Assessing the perceived indoor acoustic environment quality across building occupants in a tertiary-care public hospital in Singapore^

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^The research protocols used in this research were approved by the centralised institutional review board [IRB Ref. No. 2020/2204].

Abstract

Although hospitals are notorious for poor acoustics, the acoustic environment is usually evaluated in silos, or in conjunction with few indoor environmental quality (IEQ) factors. With only anecdotcal evidence, it is important to first establish a holistic baseline perception of the hospital acoustic environment before commissioning costly measurement campaigns. A psychometric questionnaire based on the industry-standard IEQ survey and ISO 12913-2 soundscape standard was administered to examine the perceived indoor acoustic environment quality across major occupant groups (i.e. staff, patients, visitors) in an acute hospital in Singapore. Of the 16 IEQ factors examined, all occupant groups expressed the greatest dissatisfaction with noise levels and sound privacy. Notably, the staff were significantly more dissatisfied than the other groups in terms of sound privacy and overall IEQ. When assessing the overall quality (OQ) and appropriateness (OA) of the acoustic environment, OQ was similarly neutral across all groups, whereas the staff expressed significantly lower OA than both patients and visitors. The dissatisfaction in the acoustic environment could be attributed to the perceived dominance and annoyance of vocal and operational sounds across all occupant groups, as well as the environment set-up with most being housed in cohort rooms. Particularly, the staff were significantly more annoyed with vocal and operational sounds than patients and visitors. This study also yielded evidence that challenges the validity of the 5-item Weinstein noise sensitivity scale when used in an Asian context, as well as the applicability of the perceived affective quality circumplex model in ISO 12913-3 for indoor environments.

Keywords: Indoor soundscape; Noise sensitivity; Acoustic environment; Hospital acoustics; Hospital soundscapes

1. INTRODUCTION

Poor acoustics is a common hallmark of hospitals around the world. Despite established international and local regulations, and advancements in noise control engineering [1–3], noise levels in indoor hospital environments have been gradually increasing over the past 70 years [4,5]. High background noise and the lack of speech privacy are common sources of dissatisfaction across all hospital occupant groups (i.e. staff, patient, and visitors) [6–8].

Noisy environments have been known to elevate stress levels for medical staff, which becomes detrimental to their mental wellbeing [6,9]. Overly stressed medical personnel leads to reduced quality of care, exacerbates burnout, and may worsen already high turnover rates [4,6,10–12]. Moreover, due to their physical and mental vulnerability, as well as dearth of coping mechanisms, the patient population is negatively impacted by noise to a greater extent. Noise-induced sleep disturbance, physiological, and psychological impacts of noise reduce overall well-being and lengthen recovery time [6,7,13,14], even more so for the critically-ill or neonates [10,15–17]. Unmistakably, the adverse effects of noise go directly against the principal function of a hospital – to provide a restful environment for recovery.

1.1 Assessment of hospital acoustics

Thus far, characterization of hospital acoustics has been predominantly objective. Both equivalent sound pressure level (L_{eq}), a time-averaged representation of the sound energy, and occurrence rates [$OR(N)$], the percentage of time where the sound levels are above N dB, are usually measured and used to correlate with other observed effects [4]. The absence of context in objective scores [i.e. L_{eq} and $OR(N)$], and non-standardized acoustic measurement methodologies, cause them to lack perceptual traits to account for how sounds are conceived by humans [6]. It is worth noting that decreased sound levels do not necessarily translate to improved well-being [18,19]. This is in addition to the inherent limitation of physical metrics in predicting annoyance, especially for complex acoustic environments [20].

In healthcare environments, Mackrill et al. proposed an emotional–cognitive framework for a qualitative perceptual assessment of hospital ‘soundscapes’ to help understand perceptual effects beyond reduced sound levels [21–25]. It was acknowledged that the framework was developed in the absence of context, a critical factor in one’s perception of the complex acoustical environment [26,27].

To assess “sounds as perceived in an environment in all its complexity” [28], and in context, the notion of soundscape was proposed and standardized by the International Organization for Standardization (ISO) [28–30]. Soundscape provides a holistic approach to sound management, which is primarily centered on human perception and supplemented by physical measurements. Since the inception of the ISO 12913 series of standards, the soundscape approach has been primarily employed in urban outdoor environments [31,32], and recently in indoor soundscapes [33–35]. As the standards were developed for an outdoor urban context, the applicability of the standard (i.e. ISO 12913-3 circumplex model of perceived affective quality) to evaluate indoor acoustic quality is still an active area of research [36,37]. Importantly, the soundscape approach differentiates from other subjective assessments used to assess hospital acoustics (e.g. HCAHPS [Hospital Consumer Assessment of Healthcare Providers and Systems] survey, emotional–cognitive response framework [21,22,24,25]) through the consideration of context – the “interrelationships between person and activity and place, in space and time" [29]. Hence, it is also paramount for all users of the space (i.e. hospital occupants) to evaluate the acoustic environment to obtain a holistic understanding of the acoustic environment for effective user-centric intervention and design measures.

1.2 Overall indoor environmental quality

The overall indoor environment quality (IEQ) is not solely determined by the perception of acoustic quality, but also by the perception of lighting, air quality, thermal comfort, and acoustic comfort [38–40]. However, IEQ protocols were originally designed for residential and office buildings, and their implementation in medical facilities has been hampered by their inherent complexity [41,42]. From the small sample of healthcare buildings surveyed (i.e. 30 of 897 buildings) over 20 years with the industry standard Center for the Built Environment (CBE) occupant survey, there appears to be a large variation in air, lighting, and acoustic environment satisfaction scores across occupants (Figure A1 in [38]). The large variance points to possible perceptual differences between occupant groups in healthcare facilities (e.g. staff, patients, visitors) due to distinct differences in their needs. This lack of distinction between occupants has also been identified in a review of IEQ assessments in healthcare facilities and warrants further investigation [41,43].

It has also been established that the health and well-being of the staff and patients in healthcare facilities are influenced by a multitude of physical environment factors [44–46]. However, there are still few studies that have examined hospital soundscapes in conjunction with other dominant factors in the overall perception of the hospital IEQ amongst all major occupant types [44,46,47]. Moreover, there has not been an assessment of indoor soundscapes via the ISO 12913-2 protocols in conjunction with IEQ assessments in healthcare facilities [34].

In Singapore, the Environmental Protection and Management act only specifies boundary noise limits for construction sites and industrial premises [48,49]. Moreover, existing building codes only provide guidelines for ambient sound levels produced by air-conditioning or mechanical ventilation systems [50]. Indoor ambient sound levels are not specifically regulated in healthcare facilities in Singapore. Although not mandatory, it is noteworthy that IEQ is assessed through post-occupancy evaluations as part of the green building assessment criteria for non-residential buildings in Singapore [51]. It should be noted that green building certifications have mostly not affected perceived acoustic quality and even worsened them [52–54]. To date, there are no widely-adopted and validated psychometric questionnaires to holistically assess the indoor hospital soundscape across all occupant groups.

1.3 Research questions

To this end, a quantitative assessment appears to be a cost-effective method to establish a baseline of the perceived indoor acoustic quality across occupant groups in a large tertiary-care public hospital in Singapore. This baseline assessment places the acoustic quality in the context of all important IEQ factors, across majority of the occupant groups, which helps to prioritise operational interventions and design decisions to improve overall IEQ. Moreover, this case study also assess the validity of established tools (e.g. IEQ, ISO 12913-2) in the context of acute healthcare environments. Without precedent, at least in Singapore healthcare facilities, the indoor acoustic quality is assessed based on a psychometric approach with the following emphases:

(1) How satisfactory is the acoustic quality amongst other indoor environmental quality factors across all occupant groups?
(2) Is the soundscape quality in terms of overall quality and appropriateness significantly different across all occupant groups?
(3) Does the generality of the ISO 12913-3 circumplex model of perceived affective quality hold for indoor soundscapes of healthcare facilities across all occupant groups?
(4) Are there significant differences in the perception of sound source dominance and

annoyance across all occupant groups?

2. METHOD

For this baseline study, a survey was prepared and customized to the target population group where necessary. Basic demographics, noise sensitivity, and self-reported hearing ability were collected for all occupant groups.

2.1 Study site and administration

The survey was conducted in a public tertiary acute hospital in Singapore. Most patients were nursed in 4-6 bedded cohort rooms, with the rest being in single bedded rooms. Each bedspace in multi-bedded cohort rooms is fitted with retractable curtains that can be drawn to provide visual privacy as shown in Figure 1. Three groups of hospital occupants were surveyed, i.e. healthcare staff, patients and visitors. Due to operational challenges and COVID-19 restrictions, the survey was administered via the web-based FormSG platform [55]. The staff survey was broadcasted hospital wide via an internal messaging system with no restrictions to the staff role and function, whereas the patients and visitors were administered on an electronic tablet. Formal ethical approval was granted by the institutional review board of the hospital for this study (IRB Ref. No. 2020/2204). The survey was administered during December 2020 to January 2021.

Figure 1: Photo of a typical 4-6 bedded cohort room [56]

2.2 Data Collection Method

Since subjective adverse effects of noise and soundscape perception are also influenced by non-acoustic factors, personal factors such as demographics, hearing ability, and noise sensitivity, as well as situational factors, such as the activity and length of occupancy should be considered [57]. Hence, basic demographic information such as occupant group, age, gender and self-reported hearing ability were collected.

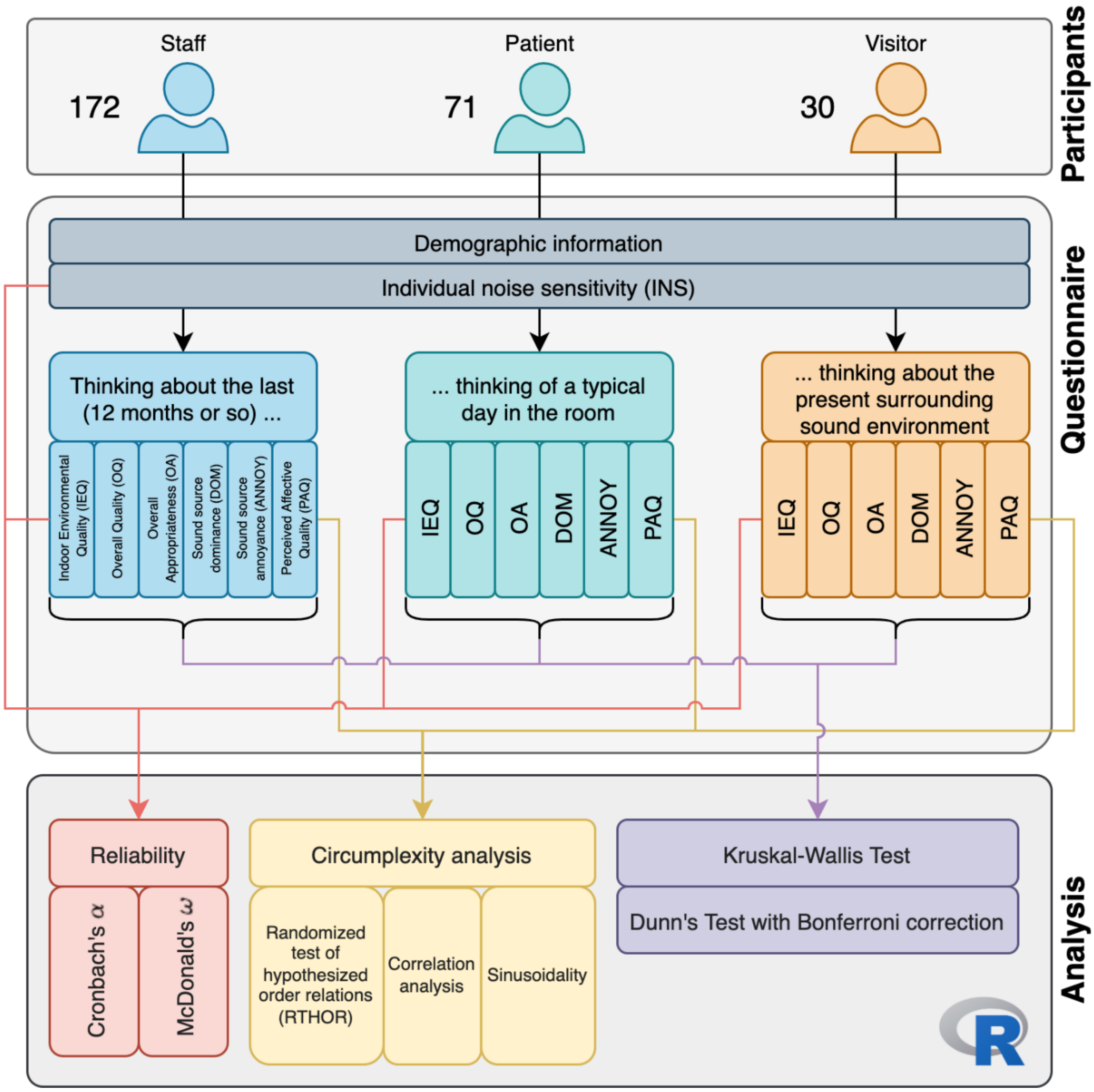


Figure 2: Visual overview of the research methodology depicting the population groups, shared and population-specific questionnaire items, and broad analyses for the questionnaire items.

To investigate the effects of the indoor acoustic environment across the three groups of building occupants, the questionnaire broadly assessed the perceptions of individual noise sensitivity (INS) [58]; overall indoor environmental quality (IEQ) [59,60]; and soundscape quality [28], which is determined by factors such as its overall quality (OQ), overall appropriateness (OA), and perceived affective quality (PAQ), and sound source dominance (SSD). For readability and easy reference, each variable is coded with abbreviations based on ISO 4 and prefixed by its categorical acronym as [CATEG:VAR]. For instance, the *pleasantness* variable in PAQ is coded as [PAQ:PLEAS].

The 21-item Weinstein Noise Sensitivity Scale (WNSS) is widely regarded as the most reliable psychometric measure of noise sensitivity, but it is usually too lengthy for field surveys. To minimize unnecessary participant fatigue, a shortened 5-item variant of the WNSS, which has so far exhibited good consistency, was adopted in this study [35,58,61]. The 5-item noise sensitivity scale (5NSS) was evaluated on a 5-point scale from ‘Strongly Disagree’ to ‘Strongly Agree’, and coded as [INS.SENSIT, INS:RELAX, INS:MAD INS:ANNOY, and INS:USEDTO], as shown in Table A.1 in Appendix A. Note that INS:USEDTO is reverse-coded in the computation of noise sensitivity based on 5NSS.

Assessment of the IEQ was modeled after the “industry standard” Post-Occupancy Evaluation survey from the Centre for the Built Environment (CBE) at the University of California, Berkley [38]. Since the CBE’s POE 16-item questionnaire was originally designed to evaluate office spaces, the items were customized to reflect corresponding conditions in staff workspaces and patient bedspaces. The customized 16-item IEQ questionnaires were rated on a 5-point scale from ‘Extremely Dissatisfied’ to ‘Extremely Satisfied’ and coded as [IEQ:TEMP, IEQ:AIR, IEQ:LIGHT, IEQ:VISCOMF, IEQ:NOISE, IEQ:SOUNDPRIV, IEQ:SPACE, IEQ:VISPRIV, IEQ:INTERACT, IEQ:FURNISH, IEQ:ADJUST, IEQ:COLOR, IEQ:CLEAN, IEQ:CLEANSERV, IEQ:GENMAINT, and IEQ:OVERALL], as shown in Table A.2 to A.4, across staff, patients and visitors, respectively.

Although there are no definitive qualitative measures for assessing soundscape quality in healthcare facilities, the ISO 12913-2 standard provides comprehensive data collection guidelines for evaluating soundscapes. Following the questionnaire design described as “Method A” in ISO 12913-2, general perception of the acoustic environment was first assessed by rating its overall quality and appropriateness. The overall quality was assessed on a 5-point scale from ‘Very Good’ to ‘Very Bad’ and coded as [OQ], while the appropriateness was rated from ‘Not at All’ to ‘Perfectly’ and coded as [OA], as shown in Table A.1

To assess the affective aspect of soundscape quality, it is suggested in both ISO 12913-2 and ISO 12913-3 that a soundscape can be appraised via 8 affective attributes (i.e. *Eventful*, *Vibrant*, *Pleasant*, *Calm*, *Uneventful*, *Monotonous*, *Annoying*, *Chaotic*) to derive a weighted “pleasantness” and “eventfulness” score, which measures the perceived affective quality (PAQ) of a soundscape [28,30]. Since the generality of this affective model is still under examination [30], especially in indoor environments [36,37], its suitability is evaluated here in the context of indoor environments of healthcare facilities. The PAQ of the experienced surrounding sound environment was evaluated on a five-point "categorical scale from ‘Strongly Agree’ to ‘Strongly Disagree’ and coded as [PAQ:EVENT, PAQ:VIBRANT, PAQ:PLEAS, PAQ:CALM, PAQ:UNEVENT, PAQ:MONOT, PAQ:ANNOY, and PAQ:CHAOTIC], as shown in Table A.1 in Appendix A.

Lastly, the acoustic environment should be characterized by identifying and assessing perceived dominance as well as the perceived annoyance of sound sources [28]. A total of 8 sound source types were identified by the authors for evaluation in the survey, namely (1) human sounds – vocal, (2) human sounds – non-vocal, (3) mechanical ventilation sounds, (4) operational sounds – physical, (5) electronic sounds, (6) environmental sounds, (7) sounds of nature, and (8) medical device sounds. Participants were provided with examples of each sound source type in the questionnaire, as described in Table A.1 in Appendix A. The perceived dominance of the 8 pre-defined sound source types were evaluated on a five-item categorical scale from ‘Not at All’ to ‘Completely’. This is followed by the evaluation of the perceived annoyance on the same set of sound source types to examine the relation between dominance and annoyance using the same five-point scale, as shown in Table A.1. The sound source dominance and annoyance are coded as [VOCAL, NON-VOCAL, MECH, OPER, ELECTRON, ENV, NAT, and MED], wherein each variable is prefixed with [DOM:] or [ANONY:] respectively.

In consideration of the inherent length of occupancy across the three occupant groups, the acoustic environment was evaluated across independent timelines for each group. Hospital staff are considered long-term occupants and thus, their general perception of the acoustic environment should be assessed on a 12 month timeline. This is in line with recommendations in ISO/TS 15666, and WHO's timeline for assessment of burden of disease from environmental noise exposure [62,63]. Since the average length of hospitalization is about 5 days [64], and visitors are usually transient, the assessment time periods should be adjusted accordingly [62]. Hence, the hospital staff evaluated the surrounding sound environment based on recollection of a typical day in the last 12 months or so, whereas patients were instructed to assess the based on a typical day in the ward. The visitors assessed only the present surrounding sound environment during the questionnaire. The specific instructions pertaining to each occupant group across all questionnaire items are detailed in Table A.5 in Appendix A.

2.3 Participants

In total, 172 staff, 71 patients and 30 visitors answered the questionnaire. The demographics of the survey participants are a general reflection of the building occupant demographics, where the hospital staff are generally young (21-40 years old) and mostly females (21 male, 151 female); the patients are generally elderly (>50 years old) with slightly more females (30 male, 41 female); and the visitors are evenly distributed across the ages but mostly male (21 male, 9 female). Based on the Singapore Nursing Board's 2020 annual report, the male-female breakdown of registered nurses in Singapore was

11.6%-88.4%, matching the staff distribution in Table 1 almost exactly [65]. Only 5 of the patients surveyed had self-reported hearing loss, whereas participants across the board reported normal hearing ability. Three of the 5 patients reported hearing loss in one ear, whereas the other 2 reported hearing loss in both ears. Considering the advanced age of the 5 patients, with 4 of them greater than 60 years old and one between 51 and 60, all participants' data were included to accurately reflect the distribution of actual occupants.

Table 1: Summary of participants demographic data

		Staff	Patient	Visitors
Total		172	71	30
Hearing impaired (self-reported)		0	5	0
Gender	Male	21 (12.2%)	30 (42.3%)	21 (70%)
	Female	151 (87.8%)	41 (57.7%)	9 (30 %)
Age group	<21	2 (1.2%)	1(1.4%)	0 (0.0%)
	21-30	62 (36.0%)	2 (2.8%)	5 (16.7%)
	31-40	67 (39.0%)	9 (12.7%)	9 (30.0%)
	41-50	25 (14.5%)	7 (9.9%)	4 (13.3%)
	51-60	12 (7.0%)	14 (19.4%)	7 (23.3%)
	>60	4 (2.3%)	38 (52.8%)	5 (16.7%)

2.4 Data analysis

The reliability of survey subsections measuring latent constructs (i.e. INS, IEQ) was evaluated with both Cronbach's Alpha (α) and McDonald's Omega (ω) [66,67]. Due to the ordinal nature of the data, both α and ω were computed using polychoric correlations [68,69].

Mardia's multivariate normality tests in skewness and kurtosis were conducted for INS, IEQ, and PAQ [70–72], while Shapiro-Wilk's test was employed for each OQ variable (i.e. general overall quality and appropriateness). Owing to the lack of normality, the categorical nature of the responses and unequal group sample sizes, the differences between the hospital occupant groups on IEQ, OQ, and PAQ, SSD, and SSA were determined by the non-parametric Kruskal-Wallis (KW) test. Where significant differences between the groups were found, further examination was conducted via a pairwise comparison approach through the post hoc Dunn's test with Bonferroni correction.

All data analyses were conducted with the R programming language [73] on a 64-bit ARM environment.

3. RESULTS

3.1 Perceived indoor environmental quality across occupant groups

The tailored IEQ questionnaire was both reliable and internally consistent for each hospital occupant group ($\alpha > 0.7, \omega > 0.7$), as shown in . Since multivariate normality in skewness ($p \ll 0.001$) and kurtosis ($p \ll 0.001$) for all groups were violated, a non-parametric KW test was conducted to compare between groups. Results of the KW test suggests that a significant difference exists between groups for the IEQ factors ($p \ll 0.001$), with a large effect size ($\eta^2 \geq 0.14$), as summarized in Table 2.

A post hoc Dunn's test with Bonferroni correction unveiled a significant difference between staff and patient groups for all but thermal comfort (IEQ:TEMP), luminance levels (IEQ:LIGHT), visual comfort due to lighting (IEQ:VISCOMF), and noise levels (IEQ:NOISE). Staff and visitors were only significantly different ($p < 0.01$) on six factors, namely on sound privacy (IEQ:SOUNDPRIV, $p < 0.01$); amount of work and storage space (IEQ:SPACE, $p < 0.0001$); visual privacy (IEQ:VISPRIV, $p < 0.0001$); comfort of furnishings (IEQ:FURN, $p < 0.05$); colors (IEQ:COLOR, $p < 0.001$); and overall satisfaction of IEQ (IEQ:OVERALL, $p < 0.01$). Differences between patient and visitors were not significant across all IEQ items ($p > 0.05$). Results of the Dunn's test for the IEQ items are summarized in Table B.1 in Appendix B.

Table 2: Summary of Kruskal-Wallis test statistics (χ^2) and effect sizes (η^2) in each assessment category, where n is the total number of observations and k is the number of groups

Category	χ^2	n	k	p	p signif.	η^2	Effect size
Indoor environmental quality (IEQ)	39.23	273	3	3.03×10^{-9}	****	0.138	Moderate
Overall quality of the acoustic environment (OQ)	14.90	273	3	5.81×10^{-4}	***	0.048	Small
Overall appropriateness of the acoustic environment (OA)	38.80	273	3	3.76×10^{-9}	****	0.136	Moderate
Perceived affective quality (PAQ)	64.28	273	3	3.76×10^{-14}	****	0.231	Large
Sound source dominance (DOM)	36.41	273	3	1.24×10^{-8}	****	0.127	Moderate
Sound source annoyance (ANNOY)	94.07	273	3	3.04×10^{-22}	****	0.341	Large

Based on the ranked divergent bar plots of the IEQ responses, the staff exhibited more dissatisfaction in general, whereas the patient and visitors were generally satisfied with all IEQ factors, as shown in Figure 3, Figure 4, and Figure 5 for staff, patient and visitors, respectively. All three groups of hospital occupants were mostly satisfied with the cleanliness (IEQ:CLEAN) and cleaning services (IEQ:CLEANSERV). Both the staff and visitors felt that the lighting levels (IEQ:LIGHT) and visual comfort provided by the lightings (IEQ:VISCOMF) were the most satisfactory amongst other IEQ factors, whereas the patients felt otherwise.

Among the 16 IEQ factors, noise levels (IEQ:NOISE) and sound privacy (IEQ:SOUNDPRIV) were respectively ranked 13th and 16th by staff, 16th and 15th by patients, and 16th and 15th by visitors. Both the staff and visitors rated the comfort of the furnishings (IEQ:FURNISH) amongst the lowest. Moreover, some staff were dissatisfied with the amount of storage space (IEQ:SPACE) and visual privacy (IEQ:VISPRIV). It is also worth noting that a small number of patients were dissatisfied with the temperature (IEQ:TEMP), luminance (IEQ:LIGHT), and visual comfort due to lighting (IEQ:VISCOMF).

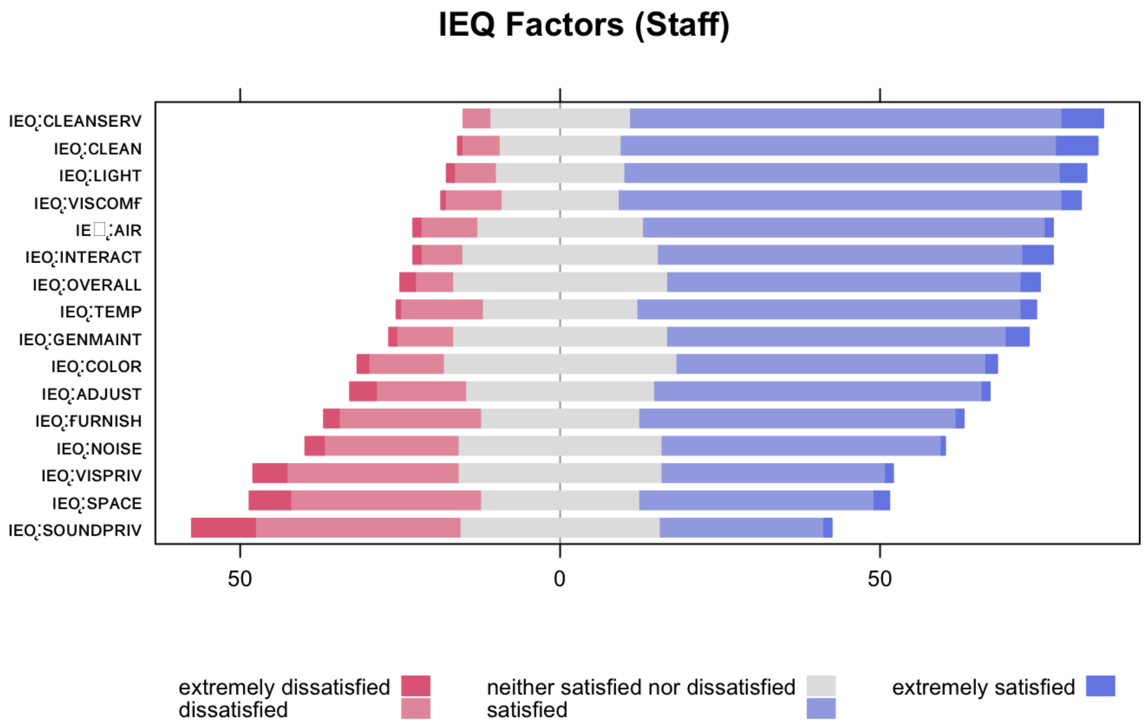


Figure 3: Divergent bar plots of staff IEQ responses ranked from top to bottom from most satisfied to most dissatisfied.

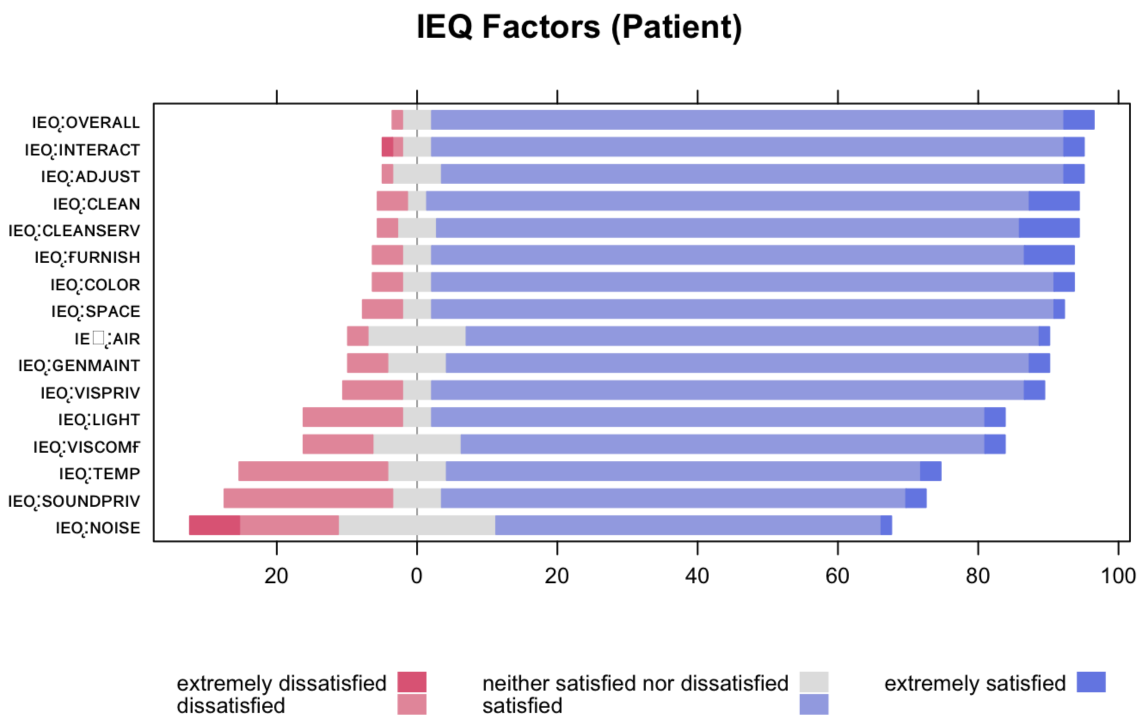


Figure 4: Divergent bar plots of patient IEQ responses ranked from top to bottom from most satisfied to most dissatisfied.

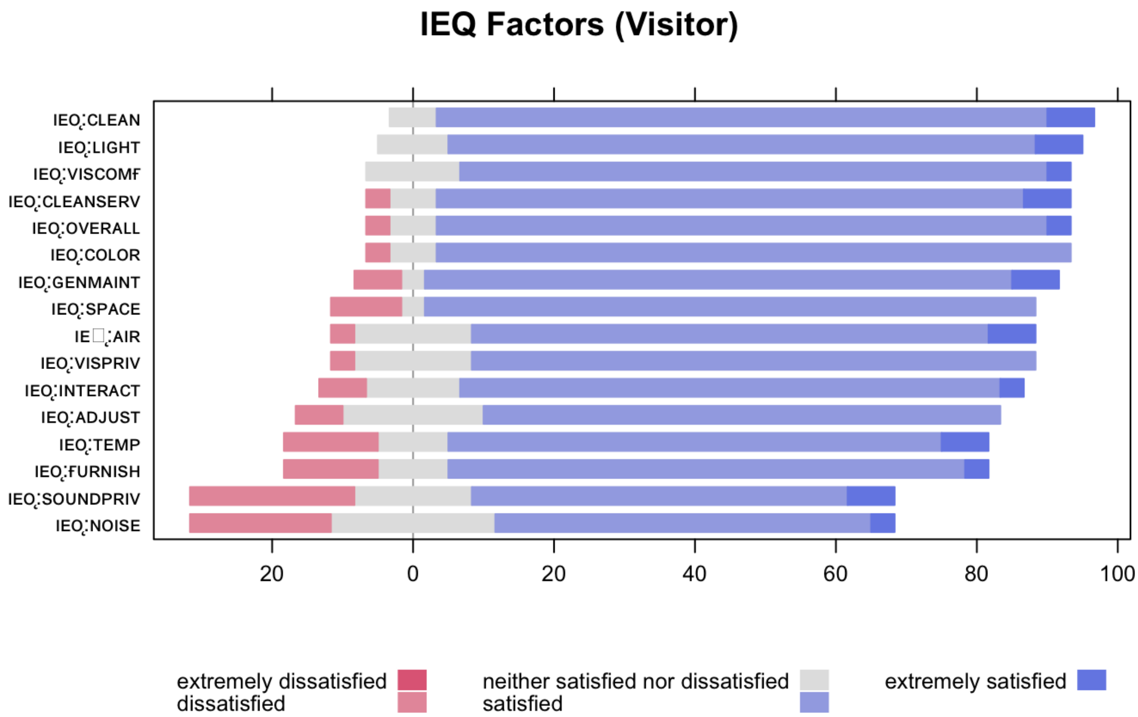


Figure 5: Divergent bar plots of visitor IEQ responses ranked from top to bottom from most satisfied to most dissatisfied.

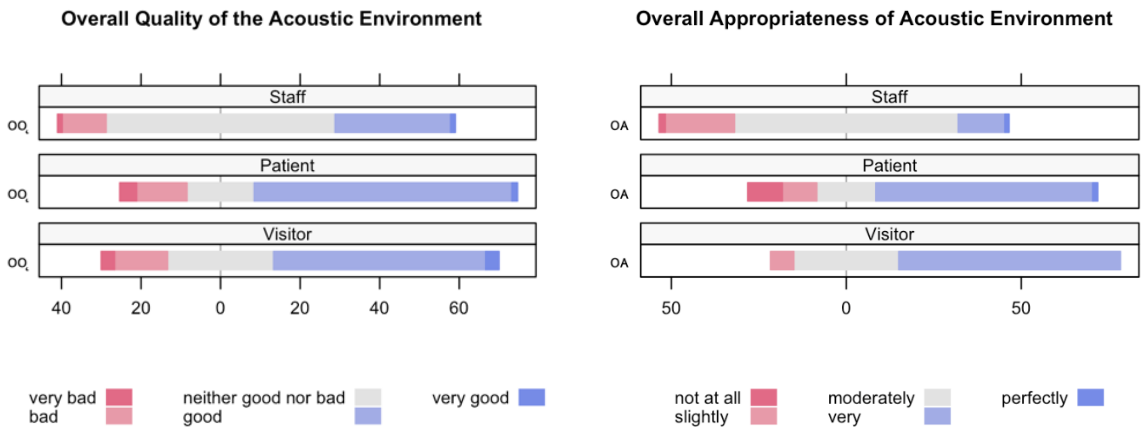
3.2 Overall quality and appropriateness of the acoustic environment

The acoustic environment was assessed based on overall perception of quality (i.e. OQ) and overall appropriateness (i.e. OA) as adapted from method A questionnaire part 3 and 4 in ISO 12913-2 [28], respectively. Shapiro-Wilk's test for normality showed that the responses were not normally distributed across all occupant groups ($p \ll 0.001$), for both OQ and OA, as shown in Table B.2 in Appendix B. Hence, a non-parametric KW test was employed to compare between groups independently for OQ and OA, as summarized in Table 2. Responses for OQ ($p = 5.81 \times 10^{-4} \ll 0.001$) and OA ($p = 3.76 \times 10^{-9} \ll 0.001$) were significantly different across groups. A small effect was observed for OQ ($\eta^2 = 0.048 < 0.06$), while a moderate effect was observed for OA ($\eta^2 = 0.136 < 0.14$).

To further examine the differences between the groups, a post hoc Dunn's test was conducted with Bonferroni correction. For OQ, a significant difference occurred only between staff and patient responses ($p < 0.001$), as detailed in Table B.3 in Appendix B.

However, significant differences were found between staff-patient ($p < 0.0001$) and staff-visitor ($p < 0.0001$) pairs for OA. These results reveal that the staff respondents felt that the appropriateness of the overall acoustic environment was significantly worse, as compared to the other occupant groups. This can also be observed visually in Figure 6(b).

The staff were mostly neutral when asked to describe the overall acoustic environment ($M = 3.18, SD = 0.63$), whereas both the patients ($M = 3.46, SD = 0.89$) and visitors ($M = 3.40, SD = 0.89$) rated mostly positively, as depicted in Figure 6(a). In terms of appropriateness, the staff felt that the overall acoustic environment was moderately inappropriate ($M = 2.92, SD = 0.67$), whereas patients ($M = 3.35, SD = 1.03$) and visitors ($M = 3.57, SD = 0.63$) felt otherwise, as shown in Figure 6(b).



(a) (b)

Figure 6: Distribution of responses in assessing the (a) overall quality and (b) overall appropriateness of the acoustic environment across all occupant groups.

3.3 Perceived affective quality of the acoustic environment

Following from the assessment of the overall acoustic environment, the perceived affective quality (PAQ) of the acoustic environment was assessed based on the circumplex model of soundscape quality as stated in ISO 12913-2. The respondents were asked to assess the PAQ for the experienced surrounding sound environments for all 8 affective attributes. Perception of the 8 attributes (PAQ:EVENT, PAQ:VIBRANT, PAQ:PLEAS, PAQ:CALM, PAQ:UNEVENT, PAQ:MONOT, PAQ:ANNOY, and PAQ:CHAOTIC) were evaluated from "Strongly Agree" to "Strongly Disagree" on a 5-point scale. The responses were recoded such that "Strongly Disagree" to "Strongly Agree" corresponded to a numeric rating of 1 to 5, respectively.

3.3.1 Perceived affective quality across occupant groups

Although multivariate normality in skewness ($p \ll 0.001$) and kurtosis ($p \ll 0.001$) was violated only for the staff and patient groups, all groups violated multivariate normality in the energy test with 100 bootstrap replicates ($p \ll 0.001$), as shown in Table B.4 in Appendix B. Hence, a non-parametric KW test was conducted to determine the difference in the perceived PAQ of the experienced acoustic environment between groups. A significant difference was found between the occupant groups ($p = 1.10 \times 10^{-14}$) with a large effect size ($\eta^2 = 0.231 > 0.14$), warranting a further investigation with a post hoc test, as summarized in Table 2.

The post hoc Dunn's test with Bonferroni correction revealed that there were significant differences ($p < 0.01$) between the staff and patient groups for PAQ:EVENT ($p < 0.0001$), PAQ:VIBRANT ($p < 0.0001$), PAQ:UNEVENT ($p < 0.0001$), PAQ:MONOT ($p < 0.01$), PAQ:ANNOY ($p < 0.0001$), and PAQ:CHAOTIC ($p < 0.0001$). However, significant differences were only observed between staff and visitors for PAQ:ANNOY ($p < 0.001$), PAQ:CHAOTIC ($p < 0.0001$), and albeit marginally for PAQ:CALM ($p < 0.05$). Between patient and visitors, there were no significant differences across all PAQ attributes except marginally for PAQ:VIBRANT (< 0.05). Overall, there is no significant difference between all groups for PAQ:PLEAS and PAQ:CALM, wherein all groups had a similar perception of pleasantness and calmness of their acoustic environment. Results of the Dunn's test are summarised in Table B.5 in Appendix B.

To prevent misinterpretation with the mean scores and to aid in visualization, median scores were computed from the kernel density estimate (KDE) of the probability density function, as shown in Table B.6. The median scores of the 8 attributes are visualized on the circumplex model [30,74], as shown in Figure 7. Although the perception of PAQ:PLEAS and PAQ:CALM was similar across the occupant groups, only the patients and visitors felt that the surrounding acoustic environment was predominantly pleasant and clam. Oddly, the staff respondents expressed neutrality across all 8 attributes.

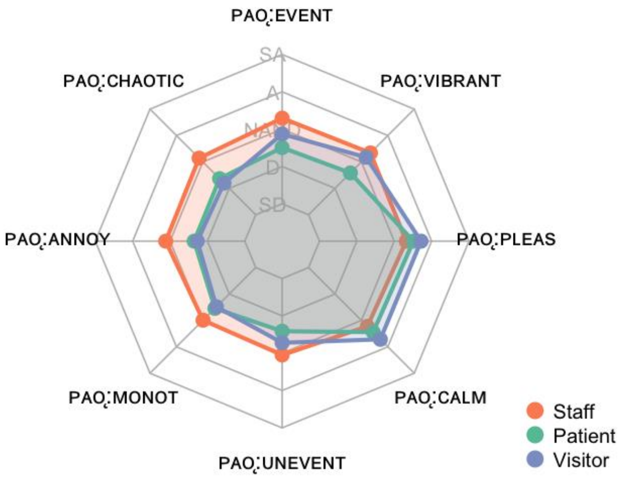


Figure 7: Median scores of the 8 perceived affective quality attributes across all occupant groups when assessing the acoustic environment. The Likert scale responses are indicated by their acronyms for brevity, i.e. "SD" representing "Strongly Disagree".

3.3.2 Integrity of the circumplex model for perceived affective quality of the hospital acoustic environment

To investigate the integrity of the underlying circumplex model of PAQ [30], tests of circumplexity based on correlations via the randomized test of hypothesized order relations (RTHOR) and sinusoidality are employed [75,76]. To form a circumplex model, the intercorrelations between variables must conform to a minimum criteria [75,76]. Ideally, correlations of adjacent variables, P_1, must be greater than the correlations of orthogonal variables, P_2, and in turn be greater than the correlations of variables 135° apart, P_3, which follows by being greater than correlations of opposing variables on the axes, P_4, i.e. $P_1 > P_2 > P_3 > P_4$. Specific correlation pairs (i.e. $r_{\text{EVENT,VIBRANT}}$) in each correlation parameter set are defined in Table 3, where the subscripts denote the 8 PAQ attributes and the categorical label (i.e. PAQ) has been dropped in this section for brevity. The computed polychoric correlation matrices for all three occupant groups are shown in Table 5, across all occupant groups. To aid in visualization, P_1 to P_4 correlations are denoted in blue, green, yellow, and red, respectively.

Table 3: Specific correlation pairs in each parameter set

Parameter	Correlation of variable pairs
P_1	$r_{\text{EVENT,VIBRANT}}$, $r_{\text{VIBRANT,PLEAS}}$, $r_{\text{PLEAS,CHAOTIC}}$, $r_{\text{CALM,UNEVENT}}$, $r_{\text{UNEVENT,MONOT}}$, $r_{\text{MONOT,ANNOY}}$, $r_{\text{ANNOY,CHAOTIC}}$, $r_{\text{CHAOTIC,EVENT}}$
P_2	$r_{\text{EVENT,PLEAS}}$, $r_{\text{VIBRANT,CALM}}$, $r_{\text{PLEAS,UNEVENT}}$, $r_{\text{CALM,MONOT}}$, $r_{\text{UNEVENT,ANNOY}}$, $r_{\text{MONOT,CHAOTIC}}$, $r_{\text{ANNOY,EVENT}}$, $r_{\text{CHAOTIC,VIBRANT}}$
P_3	$r_{\text{EVENT,CALM}}$, $r_{\text{VIBRANT,UNEVENT}}$, $r_{\text{PLEAS,MONOT}}$, $r_{\text{CALM,ANNOY}}$, $r_{\text{UNEVENT,CHAOTIC}}$, $r_{\text{MONOT,EVENT}}$, $r_{\text{ANNOY,VIBRANT}}$, $r_{\text{CHAOTIC,PLEAS}}$
P_4	$r_{\text{EVENT,UNEVENT}}$, $r_{\text{VIBRANT,MONOT}}$, $r_{\text{PLEAS,ANNOY}}$, $r_{\text{CALM,CHAOTIC}}$

Based on visual inspection, the correlation pairs did not meet the inequality criteria for circumplexity across all occupant groups, as observed in Table 5. For example, for staff, $r_{\text{VIBRANT,MONO}} = 0.10$ is a P4 quantity and $r_{\text{ANNOY,VIBRANT}} = 0.15$ is a P3 quantity, but $0.10 > 0.15$, which violates the requirement that P3 > P4. The degree of adherence to the inequality criteria is further tested through the RTHOR method, which computes a correspondence index (CI). The CI is a correlation coefficient that indicates the degree of circumplexity, wherein a CI of –1 indicates complete violation, 0 indicates chance, and that of 1.0 indicate a perfect fit. The resultant CI values indicated that there was an 72%

circumplexity fit ($p < 0.0001$) of the staff responses and an 63% fit ($p < 0.0001$) for both the patient and visitor responses, as shown in Table 4.

Table 4: Correspondence index (CI) from RTHOR across all occupant groups

Group	CI	p
Staff	0.72	3.97×10^{-4}
Patient	0.63	3.97×10^{-4}
Visitors	0.63	3.17×10^{-3}

To check for sinusoidality, the loadings on the first two components, i.e. pleasant-annoying (PLEAS-ANNOY) and eventful-uneventful (EVENT-UNEVENT), of the principal components analysis (PCA) of the correlations across the occupant groups were computed, and are shown in the last two columns of Table 5. Both components explained 57%, 57%, and 53% of the variance across staff, patient and visitor groups, respectively.

Table 5: Polychoric correlations and principal component analysis loadings across all occupant groups

Groups		Polychoric Correlations								Loadings	
		EVENT	VIBRANT	PLEAS	CALM	UNEVENT	MONOT	ANNOY	CHAOTIC	PLEAS-ANNOY	EVENT-UNEVENT
Staff	EVENT	1.00	P_1	P_2	P_3	P_4	P_3	P_2	P_1	0.49	0.16
	VIBRANT	0.53	1.00	P_1	P_2	P_3	P_4	P_3	P_2	0.65	0.15
	PLEAS	0.45	0.55	1.00	P_1	P_2	P_3	P_4	P_3	0.87	0.08
	CALM	0.25	0.29	0.60	1.00	P_1	P_2	P_3	P_4	0.78	0.09
	UNEVENT	-0.07	0.08	0.27	0.38	1.00	P_1	P_2	P_3	0.38	0.59
	MONOT	-0.02	0.10	0.13	0.18	0.55	1.00	P_1	P_2	0.16	0.79
	ANNOY	-0.03	-0.15	-0.34	-0.27	0.00	0.26	1.00	P_1	-0.53	0.64
	CHAOTIC	0.11	-0.10	-0.31	-0.41	-0.03	0.19	0.66	1.00	-0.53	0.61
Patients	EVENT	1.00	P_1	P_2	P_3	P_4	P_3	P_2	P_1	0.24	0.79
	VIBRANT	0.38	1.00	P_1	P_2	P_3	P_4	P_3	P_2	0.19	0.72
	PLEAS	-0.13	0.07	1.00	P_1	P_2	P_3	P_4	P_3	-0.79	0.14
	CALM	-0.16	-0.10	0.73	1.00	P_1	P_2	P_3	P_4	-0.87	0.02
	UNEVENT	-0.19	-0.04	-0.07	-0.04	1.00	P_1	P_2	P_3	0.17	-0.51
	MONOT	0.09	0.19	-0.28	-0.44	0.30	1.00	P_1	P_2	0.57	-0.06
	ANNOY	0.14	0.10	-0.55	-0.57	0.17	0.30	1.00	P_1	0.81	-0.07
	CHAOTIC	0.08	0.12	-0.50	-0.62	0.02	0.31	0.69	1.00	0.81	-0.02
Visitors	EVENT	1.00	P_1	P_2	P_3	P_4	P_3	P_2	P_1	0.26	0.67
	VIBRANT	0.55	1.00	P_1	P_2	P_3	P_4	P_3	P_2	0.19	0.87
	PLEAS	0.21	0.44	1.00	P_1	P_2	P_3	P_4	P_3	-0.27	0.70
	CALM	0.01	0.18	0.26	1.00	P_1	P_2	P_3	P_4	0.11	0.35
	UNEVENT	-0.09	-0.22	0.08	0.27	1.00	P_1	P_2	P_3	0.25	-0.20
	MONOT	0.17	0.30	-0.06	0.18	-0.02	1.00	P_1	P_2	0.77	0.23
	ANNOY	0.04	0.04	-0.31	-0.06	0.22	0.65	1.00	P_1	0.90	-0.18
	CHAOTIC	0.17	-0.02	-0.27	0.02	0.25	0.32	0.63	1.00	0.79	-0.18

In the PLEAS-ANNOY dimension of the staff responses, PLEAS and adjacent variables exhibited positive loadings, whereas ANNOY and adjacent variables (except MONOT) exhibited negative loadings; on the EVENT-UNEVENT dimension, EVENT and adjacent variables exhibited positive loadings, whereas UNEVENT and adjacent variables did not exhibit negative loadings. It is also important to note that the loadings of EVENT in the EVENT-UNEVENT dimension were lower than CHAOTIC.

In the PLEAS-ANNOY dimension of the patient responses, PLEAS and adjacent variables (except VIBRANT) did not exhibit positive loadings, whereas ANNOY and adjacent variables did not exhibit negative loadings; on the EVENT-UNEVENT dimension, EVENT and adjacent variables (except CHAOTIC) exhibited positive loadings, whereas UNEVENT and adjacent variables (except CALM) did not exhibit negative loadings.

Lastly, in the PLEAS-ANNOY dimension of the visitor responses, PLEAS did not exhibit a positive loading (its loading was -0.27), but variables adjacent to it did (the loadings for VIBRANT and CALM were 0.19 and 0.11, respectively). On the other hand, ANNOY (with a loading of 0.90) and variables adjacent to it (MONOT, CHAOTIC with respective loadings 0.77, 0.79) did not exhibit negative loadings; on the EVENT-UNEVENT dimension, EVENT and adjacent variables (except CHAOTIC) exhibited positive loadings, whereas UNEVENT exhibited negative loadings, but adjacent variables did not.

The mediocre CI values and a lack of sinusoidality in PCA component loadings across all occupant group responses indicate a lack of adherence toto the underlying circumplex model of perceived affective attributes.

3.4 Sound source dominance

To assess the subjective exposure to noise source types, the perceived dominance of acoustic sources was also assessed across the hospital occupant groups. Since multivariate normality was violated for all groups in terms of skewness, kurtosis and E-statistic, the KW test was employed to evaluate differences between the groups. A significant difference was observed ($p = 1.24 \times 10^{-8} \ll 0.0001$), with a moderate effect size ($\eta^2 = 0.127 < 0.14$), as shown in Table 2.

The post hoc Dunn's test revealed that there were significant differences between staff and patient response in the perception of electronic ($p < 0.0001$), environment ($p \ll 0.0001$), mechanical ($p \ll 0.0001$), medical ($p < 0.01$), nature ($p < 0.0001$), and non-vocal human ($p < 0.0001$) sound sources.

Between staff and visitors, significant differences were only observed for environment ($p < 0.001$), mechanical ($p < 0.01$), and medical ($p < 0.05$) sounds. No significant differences were observed amongst all groups for operational and vocalized human sounds. Moreover, there is insufficient evidence to suggest that there is a difference between the patient and visitor responses across all categories. Results of the Dunn's test are summarized in Table B.7 in Appendix B.

3.5 Sound source annoyance

The perceived annoyance of the same set of 8 sound sources was assessed following the assessment of their perceived dominance in the same context, and on the same 5-point rating scale. Based on multivariate normality tests, a KW test revealed a significant difference in perceived annoyance across occupant groups ($p = 3.04 \times 10^{-22} \ll 0.0001$) with a large effect size ($\eta^2 = 0.341 > 0.14$), as shown in Table 2.

Hence, a post hoc Dunn's pairwise comparison test with Bonferroni correction was conducted, as summarized in Table B.8. Strong evidence of difference was observed for all sound sources between staff and patients ($p \ll 0.0001$). Between staff and visitors, significant difference in perceived annoyance was observed for non-vocal and electronic sounds ($\ll 0.0001$); vocal, mechanical, operational and medical sounds (< 0.001); as well as nature sounds (< 0.01). No significant difference was observed between patients and visitors.

3.6 Individual noise sensitivity of hospital occupants

To evaluate the internal consistency or reliability of the 5NSS, both the Cronbach’s α and the McDonald’s ω were computed. The INS scores from the 5NSS appear to be only marginally reliable, as evaluated with McDonald’s ω using polychoric correlations, when considering all respondents as a single “hospital occupant” population ($\omega = 0.71 > 0.7$). Individually, the staff responses appear to be the noisiest ($\omega = 0.64$), followed by the patient responses ($\omega = 0.68$), whereas visitor responses were the most reliable ($\omega = 0.74$). The heavily attenuated Cronbach’s α scores for INS ($\alpha < 0.7$) indicates that there could a serious violation of tau-equivalence, and thus suggests that Cronbach's alpha should not be used as a reliability measure [67]. The abovementioned α and ω scores are summarized for INS for both the combined population (i.e. considering staff, patients and visitors as a whole) and individual occupant groups in .

Table 6: Cronbach’s alpha and McDonald’s omega of the groups of survey items based on polychoric correlation.

Survey Sections	Cronbach’s α (Ordinal)			McDonald’s ω (Ordinal)		
	Staff	Patient	Visitor	Staff	Patient	Visitor
Individual noise sensitivity		0.49			0.71	
	0.47	0.34	0.65	0.64	0.68	0.74
Indoor Environmental Quality	0.92	0.81	0.87	0.92	0.79	0.87

Considering the lack of reliability in the INS scores, no further statistical analyses were conducted. However, it is worth noting that the staff appeared to be more sensitive to noise than both the patient and visitor groups, as shown in the Likert distributions in in Appendix A.

4. DISCUSSION

The four research questions investigated in this study are discussed in the first four sub-sections in the abovementioned order in Section 1.

4.1 Satisfaction of acoustic quality

Based on the results from the IEQ questionnaire items in Section 3.1, it is apparent that the acoustic quality is the most dissatisfactory amongst all other indoor environmental factors. However, the most dissatisfactory factor amongst major IEQ factors, such as indoor air quality (IAQ), thermal comfort, and luminance, varies across other hospital environments. Recent IEQ evaluations in hospitals or healthcare facilities have reported greatest dissatisfaction in IAQ [38], thermal comfort [47], acoustic comfort [77], luminance [78], and even a lack of space [79].

Noise exposure and sound privacy were rated the most dissatisfactory among all IEQ factors within patient and visitor groups. The staff were the most dissatisfied with sound privacy and noise exposure among all three occupant groups. Notably, the dissatisfaction in noise exposure was similar between groups, whereas the staff exhibited significantly greater dissatisfaction in terms of sound privacy over patient and visitors. The greater dissatisfaction of sound privacy among hospital staff could be attributed to the awareness of difficulty in preserving the privacy of patients when discussing confidential matters in multi-bedded cohort rooms. The issue of sound privacy is greatly reduced in single-bedded rooms.

The dissatisfaction of acoustic quality across occupant groups corroborates with internal complaint data from the hospital, whereby most complaints are regarding noise-induced disturbances or speech privacy. This could be related to the large majority of patients being nursed in cohort rooms. Moreover, there is a greater scarcity of coping mechanisms or lower controllability with regards to the acoustics as opposed to other IEQ factors such as temperature or luminance.

4.2 Overall quality and appropriateness of acoustic environment

When asked to assess the overall quality (OQ) of the acoustic environment in terms of the overall quality and appropriateness, the staff and visitor occupant group exhibited similar neutral tendencies. Although the patient group rated the OQ to be significantly higher than staff, there was no difference between patient and visitor groups. The strong neutrality for staff and visitors and weak positive perception of overall quality in patients warrants further investigation and implementation of soundscape intervention measures to improve the OQ across all occupant groups.

In terms of overall perceived appropriateness (OA), the staff felt that the acoustic environment was significantly less appropriate than either the patients or visitors. Since the staff are experiencing the soundscape in the context of work, as compared to patients or visitors who are experiencing the soundscape for rest, relaxation, or recovery, this provides further evidence that the acoustic environment is not conducive for work and may potentially impact the quality and safety of healthcare delivered [6].

4.3 Generality of ISO 12913-3 circumplex model perceived affective quality

The results of RTHOR and analysis of the PCA loadings revealed that the responses did not adhere to the underlying circumplex model of PAQ in ISO 12913-3, across all occupant groups. This challenges the generality of the PAQ model in indoor environments, which corroborates with a recently proposed update to the ISO 12913-3 circumplex model for indoor residential living spaces [36].

However, the PAQ ratings are plausibly affected by the temporal scale of the assessment. Owing to stark differences in the occupancy period across all three groups, assessment time periods were adjusted accordingly to reflect the general response over the typical occupancy period, i.e. a typical day in the last 12 months for staff, a typical day in the ward for patients, and the present time for visitors. Even though this is a similar approach used in assessing community annoyance [62], and soundscapes in hospices [35], the long time scale (i.e. for the staff) poses an inherent challenge in an acute care setting, where a typical day could have soundscapes oscillating between opposing affective scales, e.g PAQ:CHAOTIC–PAQ:CALM, PAQ:EVENT–PAQ:UNEVENT. This is illustrated in the neutral tendencies in the staff responses across all PAQ attributes in Figure 7.

4.4 Sound source dominance and annoyance

For the ease of interpretability and visualisation, the Likert scores for dominance and annoyance were evaluated as a continuous distribution via the kernel density estimate (KDE), as shown in Figure 8. Overall, staff respondents perceived a greater dominance of environmental, mechanical, and medical sounds than both patients and visitors, whereas there was a similar perception of dominance for both patients and visitors across all sound sources. These significant differences in dominance reiterates the need for the investigation occupant-specific perceptions especially in acute healthcare facilities. Moreover, it is worth noting the neutrality in which the dominance of sound source was assessed in this study rather than the usual assessment of "noise" sources in hospital acoustics [11,43,80]. The assessment of noise sources carries a negative connotation and excludes all other sound sources that form the entire soundscape.

Based on the median scores in Table B.9, vocal sounds, followed by operational sounds, were perceived to be the two most dominant sound sources, and were similarly dominant across all occupant groups. Dominance of vocal sounds and operational sounds have also been commonly reported in geriatric wards [80], critical care wards [43], and general inpatient wards [11]. This dominance manifested as perceived annoyance in the staff responses, in which the staff were most annoyed by vocal followed by operational sounds. However, the dominance of vocal and operational sounds did not translate into notable annoyance for both patients and visitors. Even though both the patients and visitors did not appear to be annoyed by any sound source, it is worth noting that there were a small number of patients that felt completely annoyed by vocal, operational, and mechanical sounds.

Therefore, the dissatisfaction in the overall soundscape quality observed by the staff group in Section 3.2 could be attributed to perceived annoyance from vocal and operational sounds, especially in the work environment.

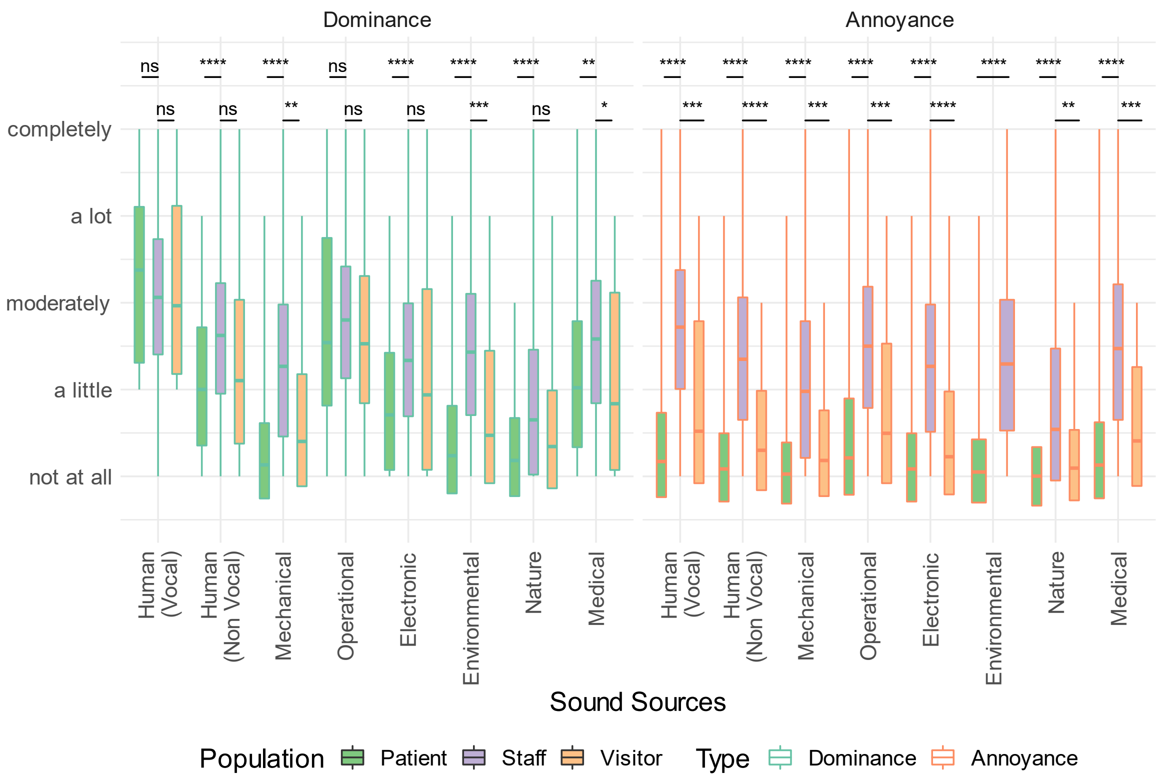


Figure 8: Summary statistics estimated with KDE for both the perceived dominance and annoyance of the sound sources across occupant groups. The asterisks indicate significance level of the Dunn's pairwise comparison test. Non-significance of patient-visitor pairs for both dominance and annoyance were omitted for conciseness.

4.5 Limitations and future work

Due to operational constraints in an acute-care hospital, the hospital staff were recruited via an internal messaging system to complete the survey. In contrast, the patients and visitors were recruited physically through ward visits, and the survey was administered via a tablet. Additional interaction with the investigator could thus be a confounding factor in the patient and staff responses.

The discrepancies in the evaluation time scale across all occupant groups could have affected the perception of the acoustic environment due to the dynamic environment of an acute hospital. However, it is worth noting that an "in situ" assessment approach for the visitor occupant group still did not yield adherence to the circumplexity of the PAQ attributes, albeit with a smaller sample size. Hence, the validity of the ISO 12913 PAQ attributes should be further examined for acute hospitals through in situ soundscape assessment methods with a larger population size.

From the literature, it is known that the acoustic environment can be significantly influenced by the layout of the rooms (i.e. single- or multi-bedded) or the patient types (e.g. geriatric, acute) [11,80]. Since most of the patients surveyed were from multi-bedded cohort rooms, the results cannot be generalized across all hospital ward types. It should be mentioned that patients in critical care wards are usually not in the right mental nor physical state for subjective evaluations. Thus, objective measurements may be the only viable method for soundscape evaluation in these scenarios.

For a holistic soundscape assessment, the quantitative approach should be combined with qualitative methods (e.g. interviews, focus group discussions), as well as physical metrics (e.g. psychoacoustic parameters, decibel measures) as suggested in ISO/TS 12913-3. Given that acoustic quality has been identified as the most dissatisfactory IEQ factor, measurement campaigns and qualitative studies would next be commissioned and tailored to address priority areas within the hospital. For instance, physical characteristics and occurrence rates of sound events should be investigated through measurements and interviews to address the staff's annoyance from the dominance of vocal and operational sounds. Future acoustic standards and design considerations for acute care hospitals would ideally be more robust when derived from such "triangulation" methodologies.

5. CONCLUSIONS

A survey was designed and administered electronically to obtain a baseline holistic perception of the acoustic environment in an acute-care hospital in Singapore, across major occupant groups (i.e. staff, patients, visitors). The survey was designed based on the industry-standard indoor environmental quality (IEQ) post-occupancy survey and the soundscape evaluation questionnaire in ISO 12913-2.

Among the 16 IEQ factors, all the occupant groups expressed the most dissatisfaction with sound levels and sound privacy, which holistically reaffirms the stereotype of poor acoustic quality in healthcare facilities. This dissatisfaction is further reflected in the similar neutral perception towards the overall quality of the acoustic environment, and the significantly lower mean rating of appropriateness in the staff group. The negative perception of the acoustic environment was mainly due to the perceived dominance and annoyance of vocal and operational sounds across all occupant groups. Overall, the staff were significantly more annoyed by vocal and operational sounds when compared to either patients or visitors.

This survey brought to light potential issues with two previously proposed psychometric measures for the perceptual evaluation of acoustic environments, i.e. individual noise sensitivity (INS) and perceived affective quality (PAQ). To minimize fatigue, a shortened 5-item version (5NSS) of the 21-item WNSS scale was adopted as a field-tested proxy. However, the INS responses within each occupant group and as a single population were found to be marginally unreliable based on the computed McDonald's omega. This indicates a high level of measurement noise in 5NSS and hence the 5NSS should be used with caution, at least for acute-care hospital occupants. In the assessment of the PAQ, analysis of the circumplexity of the responses by the RHTHOR and sinusoidality tests revealed that there is a lack of adherence to the underlying circumplex model. Hence, this survey provides additional evidence to the lack of applicability and validation of the PAQ attributes for indoor acoustic environments.

The combined approach of IEQ and soundscape assessment has highlighted the importance of acoustics in context of the entire indoor environmental quality. Moreover, there is a greater urgency to improve the work environment soundscape for medical staff in acute-care facilities. Nevertheless, any soundscape interventions with the emphasis of reducing the negative perception of vocal or operational sounds and the improvement of sound privacy would improve the overall impression of acoustic as well as the overall indoor environmental quality.

CRediT AUTHOR STATEMENT

Bhan Lam: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing; **Esther Monica Peijin Fan**: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing; **Kenneth Ooi**: Formal analysis, Validation, Writing – review & editing; **Zhen-Ting Ong**: Project administration, Resources, Writing – review & editing, **Joo Young Hong**: Conceptualization, Methodology, Writing – review & editing; **Woon-Seng Gan**: Resources, Supervision, Writing – review & editing; **Shin Yuh Ang**: Conceptualization, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing

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DATA AVAILABILITY

Replication data is available at [https://doi.org/10.21979/N9/YSQNDY], an institutional open access research data repository for Nanyang Technological University (NTU) based on the open-source web application, Dataverse [81].

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Appendix A Questionnaire items

Table A.1: Common questionnaire items across occupant groups

Question Category	Code	Specific Questions	Rating Scale (1–5)
Individual Noise Sensitivity (INS)	INS:SENSIT	'I am sensitive to noise'	Strongly Disagree–Strongly Agree
	INS:RELAX	'I find it difficult to relax in a place that's noisy'	
	INS:MAD	'I get mad at people who make noise that keeps me from falling asleep'	
	INS:ANNOY	'I get annoyed when my neighbours are noisy'	
	INS:USEDTO	'I get used to most noises without much difficulty'	
Overall quality (OQ)	OQ	Overall, how would you describe the surrounding sound environment?	Very Good–Very Bad
Overall appropriateness (OA)	OA	Overall, to what extent is the surrounding sound environment appropriate to its place?	Not at all–Perfectly
Perceived Affective Quality (PAQ)	PAQ:EVENT	Eventful	Strongly Agree–Strongly Disagree
	PAQ:VIBRANT	Vibrant	
	PAQ:PLEAS	Pleasant	
	PAQ:CALM	Calm	
	PAQ:UNEVENT	Uneventful	
	PAQ:MONOT	Monotonous	
	PAQ:ANNOY	Annoying	
	PAQ:CHAOTIC	Chaotic	
Sound Sources (Dominance)	DOM:VOCAL	Human sounds – vocal (e.g. voices, laughter, and sounds from individuals in the room/corridor)	Not at all–Completely
	DOM:NON-VOCAL	Human sounds – non-vocal (e.g. footsteps, clapping hands, hitting objects)	
	DOM:MECH	Mechanical ventilation sounds (e.g. fan/ air-conditioning)	
	DOM:OPER	Operational sounds – physical (e.g. door slamming, trolleys passing-by)	
	DOM:ELECTRON	Electronic sounds (e.g. TV, radio, music, other entertainment devices)	
	DOM:ENV	Environmental sounds (e.g. transportation noise, construction noise, sounds from people outside the building)	
	DOM:NAT	Sounds of nature (e.g. birdsongs, water sounds, rain, wind)	
	DOM:MED	Medical device sounds (e.g. alarms, ventilators, beep sound during scanning of the RFID tag before medication administration)	
Sound Sources (Annoyance)	ANNOY:VOCAL	Human sounds – vocal (e.g. voices, laughter, and sounds from individuals in the room/corridor)	Not at all–Completely
	ANNOY:NON-VOCAL	Human sounds – non-vocal (e.g. footsteps, clapping hands, hitting objects)	
	ANNOY:MECH	Mechanical ventilation sounds (e.g. fan/ air-conditioning)	
	ANNOY:OPER	Operational sounds – physical (e.g. door slamming, trolleys passing-by)	
	ANNOY:ELECTRON	Electronic sounds (e.g. TV, radio, music, other entertainment devices)	
	ANNOY:ENV	Environmental sounds (e.g.	

		transportation noise, construction noise, sounds from people outside the building)	
	ANNOY:NAT	Sounds of nature (e.g. birdsongs, water sounds, rain, wind)	
	ANNOY:MED	Medical device sounds (e.g. alarms, ventilators, beep sound during scanning of the RFID tag before medication administration)	

Table A.2: Occupant specific questionnaire items for indoor environment quality (Staff)

Question Category	Code	Specific Questions	Rating Scale (1–5)
Indoor Environmental Quality (IEQ)	IEQ:TEMP	The temperature in your room.	Extremely Dissatisfied–Extremely Satisfied
	IEQ:AIR	The air quality in your workspace (i.e stuffy/stale air, cleanliness, odours).	
	IEQ:LIGHT	The amount of light in your workspace.	
	IEQ:VISCOMF	The visual comfort of the lighting.	
	IEQ:NOISE	The noise level in your workspace.	
	IEQ:SOUNDPRIV	The sound privacy in your workspace (ability to have conversations without others overhearing). E.g. If you speak to one patient, you can be sure that the next patient is not able to overhear the conversation.	
	IEQ:SPACE	The amount of space available for individual work and storage.	
	IEQ:VISPRIV	The level of visual privacy. E.g. If you are using the COW, you can be sure that nobody is able to look at the confidential information on your screen.	
	IEQ:INTERACT	Ease of interaction with co-workers.	
	IEQ:FURNISH	The comfort of your office furnishings (chair, desk, computer, equipment, etc.).	
	IEQ:ADJUST	The ability to adjust your furniture to meet your needs. Eg. Height of the COW, height and position of the furniture.	
	IEQ:COLOR	The colours and textures of flooring, furniture and surface finishes.	
	IEQ:CLEAN	The general cleanliness of the environment.	
	IEQ:CLEANSERV	The cleaning service provided for your workplace?	
	IEQ:GENMAINT	General maintenance of the building.	
	IEQ:OVERALL	Overall, how satisfied are you with your work environment?	

Table A.3: Occupant specific questionnaire items for indoor environment quality (Patients)

Question Category	Code	Specific Questions	Rating Scale (1–5)
Indoor Environmental Quality (IEQ)	IEQ:TEMP	The temperature in your room.	Extremely Dissatisfied–Extremely Satisfied
	IEQ:AIR	The air quality in your room (i.e stuffy/stale air, cleanliness, odours).	
	IEQ:LIGHT	The amount of light in your room.	
	IEQ:VISCOMF	The visual comfort of the lighting.	
	IEQ:NOISE	The noise level in your room.	
	IEQ:SOUNDPRIV	The sound privacy in your room (ability to have conversations without your neighbours overhearing and vice versa).	
	IEQ:SPACE	The amount of space available for you, your visitors and for storage.	
	IEQ:VISPRIV	The level of visual privacy.	
	IEQ:INTERACT	The ease of interaction with visitors/medical staff.	
	IEQ:FURNISH	The comfort of your room furnishings (bed, over-bed table, chair, etc.).	
	IEQ:ADJUST	The adjustability of your furniture to meet your needs.	
	IEQ:COLOR	The colours and textures of flooring, furniture and surface finishes.	
	IEQ:CLEAN	The general cleanliness of the environment.	
	IEQ:CLEANSERV	The cleaning service provided for your room	
	IEQ:GENMAINT	General maintenance of the building.	
	IEQ:OVERALL	All things considered, how satisfied are you with your personal bed space?	

Table A.4: Occupant specific questionnaire items for indoor environment quality (Visitors)

Question Category	Code	Specific Questions	Rating Scale (1–5)
Indoor Environmental Quality (IEQ)	IEQ:TEMP	The temperature in your room.	Extremely Dissatisfied–Extremely Satisfied
	IEQ:AIR	The air quality in your room (i.e stuffy/stale air, cleanliness, odours).	
	IEQ:LIGHT	The amount of light in your room.	
	IEQ:VISCOMF	The visual comfort of the lighting.	
	IEQ:NOISE	The noise level in your room.	
	IEQ:SOUNDPRIV	The sound privacy in your room (ability to have conversations without your neighbours overhearing and vice versa).	
	IEQ:SPACE	The amount of space available for you, your visitors and for storage.	
	IEQ:VISPRIV	The level of visual privacy.	
	IEQ:INTERACT	The ease of interaction with visitors/medical staff.	
	IEQ:FURNISH	The comfort of your room furnishings (bed, over-bed table, chair, etc.).	
	IEQ:ADJUST	The adjustability of your furniture to meet your needs.	
	IEQ:COLOR	The colours and textures of flooring, furniture and surface finishes.	
	IEQ:CLEAN	The general cleanliness of the environment.	
	IEQ:CLEANSERV	The cleaning service provided for your room	
	IEQ:GENMAINT	General maintenance of the building.	
	IEQ:OVERALL	All things considered, how satisfied are you with your personal bed space?	

Table A.5: Specific instructions for all questionnaire items in each occupant group

Variable	Code	Occupant group	Instructions
Individual Noise Sensitivity	INS:SENSIT INS:RELAX INS:MAD INS:ANNOY INS:USEDTO	Staff Patient Visitor	To what extent you disagree/agree with the following sentences?
Indoor Environmental Quality	IEQ:TEMP IEQ:AIR IEQ:LIGHT IEQ:VISCOMF IEQ:NOISE IEQ:SOUNDPRIV IEQ:SPACE IEQ:VISPRIV IEQ:INTERACT IEQ:FURNISH IEQ:ADJUST IEQ:COLOR IEQ:CLEAN IEQ:CLEANSERV IEQ:GENMAINT IEQ:OVERALL	Staff	For all the following questions, please answer while thinking of a typical day in the workplace. Thinking about the last (12 months or so)… Please state to what extent you are dissatisfied/satisfied with the following:
		Patient	For all the following questions, please answer while thinking of a typical day in the room. Please state to what extent you are dissatisfied/satisfied with the following:
		Visitor	For all the following questions, please answer while thinking about the present surrounding sound environment. Please state to what extent you are dissatisfied/satisfied with the following:
Overall quality and appropriateness of the acoustic environment	OQ OA	Staff	For all the following questions, please answer while thinking of a typical day in the workplace. Thinking about the last (12 months or so) … Please state to what extent you are dissatisfied/satisfied with the following:
		Patient	For all the following questions, please answer while thinking of a typical day in the room. Please state to what extent you are dissatisfied/satisfied with the following:
		Visitor	For all the following questions, please answer while thinking about the present surrounding sound environment. Please state to what extent you are dissatisfied/satisfied with the following:
Perceived Affective Quality	PAQ:EVENT PAQ:VIBRANT PAQ:PLEAS PAQ:CALM PAQ:UNEVENT PAQ:MONOT PAQ:ANNOY PAQ:CHAOTIC	Staff	Thinking about the last (12 months or so), for each of the 8 scales below, to what extent do you agree or disagree that the surrounding sound environment you experienced was …
		Patient	For each of the 8 scales below, to what extent do you agree or disagree that the surrounding sound environment you experienced in a typical day was…
		Visitor	For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is…
Sound Sources (Dominance)	DOM:VOCAL DOM:NON-VOCAL DOM:MECH DOM:OPER DOM:ELECTRON DOM:ENV DOM:NAT	Staff	Thinking about the last (12 months or so), to what extent the following sound sources were dominant …
		Patient	In a typical day, to what extent the following sound sources were dominant …
		Visitor	To what extent do you presently hear the following sound sources…

	DOM:MED		
Sound Sources (Annoyance)	ANNOY:VOCAL ANNOY:NON-VOCAL ANNOY:MECH ANNOY:OPER ANNOY:ELECTRON ANNOY:ENV ANNOY:NAT ANNOY:MED	Staff	Thinking about the last (12 months or so), to what extent the following sound sources annoyed you …
		Patient	In a typical day, to what extent the following sound sources annoyed you …
		Visitor	To what extent the following sound sources annoyed you …

Appendix B Results of statistical tests

Table B.1: Summary of Dunn's test with Bonferroni correction for indoor environmental quality

Variables	Group 1	Group 2	Z	p	p (adjusted)	p signif.
IEQ:ADJUST	Patient	Staff	-5.84	5.36×10^{-9}	1.61×10^{-8}	****
IEQ:ADJUST	Patient	Visitor	-1.78	7.46×10^{-2}	2.24×10^{-1}	ns
IEQ:ADJUST	Staff	Visitor	2.20	2.79×10^{-2}	8.37×10^{-2}	ns
IEQ:AIR	Patient	Staff	-2.96	3.06×10^{-3}	9.18×10^{-3}	**
IEQ:AIR	Patient	Visitor	0.07	9.41×10^{-1}	1.00	ns
IEQ:AIR	Staff	Visitor	2.19	2.83×10^{-2}	8.50×10^{-2}	ns
IEQ:CLEAN	Patient	Staff	-2.79	5.31×10^{-3}	1.59×10^{-2}	*
IEQ:CLEAN	Patient	Visitor	0.08	9.34×10^{-1}	1.00	ns
IEQ:CLEAN	Staff	Visitor	2.08	3.76×10^{-2}	1.13×10^{-1}	ns
IEQ:CLEANSERV	Patient	Staff	-2.80	5.12×10^{-3}	1.53×10^{-2}	*
IEQ:CLEANSERV	Patient	Visitor	-0.30	7.65×10^{-1}	1.00	ns
IEQ:CLEANSERV	Staff	Visitor	1.67	9.54×10^{-2}	2.86×10^{-1}	ns
IEQ:COLOR	Patient	Staff	-5.83	5.50×10^{-9}	1.65×10^{-8}	****
IEQ:COLOR	Patient	Visitor	-0.27	7.87×10^{-1}	1.00	ns
IEQ:COLOR	Staff	Visitor	3.86	1.13×10^{-4}	3.40×10^{-4}	***
IEQ:FURNISH	Patient	Staff	-6.12	9.37×10^{-10}	2.81×10^{-9}	****
IEQ:FURNISH	Patient	Visitor	-1.57	1.16×10^{-1}	3.47×10^{-1}	ns
IEQ:FURNISH	Staff	Visitor	2.63	8.51×10^{-3}	2.55×10^{-2}	*
IEQ:INTERACT	Patient	Staff	-4.18	2.94×10^{-5}	8.82×10^{-5}	****
IEQ:INTERACT	Patient	Visitor	-1.18	2.39×10^{-1}	7.17×10^{-1}	ns
IEQ:INTERACT	Staff	Visitor	1.68	9.24×10^{-2}	2.77×10^{-1}	ns
IEQ:LIGHT	Patient	Staff	-0.95	3.44×10^{-1}	1.00	ns
IEQ:LIGHT	Patient	Visitor	1.36	1.74×10^{-1}	5.22×10^{-1}	ns
IEQ:LIGHT	Staff	Visitor	2.17	2.99×10^{-2}	8.97×10^{-2}	ns
IEQ:GENMAINT	Patient	Staff	-3.88	1.03×10^{-4}	3.09×10^{-4}	***
IEQ:GENMAINT	Patient	Visitor	0.55	5.83×10^{-1}	1.00	ns
IEQ:GENMAINT	Staff	Visitor	3.37	7.45×10^{-4}	2.24×10^{-3}	**
IEQ:NOISE	Patient	Staff	-1.32	1.86×10^{-1}	5.58×10^{-1}	ns
IEQ:NOISE	Patient	Visitor	0.28	7.76×10^{-1}	1.00	ns
IEQ:NOISE	Staff	Visitor	1.26	2.09×10^{-1}	6.28×10^{-1}	ns
IEQ:OVERALL	Patient	Staff	-5.34	9.31×10^{-8}	2.79×10^{-7}	****
IEQ:OVERALL	Patient	Visitor	-0.50	6.20×10^{-1}	1.00	ns
IEQ:OVERALL	Staff	Visitor	3.26	1.11×10^{-3}	3.32×10^{-3}	**
IEQ:SOUNDPRIV	Patient	Staff	-5.16	2.42×10^{-7}	7.27×10^{-7}	****
IEQ:SOUNDPRIV	Patient	Visitor	-0.31	7.55×10^{-1}	1.00	ns
IEQ:SOUNDPRIV	Staff	Visitor	3.34	8.44×10^{-4}	2.53×10^{-3}	**
IEQ:SPACE	Patient	Staff	-6.81	9.67×10^{-12}	2.90×10^{-11}	****
IEQ:SPACE	Patient	Visitor	-0.44	6.58×10^{-1}	1.00	ns
IEQ:SPACE	Staff	Visitor	4.37	1.25×10^{-5}	3.74×10^{-5}	****
IEQ:TEMP	Patient	Staff	-0.64	5.21×10^{-1}	1.00	ns
EQ:TEMP	Patient	Visitor	0.95	3.43×10^{-1}	1.00	ns
EQ:TEMP	Staff	Visitor	1.50	1.33×10^{-1}	4.00×10^{-1}	ns
IEQ:VISCOMF	Patient	Staff	-0.72	4.73×10^{-1}	1.00	ns
IEQ:VISCOMF	Patient	Visitor	1.11	2.69×10^{-1}	8.06×10^{-1}	ns
IEQ:VISCOMF	Staff	Visitor	1.73	8.38×10^{-2}	2.51×10^{-1}	ns
IEQ:VISPRIV	Patient	Staff	-6.84	7.86×10^{-12}	2.36×10^{-11}	****

IEQ:VISPRIV	Patient	Visitor	-0.43	6.70 × 10−1	1.00	ns
IEQ:VISPRIV	Staff	Visitor	4.41	1.04 × 10−5	3.13 × 10−5	****

Table B.2: Shapiro-Wilks test for normality for OQ and OA

Variable	Population Group	p
OQ	Staff	1.49×10^{-13}
	Patient	4.50×10^{-14}
	Visitor	1.38×10^{-10}
OA	Staff	1.93×10^{-10}
	Patient	1.59×10^{-4}
	Visitor	8.28×10^{-7}

Table B.3: Pairwise comparison of OQ1 and OQ2 using Dunn's test with Bonferroni correction

Variable	Occupant Group 1	Occupant Group 2	Z	$p^{\wedge}$	Significance
OQ	Patient	Staff	-3.67	7.41×10^{-4}	***
	Patient	Visitor	-0.603	1	ns
	Staff	Visitor	1.95	0.154	ns
OA	Patient	Staff	-5.1	1.01×10^{-6}	****
	Patient	Visitor	0.836	1	ns
	Staff	Visitor	4.56	1.55×10^{-5}	****

^with Bonferroni correction

Table B.4: Multivariate normality tests for skewness, kurtosis and energy for perceived affective quality (PAQ) of the experienced environment.

		Skewness		Kurtosis		Energy	
Variable	Group	p	Sig.	p	Sig.	p	Sig.
PAQ	Staff	0	****	0	****	2.2×10^{-6}	****
PAQ	Patient	6.99×10^{-11}	****	6.03×10^{-8}	****	2.2×10^{-6}	****
PAQ	Visitor	0.084	ns	0.61	ns	2.2×10^{-6}	****

Table B.5: Summary of Dunn's test with Bonferroni correction for perceived affective quality

Variables	Group 1	Group 2	*Z*	*p*	*p* (adjusted)	*p* signif.
PAQ:ANNOY	Patient	Staff	5.03	4.87 × 10−7	1.46 × 10−6	****
PAQ:ANNOY	Patient	Visitor	-0.32	7.53 × 10−1	1.00	ns
PAQ:ANNOY	Staff	Visitor	-3.93	8.35 × 10−5	2.51 × 10−4	***
PAQ:CALM	Patient	Staff	-0.79	4.27 × 10−1	1.00	ns
PAQ:CALM	Patient	Visitor	1.86	6.24 × 10−2	1.87 × 10−1	ns
PAQ:CALM	Staff	Visitor	2.62	8.85 × 10−3	2.66 × 10−2	*
PAQ:CHAOTIC	Patient	Staff	5.13	2.85 × 10−7	8.56 × 10−7	****
PAQ:CHAOTIC	Patient	Visitor	-0.92	3.58 × 10−1	1.00	ns
PAQ:CHAOTIC	Staff	Visitor	-4.67	3.00 × 10−6	8.99 × 10−6	****
PAQ:EVENT	Patient	Staff	4.98	6.38 × 10−7	1.91 × 10−6	****
PAQ:EVENT	Patient	Visitor	1.21	2.27 × 10−1	6.82 × 10−1	ns
PAQ:EVENT	Staff	Visitor	-2.22	2.63 × 10−2	7.89 × 10−2	ns
PAQ:MONOT	Patient	Staff	3.06	2.21 × 10−3	6.64 × 10−3	**
PAQ:MONOT	Patient	Visitor	0.08	9.34 × 10−1	1.00	ns
PAQ:MONOT	Staff	Visitor	-2.09	3.65 × 10−2	1.10 × 10−1	ns
PAQ:PLEAS	Patient	Staff	-0.64	5.23 × 10−1	1.00	ns
PAQ:PLEAS	Patient	Visitor	1.15	2.50 × 10−1	7.50 × 10−1	ns
PAQ:PLEAS	Staff	Visitor	1.72	8.51 × 10−2	2.55 × 10−1	ns
PAQ:UNEVENT	Patient	Staff	5.23	1.67 × 10−7	5.02 × 10−7	****
PAQ:UNEVENT	Patient	Visitor	1.89	5.81 × 10−2	1.74 × 10−1	ns
PAQ:UNEVENT	Staff	Visitor	-1.65	9.99 × 10−2	3.00 × 10−1	ns
PAQ:VIBRANT	Patient	Staff	5.78	7.57 × 10−9	2.27 × 10−8	****
PAQ:VIBRANT	Patient	Visitor	2.57	1.01 × 10−2	3.02 × 10−2	*
PAQ:VIBRANT	Staff	Visitor	-1.29	1.98 × 10−1	5.95 × 10−1	ns

Table B.6: Mean and standard deviation (SD), and median and interquartile range (IQR) values across 8 perceived affective quality attributes across all occupant groups.

Attribute	Mean ± SD			Median (IQR)		
	Staff	Patient	Visitor	Staff	Patient	Visitor
PAQ:EVENT	3.32 ± 0.64	2.72 ± 0.91	2.93 ± 1.01	3.29 (2.77 to 3.88)	2.51 (1.91 to 3.60)	2.87 (2.03 to 3.84)
PAQ:VIBRANT	3.35 ± 0.69	2.69 ± 0.77	3.13 ± 0.94	3.34 (2.77 to 3.95)	2.58 (1.99 to 3.34)	3.18 (2.26 to 3.96)
PAQ:PLEAS	3.33 ± 0.73	3.32 ± 0.89	3.53 ± 0.82	3.32 (2.75 to 3.95)	3.51 (2.57 to 4.09)	3.72 (2.95 to 4.20)
PAQ:CALM	3.23 ± 0.74	3.24 ± 0.92	3.6 ± 0.72	3.23 (2.64 to 3.86)	3.45 (2.45 to 4.04)	3.72 (3.07 to 4.20)
PAQ:UNEVENT	3.04 ± 0.67	2.52 ± 0.71	2.83 ± 0.87	3.05 (2.51 to 3.58)	2.41 (1.88 to 3.09)	2.72 (2.03 to 3.65)
PAQ:MONOT	2.99 ± 0.77	2.68 ± 0.79	2.70 ± 0.88	2.99 (2.39 to 3.57)	2.55 (1.96 to 3.35)	2.49 (1.92 to 3.50)
PAQ:ANNOY	3.13 ± 0.84	2.56 ± 0.84	2.5 ± 0.82	3.12 (2.46 to 3.80)	2.36 (1.86 to 3.13)	2.27 (1.82 to 3.06)
PAQ:CHAOTIC	3.14 ± 0.87	2.55 ± 0.79	2.37 ± 0.76	3.14 (2.50 to 3.83)	2.37 (1.87 to 3.12)	2.20 (1.75 to 2.83)

Table B.7: Summary of Dunn's test with Bonferroni correction for perceived sound source dominance

Variables	Group 1	Group 2	Z	p	p (adjusted)	p signif.
DOM:ELECTRON	Patient	Staff	4.27	1.93×10^{-5}	5.79×10^{-5}	****
DOM:ELECTRON	Patient	Visitor	1.43	1.52×10^{-1}	4.57×10^{-1}	ns
DOM:ELECTRON	Staff	Visitor	-1.47	1.41×10^{-1}	4.24×10^{-1}	ns
DOM:ENV	Patient	Staff	7.78	7.26×10^{-15}	2.18×10^{-14}	****
DOM:ENV	Patient	Visitor	1.61	1.07×10^{-1}	3.21×10^{-1}	ns
DOM:ENV	Staff	Visitor	-3.77	1.61×10^{-4}	4.84×10^{-4}	***
DOM:MECH	Patient	Staff	7.58	3.33×10^{-14}	9.98×10^{-14}	****
DOM:MECH	Patient	Visitor	1.67	9.50×10^{-2}	2.85×10^{-1}	ns
DOM:MECH	Staff	Visitor	-3.57	3.57×10^{-4}	1.07×10^{-3}	**
DOM:MED	Patient	Staff	3.44	5.90×10^{-4}	1.77×10^{-3}	**
DOM:MED	Patient	Visitor	-0.09	9.28×10^{-1}	1.00	ns
DOM:MED	Staff	Visitor	-2.55	1.08×10^{-2}	3.24×10^{-2}	*
DOM:NAT	Patient	Staff	4.60	4.17×10^{-6}	1.25E-05	****
DOM:NAT	Patient	Visitor	1.32	1.85×10^{-1}	5.56×10^{-1}	ns
DOM:NAT	Staff	Visitor	-1.82	6.81×10^{-2}	2.04×10^{-1}	ns
DOM:NON-VOCAL	Patient	Staff	4.29	1.81×10^{-5}	5.44×10^{-5}	****
DOM:NON-VOCAL	Patient	Visitor	0.76	4.48×10^{-1}	1.00	ns
DOM:NON-VOCAL	Staff	Visitor	-2.22	2.63×10^{-2}	7.89×10^{-2}	ns
DOM:OPER	Patient	Staff	0.73	4.63×10^{-1}	1.00	ns
DOM:OPER	Patient	Visitor	-0.51	6.11×10^{-1}	1.00	ns
DOM:OPER	Staff	Visitor	-1.08	2.79×10^{-1}	8.36×10^{-1}	ns
DOM:VOCAL	Patient	Staff	-1.42	1.55×10^{-1}	4.64×10^{-1}	ns
DOM:VOCAL	Patient	Visitor	-0.80	4.23×10^{-1}	1.00	ns
DOM:VOCAL	Staff	Visitor	0.13	8.94×10^{-1}	1.00	ns

Table B.8: Summary of Dunn's test with Bonferroni correction for perceived sound source annoyance

Variables	Group 1	Group 2	Z	p	p (adjusted)	p signif.
ANNOY:VOCAL	Staff	Visitor	-4.13	3.65×10^{-5}	1.09×10^{-4}	***
ANNOY:VOCAL	Patient	Staff	8.33	8.33×10^{-17}	2.50×10^{-16}	****
ANNOY:VOCAL	Patient	Visitor	1.64	0.10	0.30	ns
ANNOY:NON-VOCAL	Staff	Visitor	-4.89	1.00×10^{-6}	3.01×10^{-6}	****
ANNOY:NON-VOCAL	Patient	Staff	8.99	2.44×10^{-19}	7.33×10^{-19}	****
ANNOY:NON-VOCAL	Patient	Visitor	1.38	0.17	0.50	ns
ANNOY:MECH	Staff	Visitor	-3.99	6.74×10^{-5}	2.02×10^{-4}	***
ANNOY:MECH	Patient	Staff	8.06	7.50×10^{-16}	2.25×10^{-15}	****
ANNOY:MECH	Patient	Visitor	1.60	0.11	0.33	ns
ANNOY:OPER	Staff	Visitor	-3.90	9.26×10^{-5}	2.78×10^{-4}	***
ANNOY:OPER	Patient	Staff	7.00	2.61×10^{-12}	7.82×10^{-12}	****
ANNOY:OPER	Patient	Visitor	0.98	0.33	0.98	ns
ANNOY:ELECTRON	Staff	Visitor	-4.40	1.06×10^{-5}	3.19×10^{-5}	****
ANNOY:ELECTRON	Patient	Staff	8.35	6.69×10^{-17}	2.01×10^{-16}	****
ANNOY:ELECTRON	Patient	Visitor	1.41	0.16	0.48	ns
ANNOY:ENV	Patient	Staff	9.02	1.88×10^{-19}	1.88×10^{-19}	****
ANNOY:NAT	Staff	Visitor	-3.47	5.18×10^{-4}	1.56×10^{-3}	**
ANNOY:NAT	Patient	Staff	6.99	2.80×10^{-12}	8.39×10^{-12}	****
ANNOY:NAT	Patient	Visitor	1.37	0.17	0.51	ns
ANNOY:MED	Staff	Visitor	-4.14	3.43×10^{-5}	1.03×10^{-4}	***
ANNOY:MED	Patient	Staff	7.74	9.67×10^{-15}	2.90×10^{-14}	****
ANNOY:MED	Patient	Visitor	1.25	0.21	0.63	ns

Table B.9: Mean and standard deviation, and median and interquartile range values across 8 sound sources for perceived dominance and annoyance across all occupant groups. Median scores were computed via KDE with a bandwidth of 0.5.

Attribute	Mean ± SD			Median (IQR)		
	Staff	Patient	Visitor	Staff	Patient	Visitor
DOM:VOCAL	3.06 ± 0.84	3.25 ± 1.00	3.17 ± 1.15	3.38 (2.31 + 4.10)	3.06 (2.40 + 3.73)	2.97 (2.18 + 4.12)
DOM:NON-VOCAL	2.59 ± 0.80	2.08 ± 0.89	2.27 ± 1.11	2.00 (1.36 + 2.72)	2.62 (1.95 + 3.23)	2.10 (1.38 + 3.03)
DOM:MECH	2.23 ± 0.89	1.30 ± 0.72	1.60 ± 0.86	1.13 (0.74 + 1.61)	2.27 (1.46 + 2.98)	1.40 (0.89 + 2.18)
DOM:OPER	2.78 ± 0.84	2.75 ± 1.13	2.63 ± 1.03	2.54 (1.82 + 3.75)	2.80 (2.13 + 3.42)	2.53 (1.84 + 3.31)
DOM:ELECT	2.34 ± 0.82	1.85 ± 0.92	2.17 ± 1.23	1.71 (1.07 + 2.42)	2.34 (1.69 + 2.99)	1.94 (1.08 + 3.16)
DOM:ENV	2.41 ± 0.89	1.41 ± 0.77	1.73 ± 0.98	1.24 (0.80 + 1.81)	2.43 (1.71 + 3.10)	1.47 (0.92 + 2.45)
DOM:NAT	1.78 ± 0.87	1.25 ± 0.47	1.50 ± 0.78	1.18 (0.77 + 1.67)	1.65 (1.02 + 2.46)	1.34 (0.86 + 1.99)
DOM:MED	2.56 ± 0.92	2.13 ± 0.98	2.10 ± 1.18	2.02 (1.34 + 2.79)	2.58 (1.84 + 3.25)	1.84 (1.07 + 3.12)
ANNOY:VOCAL	2.71 ± 0.90	1.49 ± 1.07	1.83 ± 1.05	1.17 (0.76 + 1.73)	2.72 (2.01 + 3.38)	1.52 (0.92 + 2.79)
ANNOY:NON-VOCAL	2.37 ± 0.90	1.24 ± 0.73	1.47 ± 0.73	1.09 (0.71 + 1.50)	2.35 (1.65 + 3.06)	1.30 (0.84 + 1.99)
ANNOY:MECH	2.02 ± 0.89	1.10 ± 0.48	1.37 ± 0.72	1.03 (0.69 + 1.39)	1.98 (1.21 + 2.79)	1.18 (0.77 + 1.76)
ANNOY:OPER	2.50 ± 0.89	1.58 ± 1.10	1.73 ± 0.94	1.21 (0.79 + 1.90)	2.50 (1.79 + 3.18)	1.50 (0.92 + 2.53)
ANNOY:ELECT	2.26 ± 0.89	1.23 ± 0.68	1.50 ± 0.90	1.09 (0.71 + 1.50)	2.27 (1.51 + 2.98)	1.23 (0.79 + 1.98)
ANNOY:ENV	2.30 ± 0.93	1.14 ± 0.54	NA	1.05 (0.70 + 1.43)	2.29 (1.53 + 3.03)	NA
ANNOY:NAT	1.74 ± 0.90	1.00 ± 0.00	1.23 ± 0.63	1.00 (0.66 + 1.34)	1.54 (0.95 + 2.47)	1.09 (0.72 + 1.54)
ANNOY:MED	2.47 ± 1.02	1.39 ± 0.96	1.60 ± 0.81	1.13 (0.75 + 1.62)	2.47 (1.65 + 3.21)	1.41 (0.89 + 2.26)

Appendix C Individual noise sensitivity scores

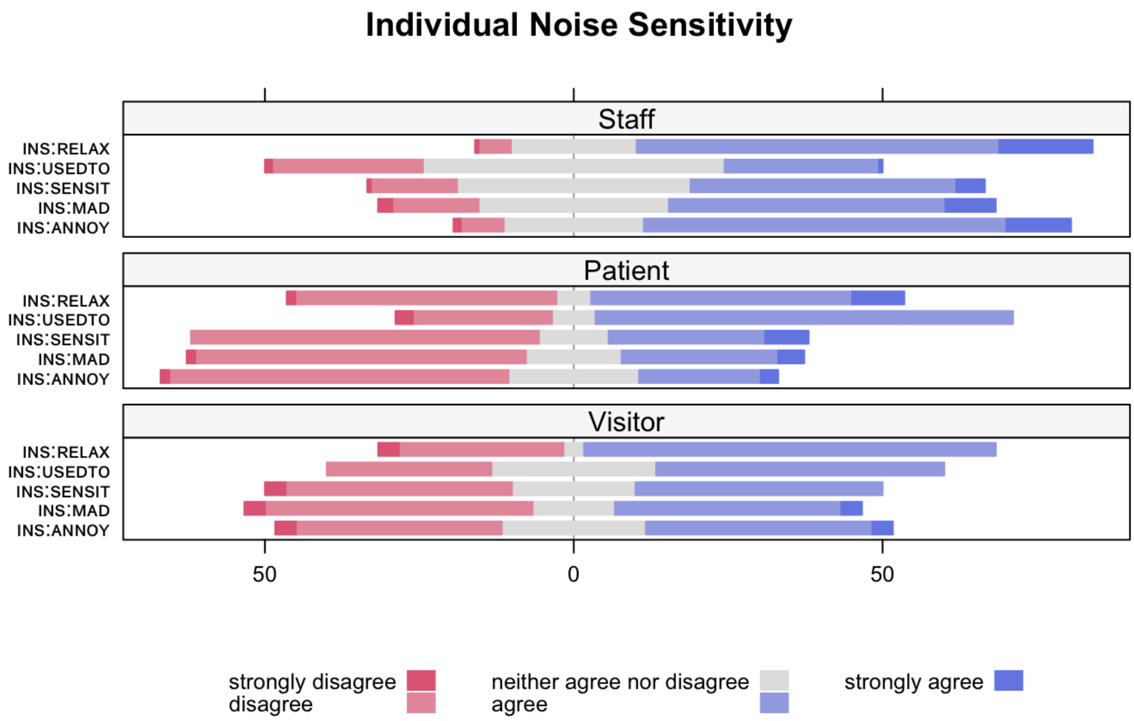

Figure C.1: Divergent bar plots of the INS scores represented by the 5NSS items by occupant groups.