contributions of the original 26 attributes to the first two components. Figure 4 shows the component loading plot for PC1 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, $v_a^2 < 0.50$; Zone 2, $0.50 \leq v_a^2 < 0.70$; Zone 3, $v_a^2 \geq 0.70$, where v_a^2 represents the amount of attribute variance explained by the plotted PCs.[11,15] The components were interpreted by identifying the most correlated variables, both positively and negatively.[11,15]

The first component was best explained by "pleasant", "comfortable" and "promoting concentration" in the positive direction, "demotivating", "irritable" and "annoying" in the negative direction and was subsequently labelled *Pleasant*. The second component was best explained positively by "eventful" and negatively by "uneventful" and was labelled *Eventful*. The third component was best explained by "empty" and "detached" in the positive direction and was labelled *Empty*.

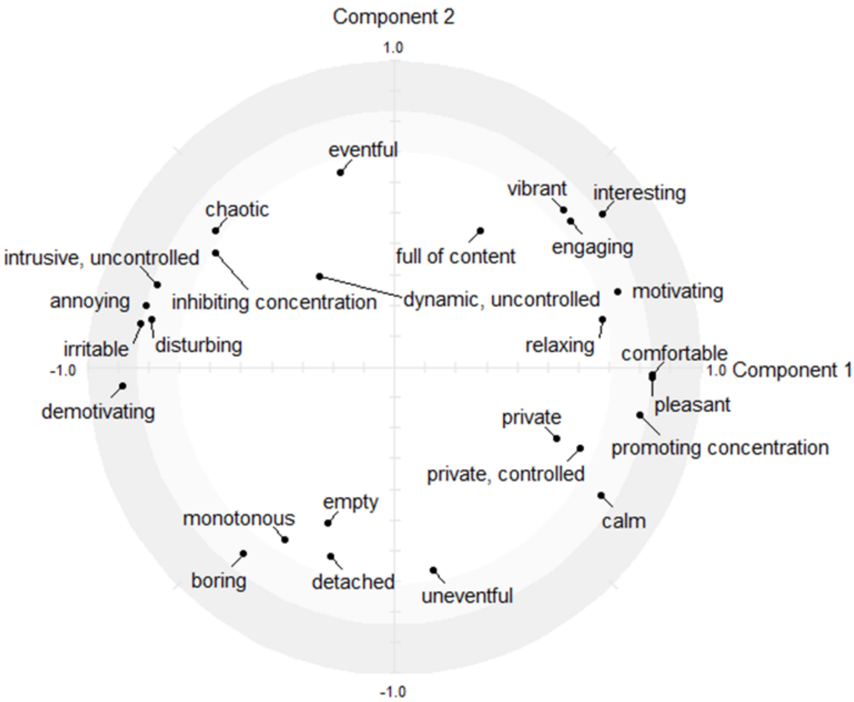

Figure 3: Loadings of the 26 attributes scales to PC1 and PC2. Three areas are indicated according to the distance between the attribute vectors (v_a) and the origin: Zone 1, $v_a^2 < 0.50$; Zone 2, $0.50 \leq v_a^2 < 0.70$; Zone 3, $v_a^2 \geq 0.70$, where v_a^2 represents the amount of attribute variance explained by the plotted PCs.

Figure 4: Loadings of the 26 attributes scales to PC2 and PC3. Three areas are indicated according to the distance between the attribute vectors (v_a) and the origin: Zone 1, $v_a^2 < 0.50$; Zone 2, $0.50 \leq v_a^2 < 0.70$; Zone 3, $v_a^2 \geq 0.70$, where v_a^2 represents the amount of attribute variance explained by the plotted PCs. Variables with $v_a < 0.5$ are not labelled.

3.2 Relationships Between Variables

Table 2 shows the Pearson correlation coefficients between the PC scores, the PD ISO/TS 12913-3:2019 two-dimensional coordinates – ISO *Pleasant* and ISO *Eventful*, WHO-5 Well-Being Index, and nine-hour acoustical indicators. PC1 *Pleasant* scores were strongly positively correlated with ISO *Pleasant* coordinates, as were PC2 *Eventful* scores with ISO *Eventful*. Both PC1 *Pleasant* and ISO *Pleasant* were moderately positively correlated with the WHO-5 Well-Being Index. No significant correlations were found between the nine-hour acoustical indicators and perceptual scores.

Spearman's rank correlation coefficients are displayed in Table 3 for the PC scores, ISO coordinates, soundscape assessment and appropriateness, sound source dominance, operational requirement, and work-related quality scores. PC1 *Pleasant* scores and ISO *Pleasant* coordinates were both strongly positively correlated with overall soundscape assessment scores. PC1 *Pleasant* scores and ISO *Pleasant* coordinates were both moderately positively correlated with soundscape appropriateness scores. ISO *Pleasant* coordinates were moderately negatively correlated with sounds from human beings scores; a moderate negative correlation was also observed with mechanical and electronic sounds scores though this was not statistically significant. PC2 *Eventful* scores and ISO *Eventful* coordinates were both moderately positively correlated with sounds from human beings scores. Figure 5 graphically displays the relationships between the ISO coordinates and sound source dominance. PC1 *Pleasant* scores and ISO *Pleasant* coordinates were both moderately positively correlated with overall work-related satisfaction. PC1 *Pleasant* was moderately positively correlated with perceived productivity scores.

Table 4 shows the one-way analysis of variance results for ISO *Pleasant*, ISO *Eventful*, gender, self-reported aural diversity, and task type. Statistically significant differences were found in ISO *Pleasant* score according to gender, aural diversity, and task type. Figure 6 and Figure 7 graphically display these associations. A statistically significant difference was also found in ISO *Eventful* score according to aural diversity.

	PC1 *Pleasant*	PC2 *Eventful*	PC3 *Empty*	ISO *Pleasant*	ISO *Eventful*
PC2 *Eventful*	-0.05				
PC3 *Empty*	-0.01	-0.09			
ISO *Pleasant*	**0.93** ***	-0.10	-0.03		
ISO *Eventful*	**-0.24** *	**0.87** ***	-0.05	**-0.28** *	
WHO5	**0.49** **	-0.11	0.06	**0.44** *	-0.14
Zonal $L_{\text{Aeq, 9 hours}}$	0.00	0.16	-0.10	-0.02	0.23
Floorplate $L_{\text{Aeq, 9 hours}}$	0.15	-0.04	-0.16	0.05	0.00
$L_{\text{A10, 9 hours}}$	0.06	0.12	-0.11	0.03	0.18
$L_{\text{A90, 9 hours}}$	0.17	0.05	-0.14	0.10	0.07
$L_{\text{A10-90, 9 hours}}$	-0.17	0.03	0.09	-0.10	0.05
Liveliness $_{\text{9 hours}}$	0.17	0.01	-0.07	0.13	0.00

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

Table 2: Pearson correlation coefficients between the PC scores, ISO *Pleasant*, ISO *Eventful*, WHO-5 Well-Being Index, and nine-hour acoustical indicators. Statistically significant correlations ($p \leq 0.05$) are highlighted in bold.

	PC1 *Pleasant*	PC2 *Eventful*	PC3 *Empty*	ISO *Pleasant*	ISO *Eventful*
Soundscape assessment	**0.84** ***	0.01	0.03	**0.74** ***	-0.20
Soundscape appropriateness	**0.60** ***	-0.17	0.00	**0.54** ***	-0.33
Sounds from human beings	-0.38	**0.47** **	-0.03	**-0.43** *	**0.51** **
Mech. and electronic sounds	-0.35	0.02	-0.12	-0.42	0.18
Outdoor sounds	-0.17	-0.07	0.10	-0.16	-0.05
Music	-0.06	0.01	0.38	-0.14	0.04
Operational requirement	0.30	0.10	0.00	0.25	-0.07
Work-related satisfaction	**0.57** ***	0.10	-0.07	**0.56** ***	-0.08
Willingness to work	0.35	0.12	0.08	0.28	0.00
Perceived productivity	**0.47** **	0.01	0.06	0.41	-0.10

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

Table 3: Spearman's rank correlation coefficients for the PC scores, ISO *Pleasant*, ISO *Eventful*, soundscape assessment and appropriateness, sound source dominance, operational requirement, and work-related quality scores. Statistically significant correlations ($p \leq 0.05$) are highlighted in bold.

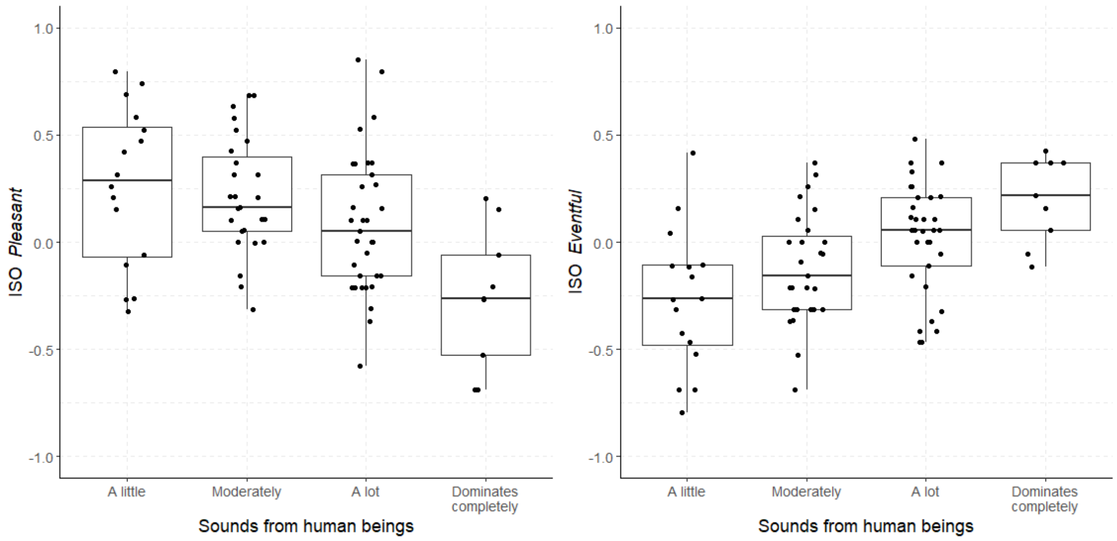

Figure 5: Boxplots of ISO *Pleasant* (left) and ISO *Eventful* (right) score by sounds from human beings. The central line within the boxes indicates the statistical median.

		df	*SS*	*MS*	*F*	*p*
ISO *Pleasant*	Gender	3	1.334	0.4448	4.01	**0.0104 ***
	Residuals	79	8.763	0.1109		
	Aural diversity	1	0.505	0.505	4.211	**0.0434 ***
	Residuals	80	9.593	0.1199		
	Task type	4	1.392	0.348	3.174	**0.0179 ***
	Residuals	80	8.773	0.1097		
ISO *Eventful*	Gender	3	0.007	0.00233	0.025	0.995
	Residuals	79	7.276	0.0921		
	Aural diversity	1	0.894	0.8941	11.27	**0.00121 ****
	Residuals	80	6.349	0.0794		
	Task type	4	0.139	0.03474	0.385	0.819
	Residuals	80	7.223	0.09029		

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

Table 4: One-way ANOVA results for ISO *Pleasant*, ISO *Eventful*, self-reported gender, aural diversity, and task type. Statistically significant associations ($p \leq 0.05$) are highlighted in bold.

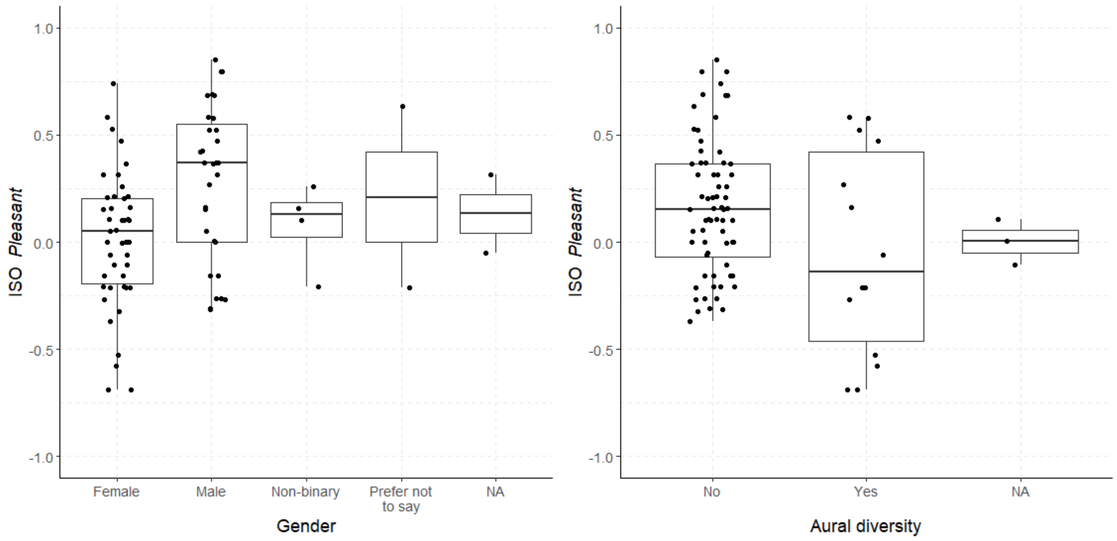

Figure 6: Boxplots of ISO *Pleasant* score by self-reported gender (left) and aural diversity (right). The central line within the boxes indicates the statistical median.

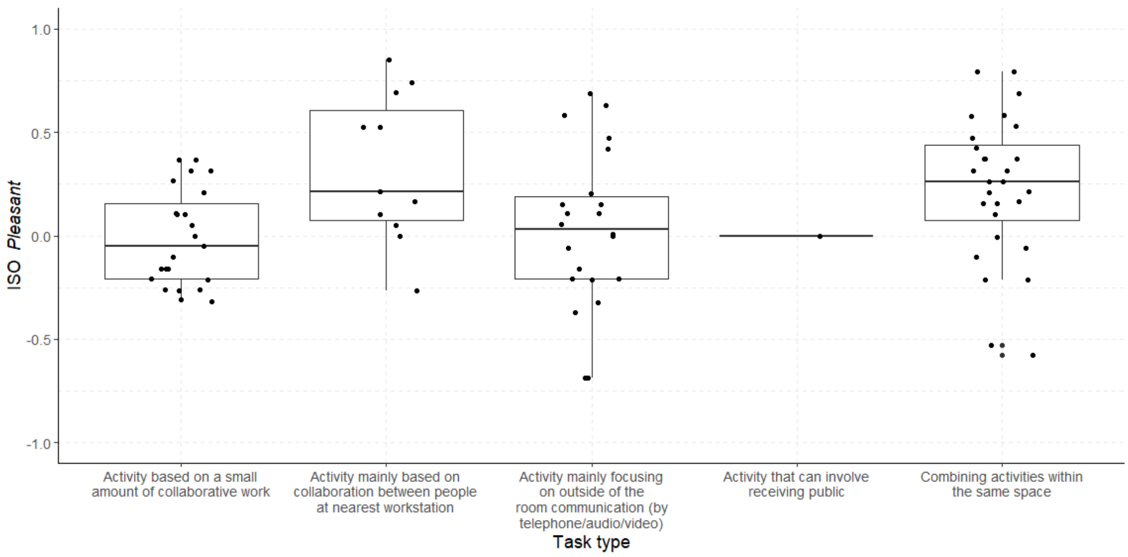

Figure 7: Boxplot of ISO *Pleasant* score by participant task type. The central line within the boxes indicates the statistical median.

4 DISCUSSION

The PCA results demonstrate the affective response to office soundscapes can largely be described by three main components: *Pleasant*, *Eventful* and *Empty*. Comparison of Figure 3 to Figure 8 – the graphical representation of the two-dimensional model of soundscape perception presented in PD ISO/TS 12913-3:2019 – identifies clear similarities.[14] Scores 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 perpendicular to the PC1 axis.

A cluster of variables with positive scores for both PC1 *Pleasant* and PC2 *Eventful* are similar to "vibrant": "interesting" and "engaging". Conversely, variables with negative scores for both PC1 *Pleasant* and PC2 *Eventful* include "boring" and "monotonous". The variable "chaotic" has a negative score for PC1 *Pleasant* and a positive score for PC2 *Eventful*, whilst "calm" observes a positive score for PC1 *Pleasant* and a negative score for PC2 *Eventful*. This distribution of variables is markedly comparable to the proposed relationship of the eight attributes contributing to the PD ISO/TS 12913-3:2019 two-dimensional model.[14] The described behaviour of PC1 and PC2 component scores, further supported by the strong correlations between PC1 *Pleasant* and ISO *Pleasant*, PC2 *Eventful* and ISO *Eventful*, indicates the applicability of the two-dimensional soundscape model to open-plan office environments. The value of the third component: *Empty* – observing positive loadings from "empty" and "detached", but also "full of content" – compels further investigation. This component may be influenced by circumstances where the immediate physical environment is "empty" but the acoustical environment is "full of content" due to background noise from distant office occupants.[8]

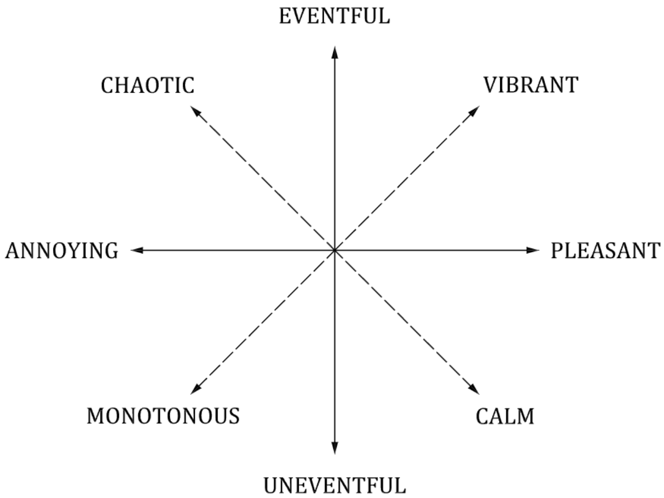

Figure 8: Graphical representation of the two-dimensional model of soundscape perception presented in PD ISO/TS 12913-3:2019[14]

A strong positive correlation between ISO *Pleasant* and overall soundscape assessment scores confirms increased perceptions of pleasantness are associated with increased overall office soundscape assessment.[15] 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.[24] 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 other methods.[8,17] Sounds from human beings were found to contribute positively to ISO *Eventful* scores, corresponding with exterior soundscape studies.[11,20] These findings imply divergency between sound source compositions leading to increased pleasantness and eventfulness scores.

Participant task type was found to mediate ISO *Pleasant* scores demonstrating an association between the activities completed by the participant and their assessment of soundscape pleasantness. A higher median score for ISO *Pleasant* was evident for participants "combining activities within the same space" compared with those engaged in "activity based on a small amount of collaborative work".[7] This infers the open-plan office soundscape, or perhaps holistic environment, is considered more pleasant for conducting collaborative activities than concentration based tasks.[17]

Gender was similarly associated with changes in ISO *Pleasant* score, with male participants observing a higher median than females: this is in contradiction with exterior soundscape studies.[20] Aural diversity was also found to mediate ISO *Pleasant*, with those self-identifying as being aurally diverse yielding a lower median score than participants who did not. This highlights the necessity for further discussion: should office environments be designed for the average occupant or those with the most sensitive needs?[7,25]

The moderate positive correlation between ISO *Pleasant* and the WHO-5 Well-Being Index indicates a relationship between occupant psychological well-being and soundscape pleasantness perception.[26] Similar effects have been observed in exterior soundscape studies, and were attributed to the concept that well-being underlies perception of the external world.[20] Moderate positive correlations between ISO *Pleasant* and both overall work-related satisfaction and perceived productivity scores further uphold this conclusion. While causality has not been proven, these findings reiterate the important relationship between the office environment and employee well-being.[27]

Finally, the lack of significant correlation between the calculated nine-hour acoustical indicators and the perceptual scores, necessitates investigation of alternative acoustical indicators for objective quantification of office soundscape perception. The usefulness of room acoustic indicators – particularly those outlined in BS EN ISO 3382-3:2022 and BS ISO 22955:2021 – and acoustical indicators with finer temporal resolution should be explored.[4,5,8]

5 CONCLUSIONS

The primary aim of this study was to investigate the suitability of soundscape perceptual assessment methodologies to the open-plan office environment. The main conclusions are:

- Three principal perceptual dimensions: *Pleasant*, *Eventful* and *Empty*, were found to explain 60% of the variance within 26 attribute rating scales;
- Similarities between the first two dimensions – *Pleasant* and *Eventful* – and the PD ISO/TS 12913-3:2019 two-dimensional model, suggest applicability of the PD ISO/TS 12913-3:2019 two-dimensional model to open-plan office environments;[14]
- ISO *Pleasant* scores were positively correlated with overall office soundscape assessment and appropriateness;
- The perceived presence of sounds from human beings was negatively correlated with ISO *Pleasant* scores, but positively correlated with ISO *Eventful* scores.

Additional findings include:

- Participant task type, gender and self-reported aural diversity were shown to mediate ISO *Pleasant* scores;
- Psychological well-being, overall work-related satisfaction and perceived productivity were found to be correlated with ISO *Pleasant* scores;
- No correlation was evident between nine-hour acoustical indicators and perceptual scores, signifying the requirement for investigation of alternative acoustical indicators for objective quantification of open-plan office soundscape perception.

Future work will investigate the relationship between sound sources, task type and soundscape ratings, with the intention of identifying the desired sound source compositions – and subsequently acoustical design parameters – for specific office activities. The efficacy of room acoustic indicators for predicting perceptual response should be explored, along with reasons for the differences in soundscape pleasantness scores between self-reported gender and aural diversity groups.

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