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Research Article

Voice use of nurses working in the intensive care unit during the COVID-19 pandemic

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A R T I C L E I N F O

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A B S T R A C T

Objective: This study aimed to investigate the voice use of nurses working in intensive care units (ICUs) and their perception of acoustic environments.
Setting and sample: The research was conducted in four different hospitals in China during the COVID-19 pandemic. A total of 60 ICU nurses were recruited for their voice use monitoring and 100 nurses participated in the survey.
Research methodology: Firstly, voice-related parameters such as voice level (SPL, dB), fundamental frequency (F0, Hz), and voicing time percentage (Dt, %) were measured using a vocal monitor. To collect data, a non-invasive accelerometer was attached to the participants' necks during their working hours. Secondly, the perception of the ICU acoustic environment was assessed using semantic differential.
Results: The results showed that nurses spoke approximately 0.9–4 dB louder to patients and colleagues in ICUs compared to quiet rooms, and their fundamental frequency (F0) significantly increased during work. The voice levels of nurses were influenced by background noise levels, with a significant correlation coefficient of 0.44 ($p < 0.01$). Furthermore, the background noise levels ranged from 58.1 to 73.9 dBA, exceeding the guideline values set by the World Health Organisation (WHO). The semantic differential analysis identified 'Stress' and 'Irritation' as the two main components, indicating the prevalence of negative experiences within ICUs.
Implications for clinical practice: This study highlights the potential risk of voice disorders among ICU nurses. The findings also underscore the importance of implementing strategies to reduce noise levels in ICUs to reduce voice disorders among nurses.

Introduction

Voice is a fundamental aspect of human communication and connection, playing a crucial role in social and professional settings. Over the past two to three decades, there has been an increasing focus on voice disorders (Rosen et al., 2020). These disorders can lead to significant psychological responses and may be influenced by the surrounding environment. Specifically, the post-COVID-19 pandemic period has highlighted the impact of factors such as noise environments and the use of face masks (Yi et al., 2021; Lin et al., 2021; Abo-Hasseba et al., 2017;31:508. e11-.). For instance, previous studies (Heider et al., 2021; Bottalico et al., 2020; Magee et al., 2020) have examined the effects of wearing different types of face masks on voice in various settings, including classrooms and hospitals. Additionally, high levels of background noise have been found to significantly affect voice intensity, fundamental frequency, and speech duration (Summers et al., 1988). Pearsons et al. (1977) investigated how background noise in classrooms can affect the voice levels of teachers. Rantala et al. (2015) also reported that teachers tend to speak louder in noisy environments, and their ability to cope with vocal loading diminishes in the presence of activity noise. Elevated background noise levels pose a significant risk factor for the development of occupational voice disorders in individuals with vocally demanding professions (Verdolini and Ramig, 2001).

González-Gamboa et al. (2022) emphasised that the risk factors and prevalence of voice disorders depend on how vocal problems are defined. Therefore, various voice-related parameters, such as sound pressure level (SPL), fundamental frequency (F0, Hz), percentage of phonation time (Dt, %), and vocal effort, have been widely used to determine the ergonomics of speech and communication interference (González-Gamboa et al., 2022; Cutiva et al., 2017;31:120. e1-.; Bottalico and Astolfi, 2012). Many studies have shown a significant increase in habitual F0 and voice SPL following prolonged voice use in noise

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environments (Hill et al., 1988; Byeon, 2019; Nusseck et al., 2018). For example, Nusseck *et al.* (Nusseck et al., 2018) reported a strong correlation between the teacher's voice SPL, F0, and classroom noise level. Stone Jr and Sharf (Stone and Sharf, 1973) investigated perceptual deviations in the voices of 10 men during a 20-minute vowel reading task conducted at various pitch and intensity levels. Negative vocal changes were observed to occur most rapidly during high-pitched phonation, while no significant findings were noted in relation to intensity. However, most studies have primarily focused on specific occupations, such as school teachers, without addressing healthcare workers.

It is well-known that hospital environments have high levels of background noise (Hampton et al., 2023:kqad109.). In particular, the intensive care unit (ICU) is one of the noisiest departments in hospitals, and several studies (Imbriaco et al., 2022; MacKenzie and Galbrun, 2007; Song et al., 2022) have demonstrated that noise levels in ICUs exceed the guidance levels set by the World Health Organisation (WHO). Therefore, nurses working in the ICUs are exposed to high background noise levels and at risk of voice problems. However, there have been no previous attempts to explore the specific voice problems faced by ICU nurses, and there is limited research investigating their perception of the acoustic environments within ICUs. Kebapcı and Güner (2021) reported human-induced noise negatively affected healthcare provider's communication within the ICU from a qualitative study. Azzahra et al. (2017) conducted a study evaluating the perception of the ICU acoustic environment using nine attributes as part of a soundscape approach. However, this research was carried out at a single hospital with a very small sample size ($N = 20$). Therefore, it is necessary to investigate how ICU nurses speak and how they perceive the acoustic environments within ICUs in a more comprehensive manner.

The present study aims to investigate the voice use of nurses and the psychological responses elicited by the noise environment in ICUs. Firstly, a total of 60 nurses from four different ICUs attended voice monitoring measurements to assess voice-related parameters using an objective approach. A non-invasive accelerometer was attached to each participant's neck during working hours. Secondly, questionnaire surveys were conducted to analyse self-reported perceptions of the acoustic environments in the ICUs using as a subjective approach. Fifteen attributes were utilised to assess the perceptual dimensions of ICU acoustic environments. Subsequently, the study examined the associations between the objective voice-related parameters and the subjective responses.

Methods

Objectives

This study had two primary objectives. First, it aimed to investigate how nurses utilised their voices in ICUs with elevated noise levels. This was accomplished by monitoring the voices of nurses during both daytime and nighttime shifts, and comparing their voice use characteristics across the sites, and contrasting voice uses in quiet rooms with those in ICUs. Secondly, the study sought to gauge nurses' perceptions of the noise environment in ICUs. To achieve this objective, a questionnaire survey was conducted to gather their views on the acoustic environment within ICUs. Subsequently, the study explored the associations between these perceptions and the voice use characteristics of the nurses.

Setting

This study was conducted at four hospitals in Chongqing, China, selected from a pool of 13 ICUs in the same city (Chongqing). The selection was based on various characteristics, including size, year of construction, and management types. Site A, established in 1937 and unrenovated, is the oldest ICU and comprises one 2-bedded room, one 5-bedded room, and one 6-bedded room. Site B, renovated in 1997, is the largest, with two 1-bedded rooms, one 2-bedded room, two 6-bedded rooms, and one 10-bedded room. Site C, built in 1985, consists of one 10-bedded room. Site D, renovated in 2006, features one 18-bedded room and two 1-bedded rooms. Among the sites, Site D boasts the most updated equipment. In terms of staffing models, Sites A and C are semi-closed ICUs managed by ICU physicians and professionals. On the other hand, Sites B and D are considered closed ICUs, where patients are under the care of full-time ICU staff.

This study involved monitoring the voice usage of 60 nurses and administering a questionnaire survey to 100 nurses. All participants who underwent voice use monitoring also participated in the questionnaire survey. Moreover, all participants were female nurses. This gender composition was not intentional but rather due to the absence of male nurses in these hospitals. This shortage of male nurses is primarily because less than 3 % of registered nurses in China are males (Gao et al., 2023).

Participants

A total of 60 participants (15 from each hospital, all females) with self-reported normal hearing took part in the voice use monitoring. The sample size was basically determined based on the number of available ICU nurses. For example, Site A, the smallest ICU, has a total of 23 nurses. It was assumed that at least 50 % of these nurses would voluntarily participate in this study. To ensure the consistency in participant numbers across the sites, 15 participants were selected from each site for comparative purposes. This sample size exceeds the 45 participants required to achieve a statistical power of 0.8 for a paired-samples *t*-test, as calculated using G*Power software. The socio-demographic and professional characteristics of the participants are presented in Table 1. The participants were aged between 25 and 37 years (mean: 31.6, SD: 3.7). Most of them (95 %) held the job title of a registered nurse and were responsible for providing direct care to patients in the ICU,

Table 1
Characteristics of nurses who took part in the vocal use monitoring.

Personal characteristics	Site A ($N = 15$)	Site B ($N = 15$)	Site C ($N = 15$)	Site D ($N = 15$)	Total ($N = 60$)
Sex					
Male	0	0	0	0	0
Female	15	15	15	15	60
Age (years)					
20–25	0	0	0	0	0
25–30	3	5	2	3	13
30–35	11	7	12	12	42
>35	1	3	1	0	5
Job title					
Nurse manager	0	1	0	1	2
Clinical nurse	0	0	0	0	0
Charge nurse	0	1	0	0	1
Registered nurse	15	13	15	14	57
Working area					
Nurse station	2	5	2	4	13
ICU wards	13	10	13	11	47
Years of working					
<1	0	0	0	0	0
1–2	0	0	0	0	0
2–5	1	1	2	4	8
5–10	11	12	9	7	39
>10	3	2	4	4	13
Hours of working per week					
<40	0	0	0	0	0
40–50	11	9	11	9	40
51–60	4	5	4	6	19
>60	0	1	0	0	1
Hours of wearing a face mask a day					
1–4	0	0	0	0	0
4–8	0	0	0	0	0
8–12	15	15	15	15	60

working in rotating shifts. Furthermore, majority of them had worked for ICU more than 5 years (86 %), and all participants wore the face mask for more than eight hours each day. The majority of beds in the four ICUs were dedicated to general surgery, cancer, and respiratory disease.

For the questionnaire survey, 100 participants were recruited from four hospitals, which also included the participants of the voice use monitoring study. Specifically, there were 20 participants from Site A, 40 from Site B, 20 from Site C, and 20 from Site D. The increase in sample size was possible because more nurses expressed interests in the questionnaire survey. Consequently, Sites B, C, and D recruited 20 nurses each, while Site B, the largest ICU with 63 nurses, recruited 40 participants. This sample size also exceeds the 84 participants required to achieve a statistical power of 0.8 for a correlation analysis, as calculated using G*Power software. The socio-demographic and professional characteristics of these participants are comparable to those of the voice monitoring participants and are provided in Supplementary Table S1. Notably, there was a greater representation of nurses with various job titles, such as clinical nurse and charge nurse, compared to the participants in the voice monitoring study.

Data collection

The voice use monitoring was carried out using the Vocal Holter Med (VHM) device, which consists of a piezoelectric contact microphone (model HX-505–1-1) and a data acquisition and processing (DAP) unit. The contact microphone was positioned at the neck with a collar and connected to a data logger. The contact microphone is designed to be insensitive to background noise in the monitoring room (Carullo et al., 2013). A calibration process was conducted to accurately estimate the sound pressure level using a sound calibrator (Type 4231, B&K). During calibration, participants vocalised the /a/ phoneme at increasing intensity until reaching their loudest voice. The calibration microphone was placed in front of the participant at a distance of 22 cm. Following calibration, the vocal device provided information on the fundamental frequency (F0, Hz), phonation time percentage (Dt, %), and vocal sound pressure level (dB). The fundamental frequency represents the rate at which the vocal cords vibrate, determining the pitch of the sound produced. A higher fundamental frequency corresponds to a higher perceived pitch, and a lower frequency corresponds to a lower perceived pitch. The f(0) was measured in Hertz (Hz), representing a range of frequencies from low to high. Phonation time percentage represents the proportion of time spent phonating during the total recording time. Sound pressure level (SPL) is a measure of sound intensity and is directly associated with the perceived loudness of sound. SPL is typically measured in decibels (dB), and when A-weighting function is applied, it is denoted as dBA. A-weighting function approximates the sensitivity of the human ear to different frequencies. In general, SPLs in the range of 0 to 40 dB are considered quiet to very quiet, while levels between 60 and 80 dB are generally described as noisy. In the present study, the voice levels produced by nurses were measured in terms of unweighted sound pressure level and were denoted as dB. Voice SPL refers to vocal effort levels at a distance of 1 m from the mouth and was converted from the levels measured at the output of the contact microphone. These parameters are pertinent for investigating voice-related issues in ICU nurses because they are measured using a contact microphone placed on the nurses' necks over an extended time period. Furthermore, these parameters have been extensively utilised in various occupations, including teachers (Bottalico and Astolfi, 2012) and conductors (Trinite et al., 2022). The DAP unit embedded an audio microphone that measured background noise while the nurses didn't speak. Thus, long-term background noise levels during working shifts were measured while the DAP unit was attached to a belt in front of the body and was not covered by clothing. The background noise level was measured in terms of A-weighted equivalent sound pressure level (L_{Aeq}).

This study analysed nurses' voices under two different conditions. Firstly, participants were asked to engage in a dialogue task ("pre-monitoring") before each monitoring session. For this task, nurses were instructed to have a conversation for a maximum of five minutes with another nurse, discussing a topic they were knowledgeable about. The dialogue took place in a quiet room, with the nurses using normal conversational voices without raising the pitch or volume. Secondly, occupational voice use was analysed while the nurses were working ("entire monitoring"). Prior to the formal measurement, eight nurses (two from each hospital) underwent a training measurement to assess potential factors that could impact the results. The findings revealed that vocal parameter measurements were affected during dining times (12:30–13:30 and 17:00–18:00) and shift times (08:00, 16:00, and 20:00). Additionally, nurses displayed different vocal behaviours during night-time to ensure patients' sleep compared to daytime. Furthermore, most nurses displayed similar vocal patterns in the morning and afternoon. As a result, measurements were conducted during daytime (08:00–12:00) and night-time (21:00–01:00), carefully avoiding dining and shift times. Each participant was involved in one set of measurements during a daytime shift and another during a night-time shift, without any repetitions.

The questionnaire consisted of two main parts: 1) basic information, including demographic and 2) perception of the acoustic environment. Firstly, participants were asked about their sex, age, and other personal information such as smoking and alcohol consumption history. Additionally, they were asked about any past or current experience with asthma and respiratory allergies. Secondly, a five-point scale (-2 to 2) semantic differential was employed to understand how nurses perceive the acoustic environments of the ICU. Mackrill et al. (2013) developed and validated 15 adjectives for measuring individual perceptual responses to the hospital noise environment through a questionnaire survey and listening tests. In the present study, those 15 adjectives were used, assuming that these adjectives could be effectively employed to assess the sound environments within ICUs.

Ethical considerations

This study was approved by the ethics committee of the University of Liverpool (approval number: 7984). The participants were informed about the study in advance and gave their written consent to participate in the study. Specifically, those interested in the study received a participant information sheet (PIS) and were given at least one week to consider their participation. The PIS made it clear that participation was voluntary, and participants were free to withdraw at any time without the need for an explanation or any adverse consequences. It was also mentioned in the PIS that wearing a voice monitoring device during their shifts might result in a minor level of discomfort or annoyance. Furthermore, all the data were anonymised after the completion of data collection.

Data analysis

Statistical analyses were conducted using SPSS-25 software (SPSS Inc., Chicago, IL) and Minitab 20. Analysis of variance (ANOVA) was employed to assess differences in voice parameters across the sites. Paired-samples *t*-test was also used to determine the differences in voice parameters between two measurements sessions. Correlation analysis was then performed to examine the relationships between objective measures and subjective ratings. To reduce the dimensionality of the adjectives and establish perceptual attributes, principal components analysis (PCA) was utilised. A rotational factor model was applied to visually represent the variables and create a perceptual framework. The reliability of the scales was assessed using Cronbach's test to ensure participants accurately understood them.

Results

Vocal-related parameters

The mean values of all voice parameters during entire monitoring (i.e., four hours) and pre-monitoring (i.e., simple dialogue for five minutes) across different sites are presented in Table 2. One-way ANOVA was performed to examine differences across the hospitals, and the results are summarised in the last column. For entire monitoring, the mean SPL values ranged from 75.3 dB to 76.9 dB, while the median SPL values varied between 75.8 dB and 77.6 dB. Site A exhibited the lowest mean F0 (246.9 Hz), whereas the highest mean F0 (280.3 Hz) was observed at Site B. The measured Dt values ranged from 6.3 % to 11.6 %, indicating that the nurses' phonating time was very limited. Among the four sites, Site B had the highest SPLs and F0 values. The ANOVA results confirmed significant differences across the sites, except for the standard deviations of SPL and F0. During pre-monitoring, the SPL values were slightly lower compared to those measured during the four-hour monitoring. For example, the mean SPL varied from 70.1 dB to 73.9 dB. Similarly, the mean values of F0 during pre-monitoring were lower than those in the entire monitoring. However, the Dt values during pre-monitoring were higher because the nurses had free dialogue with their colleagues. In contrast to entire monitoring, a significant difference across the sites was only found for mean F0 during pre-monitoring since all the measurements were conducted in quiet rooms.

Differences between entire monitoring and pre-monitoring were calculated for the parameters and sites. The differences in mean SPLs varied slightly across the sites. Site A exhibited the smallest difference in mean SPL, which was less than 1 dB, while nurses at Site B spoke approximately 4 dB louder than in a quiet room. Similarly, the smallest difference in mean F0 was found in Site A, but Site C had the largest difference of 79 Hz. Paired-samples t-tests were conducted for all the data from the four sites to investigate if the measurements in the two sessions were significantly different. The results revealed that the mean values of SPL, F0, and Dt for the two sessions were statistically different for all the sites ($p < 0.01$). This implies that the differences in mean SPLs were statistically significant, even though the increases in mean SPLs were generally below 3 dB, except for Site B, where the increase was just noticeable.

Fig. 1 displays boxplots illustrating the levels of voice and background noise during the day and night. The boxplots represent the 25th,

Table 2
Mean values of voice-related parameters across the sites. F0 and Dt represent fundamental frequency and phonation time percentages, respectively.

	Site A $N = 15$	Site B $N = 15$	Site C $N = 15$	Site D $N = 15$	One-way ANOVA results
Entire monitoring (EM)					
SPL, median (dB)	76.7	77.6	77.0	75.8	$F(3,56) = 10.210$, $p < 0.001$
SPL, mean (dB)	75.3	76.9	75.9	76.5	$F(3,56) = 6.612$, $p = 0.001$
SPL, SD (dB)	3.4	3.8	3.1	3.4	$F(3,56) = 1.328$, $p = 0.274$
F0, mean (Hz)	246.9	280.3	266.7	276.7	$F(3,56) = 281.169$, $p < 0.001$
F0, SD (Hz)	60.0	62.7	57.5	61.3	$F(3,56) = 0.852$, $p = 0.471$
Dt [%]	7.1	11.6	6.3	9.3	$F(3,56) = 3.957$, $p < 0.05$
Pre-monitoring (PM)					
SPL, median (dB)	74.8	73.0	75.2	74.5	$F(3,56) = 1.239$, $p = 0.304$
SPL, mean (dB)	70.1	72.9	72.0	73.9	$F(3,56) = 0.569$, $p = 0.569$
SPL, SD (dB)	3.7	3.2	2.60	3.4	$F(3,56) = 1.730$, $p = 0.171$
F0, mean (Hz)	226.5	233.2	195.5	197.6	$F(3,56) = 3.159$, $p < 0.05$
F0, SD(Hz)	25.8	24.2	39.4	31.8	$F(3,56) = 2.533$, $p = 0.066$
Dt [%]	37.5	40.3	42.2	38.1	$F(3,56) = 1.717$, $p = 0.174$
EM-PM					
SPL, median (dB)	1.9	4.6	2.5	3.6	$F(3,56) = 12.543$, $p < 0.001$
SPL, mean (dB)	0.9	4.0	2.0	2.4	$F(3,56) = 7.876$, $p < 0.001$
SPL, SD (dB)	−0.3	0.6	0.0	−0.5	$F(3,56) = 1.566$, $p = 0.208$
F0, mean (Hz)	20.4	47.1	79.0	71.2	$F(3,56) = 18.013$, $p < 0.001$
F0, SD(Hz)	34.2	38.5	34.9	29.9	$F(3,56) = 0.925$, $p = 0.435$
Dt [%]	−30.5	−28.7	−28.8	−34.6	$F(3,56) = 2.614$, $p = 0.060$

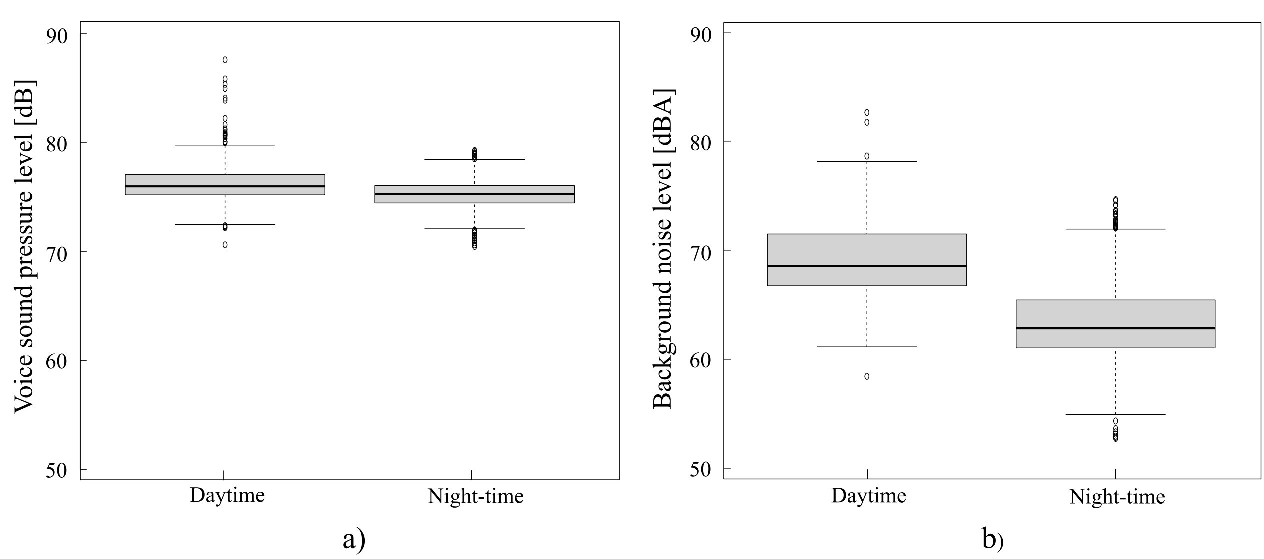

Fig. 1. Voice and background noise levels during the day and night: a) voice sound pressure levels and b) background noise levels.

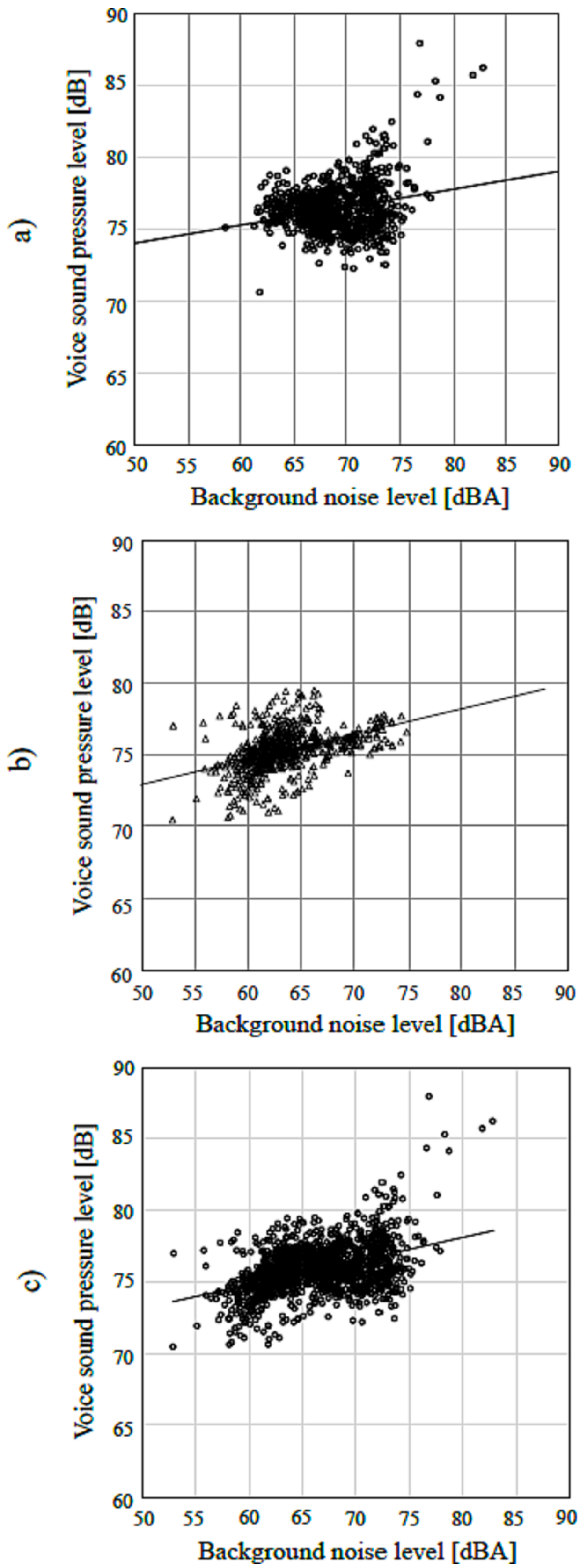

Fig. 2. Relationships between background noise levels and averaged voice levels: a) daytime, b) night-time, and c) total.

50th, and 75th percentiles, with whiskers representing 1.5 times the interquartile range, and outliers plotted individually. As depicted in Fig. 1(a), the median values of voice levels during daytime and night-time were similar, measuring 76.36 dB and 75.31 dB, respectively. However, during the day, several loud voices were located outside the upper whisker, while quiet voices were found outside the lower whisker during the night. The variation in voice levels between day and night can be attributed to differences in background noise levels, which are shown in Fig. 1(b). During the night, the median background noise level was lower than during the day, with values of 63.6 dB and 69.1 dB, respectively.

Fig. 2 displays the relationships between averaged voice levels and background noise levels of all the participants during daytime and night-time. As depicted in Fig. 2(a), the voice levels increased as the background noise levels increased, which ranged from 70.6 dB to 88.0 dB during daytime shifts. The correlation coefficient between voice levels and background noise levels was 0.244 and statistically significant ($p < 0.001$). Similarly, voice levels and background noise levels were significantly correlated ($r = 0.457$, $p < 0.001$) during night-time (see Fig. 2(b)), although the background noise levels were smaller, ranging from 70.4 dB to 79.5 dB. Furthermore, for all the data from both daytime and night-time, a positive correlation between background noise levels and voice levels was observed in Fig. 2(c) ($r = 0.435$, $p < 0.001$). Correlation analyses were conducted across the sites, and similar results were observed. As listed in Table 3, all the sites exhibited positive correlation coefficients between background noise levels and voice levels. Particularly during night-time, the correlation coefficients were much greater than those during daytime at all the sites.

The voice levels during the measurement were averaged for every 20 min, and the results are plotted in Fig. 3 for daytime and night-time. As depicted in Fig. 3(a), voice levels decreased over time during daytime for all the sites. Site B exhibited the highest voice levels, while Site C had the lowest levels. Similar trends were observed during night-time (Fig. 3(b)), with a decrease in voice levels over time. Site B and D had higher voice levels compared to Site A and Site C. Furthermore, the voice levels during night-time were lower than those during daytime in all the sites. Independent samples *t*-test results indicated that the differences in voice levels between daytime and night-time were significant for all sites ($p < 0.01$ for Sites A, B, and D; and $p < 0.05$ for Site C). For instance, Site A showed significant differences in SPLs between daytime and night-time.

Fig. 4 displays the frequency of talking averaged every hour during daytime and night-time. The number of talking events was automatically calculated through the vocal monitor. The vocal monitor examined the vocal parameter event per minute, and each valid result was recorded as a talking event. During daytime, the average frequencies of talking ranged between 30 and 50, and they remained relatively stable throughout the nurses' working hours. Conversely, the frequencies of talking significantly decreased over time during night-time. This is likely due to the nurses being more cautious about talking to ensure the patients' sleep at night.

Questionnaire survey

Kaiser-Meyer-Olkin (KMO) and Bartlett's tests were conducted to assess the suitability of the variables for factor analysis. The results indicated that the KMO value was 0.610 ($p < 0.05$) and Bartlett's test of sphericity was significant ($p < 0.01$), confirming that the adjectives

Table 3
Correlation coefficients between background noise levels and voice levels across the sites (**$p < 0.01$).

	Site A	Site B	Site C	Site D
Daytime	0.11**	0.26**	0.26**	0.13**
Night-time	0.41**	0.53**	0.55**	0.47**
Total	0.39**	0.46**	0.60*	0.37**

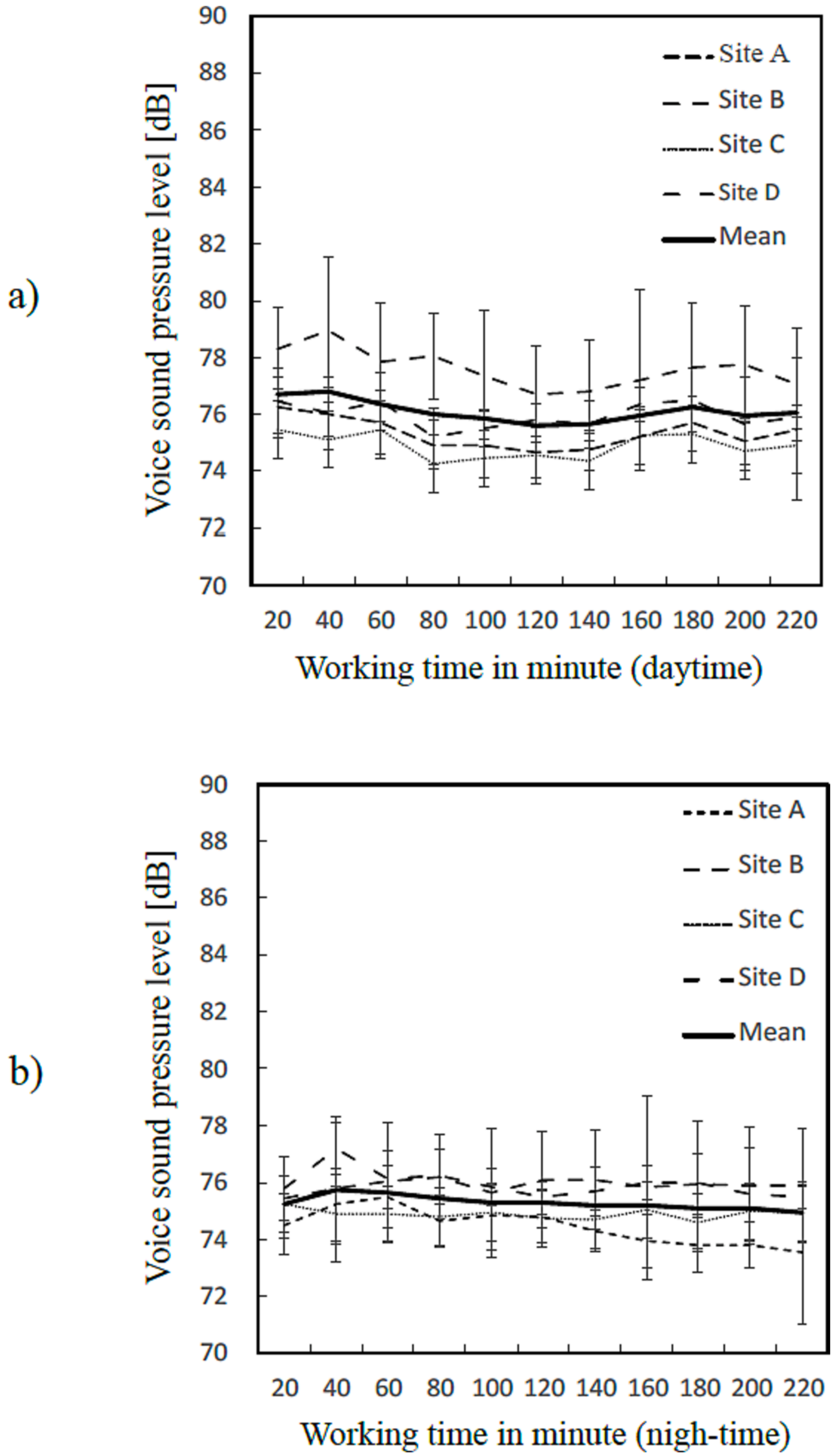

Fig. 3. Averaged voice levels over time across different sites: a) daytime and b) night-time.

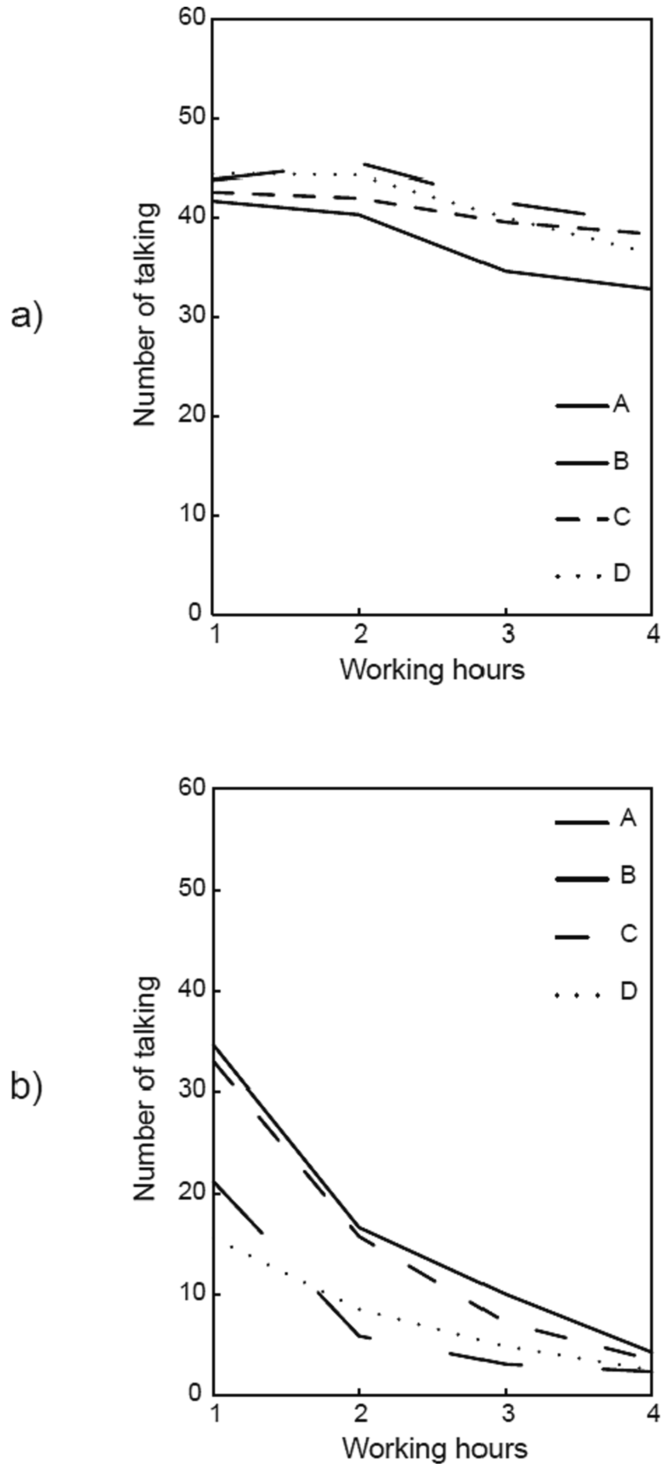

Fig. 4. Frequencies of talking during daytime and night-time across different sites: a) daytime and b) night-time.

were appropriate for factor analysis. Factor analysis was performed using the data from all four sites, employing varimax rotated principal component analysis (PCA) to extract orthogonal factors from the 15 adjective indices. Six factors were extracted based on initial eigenvalues > 1, as presented in Table 4. The three primary components accounted for 36.3 % of the total variance (14.1 %, 11.9 %, and 10.3 %, respectively).

The first component, labelled 'Stress', was best explained by undisturbed-disturbed, relaxed-stressed, and peaceful-troubled. It

Table 4
Varimax-rotated factor loadings for each principal component along with reliability measurement for each.

Semantic scale	Components					
	1	2	3	4	5	6
Relaxed-Stressed	0.683					
Content - Annoyed	−0.516					
Peaceful - Troubled	0.586					
Undisturbed - Disturbed	0.731					
Unconcerned - Concerned	0.346					
Reassured- Worried		0.428				
Curious - Apathetic		0.653				
Tolerant - Irritated		0.577				
Satisfied-Frustrated		0.653				
Intrigued-Bored			−0.714			
Comfortable - Uncomfortable			0.789			
Alert - Unprepared				0.806		
Attentive - Distracted					0.862	
Calm-Agitated						0.832
At ease-Anxious						0.682
Variance explained (%)	14.1	11.9	10.3	8.9	8.5	8.1

exhibited satisfactory internal consistency reliability, with a Cronbach's alpha of 0.728. The semantic scales in this component primarily related to negative perceptions of sounds. The second component, termed 'Irritation', was characterised by satisfied-frustrated, curious-apathetic, tolerant-irritated, and reassured-worried. It demonstrated a Cronbach's alpha of 0.693, with higher loadings for irritated and frustrated. The third component, labelled 'Discomfort', comprised intrigued-bored and comfortable-uncomfortable.

The first two components were utilised to present the perceptual framework across the sites. Fig. 5 illustrates this framework, where the horizontal axis represents the scores of Component 1 ('Stress') and the vertical axis indicates the scores of Component 2 ('Irritation'). Higher scores on both components reflect more negative perceptual experiences in ICUs. Among the four sites, Site B displayed the highest responses in

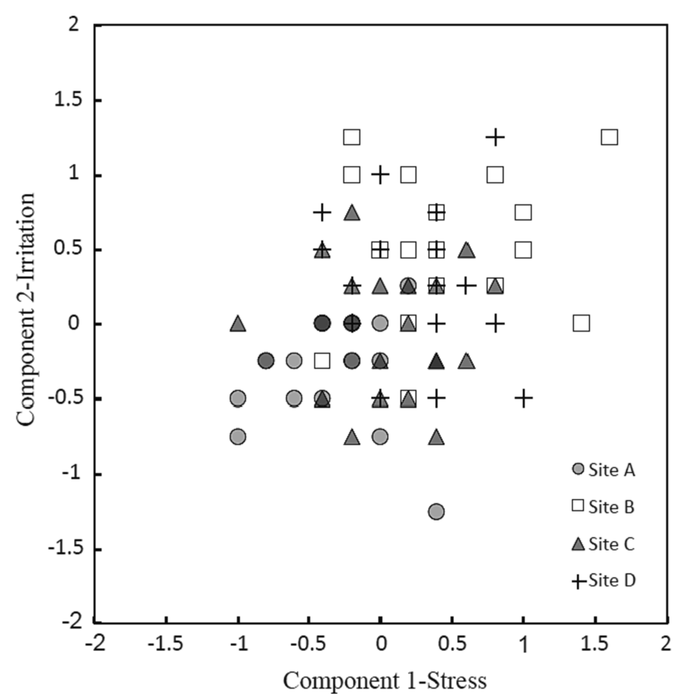

Fig. 5. The component scores of four sites along horizontal axis of 'Stress' and vertical axis of 'Irritation'.

Table 5
Correlation coefficients between the component scores and voice parameters (** $p < 0.01$ * $p < 0.05$).

Components	Voice-related parameters	*r*
Component 1 ('Stress')	Voice level (dB)	0.29*
	F0, mean (Hz)	0.43**
	Dt (%)	0.09
	Background noise level (dBA)	0.23*
Component 2 ('Irritation')	Voice level (dB)	0.20*
	F0, mean (Hz)	0.37*
	Dt (%)	0.04
	Background noise level (dBA)	0.26*

both dimensions, suggesting that nurses at Site B might experience higher levels of stress and irritation compared to the other sites. On the other hand, Site A exhibited lower responses in both dimensions, indicating that nurses' experiences at Site A might be less stressful and less irritating.

Correlation analyses were conducted to examine the relationships between the perceptual components and voice-related parameters. The results are presented in Table 5. The fundamental frequency, voice sound pressure level (SPL), and background noise level displayed positive associations with both component scores, and all correlation coefficients were statistically significant. The fundamental frequency exhibited the strongest correlation coefficient with Component 1 ($r = 0.43$). Additionally, the correlation coefficient between the fundamental frequency and Component 2 was relatively high ($r = 0.37$) compared to the correlations with other parameters. However, the correlations between the Dt (%) and the component scores were not significant ($p > 0.05$).

Discussion

This study revealed that nurses spoke approximately 0.9–4 dB louder to patients and colleagues in ICUs compared to quiet rooms. Additionally, their fundamental frequency (F0) significantly increased during work. These findings are consistent with previous studies (Åhlander et al., 2014; Rantala and Sala, 2015; Rantala and Sala, 2015) that reported similar trends in teachers' voice levels and fundamental frequencies in classrooms. However, the increases observed in teachers were greater than those in ICU nurses. For instance, Cutiva et al. (2017) observed mean voice levels of teachers ranging from 79.7 dB to 89.0 dB during four-hour monitoring, resulting in increases of 3.4–8.1 dB compared to pre-monitoring. Similarly, the changes in fundamental frequencies of teachers (49–73 Hz) were slightly greater than those of ICU nurses (20.4–79.0 Hz). These differences can be attributed to the significant environmental variations between classrooms and ICUs. In a classroom setting, the distances between the source (teacher) and receivers (students) are typically longer than those in ICUs, requiring teachers to exert more vocal effort for better speech intelligibility. Another difference between ICU nurses and teachers was observed in the results of phonation time percentage (Dt, %). In the current study, the mean Dt (%) ranged from 6.3 % to 11.6 % across the sites, while teachers' Dt (%) was around 30 % (e.g., 27 %–33 % in Cutiva's study (Cutiva et al., 2017). This difference may be due to the fact that ICU nurses spoke less compared to teachers, who continuously engage in communication with their students. Furthermore, this study demonstrated that the nurses' voice levels were influenced by background noise levels, with a significant correlation coefficient of 0.44 ($p < 0.01$). This finding is consistent with previous studies (Nusseck et al., 2018; Lindstrom et al., 2011; Guidini et al., 2012; Calosso et al., 2017) that reported significant correlations between teachers' voice levels and background noise levels in classrooms. Voice levels and F0 obtained in this study showed a significant correlation with perceived voice handicap ratings, as measured by the Voice Handicap Index (VHI-30) from a previous study (Song et al., 2023). The correlation coefficients between voice parameters and VHI-30 scores are provided in Supplementary Table S2. These findings indicate that a louder voice and higher voice pitch were associated with a more severe voice handicap among ICU nurses. This finding aligns with previous studies (Niebudek-Bogusz et al., 2010; Fulljames and Harris, 2006) that reported strong correlations between pitch-related parameters (such as F0 and pitch perturbation quotient) and VHI scores.

In the present study, the background noise levels ranged from 58.1 to 73.9 dBA, which is consistent with previous studies (MacKenzie and Galbrun, 2007; Busch-Vishniac et al., 2005; Tsara et al., 2008; Tsiou et al., 1998; Dawson et al., 2022) that have reported noise levels in hospitals exceeding the guidelines set by the WHO. These findings are particularly in lined with a recent study Song *et al.* (2022), which reported noise levels in Chinese ICUs ranging between 54.3 and 62.7 dBA. The slight differences in noise levels may be attributed to the methodology used, as Song *et al.* (2022) measured noise levels using fixed sound level meters over a 24-hour period, while this study focused on the working hours of the nurses who were constantly moving. Another study from the UK (Dawson et al., 2022) also reported that the averaged noise level in ICUs for 50 h was 65.1 dBA. The study also revealed that ICU nurses engaged in approximately 30–50 instances of talking per hour during the daytime, confirming that talking is one of the most prevalent sources of noise in the ICU (Song et al., 2022). Similarly, Dawson et al. (2022) highlighted that communication, especially conversation between nurses, was identified as the most frequently occurring sound source in the ICU. However, the frequency of talking significantly decreased during nighttime. Nevertheless, it remains possible that the nurses' speech may still contribute to sleep disturbances among patients (Park et al., 2014).

Speech intelligibility in rooms is influenced by signal-to-noise ratio (S/N), which represents the level difference between speech and background noise, and the room acoustics characteristics of the space such reverberation time. Objective measures of speech intelligibility, like the speech transmission index, are computed based on S/N and reverberation time. Consequently, to enhance speech intelligibility, it is crucial to lower the background noise level. For instance, Bradley (1985) highlighted that speech comprehension is significantly impacted once the background noise level exceeds 35 dBA. Houtgast (1981) also recommended a 15–18 dB S/N at 1 m for 100 % intelligibility. The measured background noise levels in the present study are greater than 55 dBA, resulting in an increase in voice levels and voice handicap for ICU nurses (Song et al., 2023). Thus, interventions to reduce noise levels in the ICU need to be developed.

This study aimed to measure the perceptual dimensions experienced by ICU nurses and identified two main components, namely 'stress' and 'irritation', indicating the prevalence of negative experiences within ICUs. These results can be compared to soundscape studies that also used semantic differentials. Soundscape is defined as the acoustic environment as perceived and understood by individuals, emphasising the relationships between sound, environment, and human experience (Schafer, 1993). Many studies have introduced a soundscape approach by focusing on people's experiences and perceptions to explore various environments including ICU (Okcu et al., 2011). The findings from the present study align partially with previous soundscape studies (Cain et al., 2013; Jennings et al., 2010; Russell, 1980; Torresin et al., 2020), which also identified major perceptual dimensions related to valence (e.g., 'annoyance') and arousal (e.g., 'contentment'). However, in contrast to the current study, subjective responses to outdoor environments in previous soundscape studies were also influenced by positive aspects of the soundscape, such as 'pleasantness' and 'eventfulness' (Axelsson et al., 2010; Kang and Zhang, 2010; Ma et al., 2022). The discrepancy between this study and soundscape studies may be attributed to differences in the auditory and visual environments. Unlike ICUs, urban areas and parks typically incorporate positive elements such as natural sounds and green spaces. Therefore, it becomes crucial to introduce design factors that promote positive experiences for healthcare workers in the

ICU setting.

Mackrill et al. (2013) conducted a similar assessment of hospital soundscape using the same attributes as this study, but their results differed slightly. They identified 'Relaxed' and 'Interest and understanding' as major perceptual dimensions, explaining 56.8 % and 13.2 % of the variances, respectively. The differences between the two studies can be attributed to the characteristics of the places where the questionnaire surveys were conducted. This study focused solely on ICUs, whereas Mackrill et al. (2013) presented sound clips from various areas of the hospitals, such as ward corridors and patient bays. Similarly, Sudarsono et al. (2019) identified five perceptual components of hospital wards, including privacy, disturbance, and dynamics. Azzahra et al. (2017) described the soundscape of ICUs using attributes such as calmness, dynamics, and information, which are notably different from those used in this study. The explained variances of the perceptual components in this study were smaller compared to those of Mackrill et al. (2013), indicating that the attributes used in this study might not be sufficient to fully assess the perceptions of ICU nurses' experiences. Therefore, there is a need for the development of specific semantic adjectives tailored for the ICU context in future research.

Limitations

The study has several limitations to consider. Firstly, the voice use monitoring of ICU nurses took place during the pandemic when they were required to wear face masks. This raises uncertainty about whether the study accurately reflects the voice characteristics of ICU nurses, as their communication with patients and colleagues may differ slightly without masks. In particular, wearing a face mask removes visual cues, including facial gestures and lip movements, which play an important role in understanding speech, especially in high background noise environments. Furthermore, the high workload and stressful situations during the pandemic might have led to negative perceptions in the ICUs. Therefore, a future study is needed to compare the voice usage and perception of acoustic environments in ICUs post-pandemic. Secondly, the study solely focused on ICU nurses and did not encompass other healthcare workers in different hospital departments. Noise levels in these other departments are expected to be lower than those in the ICUs, potentially leading to differences in voice usage among health professionals. Therefore, conducting additional voice monitoring and comparing the data of ICU nurses with professionals in other departments could help validate the effects of varying noise exposure levels on voice use. Furthermore, to broaden the scope, it would be beneficial to include doctors and nurses from a range of departments, including those from different countries. Thirdly, the nurses participated in voice monitoring only once, so the data may have been influenced by specific patient environments. Therefore, conducting longer monitoring periods (e.g., several days) could yield more reliable and robust data. Fourthly, due to the constraints imposed by the pandemic, this study had a relatively small sample size for voice monitoring as the recruitment of hospitals and nurses was limited. Lastly, the attributes used in the semantic differential were insufficient in fully explaining the perception of acoustic environments in the ICU. Consequently, further research is needed to identify appropriate attributes associated with the ICU by conducting semi-structured interviews.

Conclusion

The present study aimed to investigate the vocal problems experienced by nurses working in intensive care units (ICUs) during the COVID-19 pandemic. Vocal parameters and psychological responses were measured among the ICU nurses. It was found that the ICU nurses spoke at approximately 0.9–4 dB louder in the ICUs compared to quiet rooms. Their voice levels were influenced by background noise, and there was a significant increase in fundamental frequency (F0) during their work. The mean voice levels showed slight variation across different hospitals with varying noise levels. The study also confirmed that talking was one of the most common sources of noise in the ICUs. Additionally, the perceptual components of stress and irritation were found to be prominent in the acoustic environments, indicating the prevalence of negative experiences among ICU nurses. However, the explained variances of these perceptual components were small, suggesting that the attributes used in this study may not be sufficient to fully assess the perceptions of ICU nurses' experiences. Therefore, further research is needed to develop perceptual attributes for assessing the acoustic environment in ICUs.

Ethical statement

Hereby, I (Pyoung Jik Lee) consciously assure that for the manuscript (Voice use of nurses working in the intensive care unit during the COVID-19 pandemic) the following is fulfilled:

1) This material is the authors' own original work, which has not been previously published elsewhere.
2) The paper is not currently being considered for publication elsewhere.
3) The paper reflects the authors' own research and analysis in a truthful and complete manner.
4) The paper properly credits the meaningful contributions of co-authors.
5) The results are appropriately placed in the context of prior and existing research.
6) All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
7) All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

The violation of the Ethical Statement rules may result in severe consequences.

To verify originality, your article may be checked by the originality detection software iThenticate. See also https://www.elsevier.com/editors/plagdetect.

I agree with the above statements and declare that this submission follows the policies of Solid State Ionics as outlined in the Guide for Authors and in the Ethical Statement.

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Competing interests

The authors declare that they have no conflict of interest.

Contribution of all authors

Data collection was performed by Ziwei Song (ZS), and Pyoung-Jik Lee (PJL) contributed to methodological advice. ZS conducted data analysis and generated tables and figures, while PJL supervised the data analysis. ZS was responsible for manuscript writing and PJL provided critical input and reviewed drafts of the manuscript.

CRediT authorship contribution statement

Ziwei Song: Formal analysis, Writing – original draft, visualization. **Pyoung-Jik Lee:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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