Research Paper

The Impact of Structural Changes on Sound Pressure Levels in a Neonatal Intensive Care Unit

Carlos CARVALHAIS[(1),(2)*], Célia RODRIGUES[(3)], Ana XAVIER[(1)], Manuela V. SILVA[(1)], Joana SANTOS[(1),(4),(5)]

[(1)] *Scientific Area of Environmental Health, Health and Environment Research Center (CISA)*
School of Health of Polytechnic Institute of Porto (ESS|P.Porto)
Porto, Portugal; e-mail: jds@ess.ipp.pt, arfx@ess.ipp.pt, m.silva@eu.ipp.pt
*Corresponding Author e-mail: caa@ess.ipp.pt

[(2)] *Epidemiology Research Unit (EPIUnit), Institute of Public Health, University of Porto*
Porto, Portugal

[(3)] *PROA/LABIOMEP, Faculdade de Engenharia, Universidade do Porto*
Porto, Portugal; e-mail: pee10017@fe.up.pt

[(4)] *Institute of Science and Innovation in Mechanical and Industrial Engineering,*
Associated Laboratory for Energy, Transports and Aeronautics (INEGI/LAETA),
Faculdade de Engenharia, Universidade do Porto
Porto, Portugal

[(5)] *Center for Rehabilitation Research (CIR), School of Health of Polytechnic Institute of Porto (ESS|P.Porto)*
Porto, Portugal

(*received April 18, 2020; accepted March 18, 2021*)

The design of neonatal intensive care units (NICU) influences both patient safety and clinical outcomes as well as the acoustic conditions. In NICU exposure to sound pressure levels above the recommended can affect both neonates and healthcare staff.

This study aimed to evaluate the sound pressure levels and to assess noise perception of professionals in a NICU before and after structural modifications and layout redesign.

The measurements were performed with a sound level meter. A questionnaire was given to staff before and after the intervention. The opinion of healthcare staff regarding noise in NICU was better after the intervention, when compared with the responses previously given.

The results showed that noise levels were excessive in the NICU (before and after), exceeding the international recommendations, with the levels ranging between 46.6 dBA to 57.8 dBA before and 52.0 dBA to 54.0 dBA after intervention. Overall, there is a need for more research in order to verify the effectiveness of some actions and strategies to reduce the impact of noise in NICU.

Keywords: noise; layout; design; healthcare; sound.

1. Introduction

Neonatal Intensive Care Units (NICU) are very important in maintaining the health and wellbeing of infant patients in hospitals. Neonatal units are focused specifically on the health of newborns and the care for medically unstable or critically ill newborns requiring health care, surgical procedures, continual respiratory support, etc. The spaces which support the newborns include delivery rooms, nurseries, and other spaces where high-risk infants are monitored and given both intensive and intermediate care.

The design of neonatal intensive care units influences both patient safety and clinical outcomes. Design contributes to the type and quality of care given for all people involved in neonatal spaces, including newborns, parents, other family members, friends and hospital workers and must address their different needs (Joshi *et al.*, 2018). The intensity of a neonatal unit can be overwhelming for a premature infant who has not fully developed yet. Indeed, acoustical quality of the NICU plays a very important role since it is a basic design principle such as layout or family and visitor comfort. In fact, the NICU is often characterised by loud, unpredictable noise from extraneous sources such as alarms, ventilators, phones and staff conversation to which preterm infants are especially vulnerable (Santos *et al.*, 2018; Wachman, Lahav, 2011).

Nowadays, there are mainly two distinct architectural designs of NICUs: the open-bay and the single-family room designs (Szymczak, Shellhaas, 2014). The open-bay design facilitated communication between staff, collegiality, and interprofessional collaboration among members of the neonatal team. Over the last decades, the implementation of single-family room designs has been increasing due to the enhanced transmission of sound and light in open-bay designs (Meredith *et al.*, 2017). Evidence also shows improved and safer environment as well as positive health outcomes in single-family rooms (Lester *et al.*, 2014; Ramm *et al.*, 2017; Szymczak, Shellhaas, 2014). In fact, regarding noise levels, single-family rooms are much preferred to open-bay or alternative layouts. Increased noise can exacerbate stress levels on all parties, but single-family rooms aid in noise reduction through structural means. Families can also exercise greater control over the environment of their child, minimizing stimuli that may adversely affect him or her, and promoting sleep. Finally, single-family rooms provide a quiet atmosphere for private conversations among families, as well as nurses and physicians, encouraging communication and parental involvement (Stevens *et al.*, 2010). In Portugal, the most adopted NICU design is the open-bay model. Single-occupancy rooms exist, but in general they are available to newborns who present a disease that requires some isolation, such as a suspected airborne infection.

NICU layout changes and structural modifications have shown to be effective in reducing noise levels produced by staff, equipment or building generated sound. The latter is mainly promoted by the number of beds, ventilation system, location of workstation, etc. (Philbin, Gray, 2002). However, data comparing noise levels before and after a structural intervention is sparse and the confirmation of the influence of physical changes on noise reduction is needed (Santos *et al.*, 2018).

The aim of this study is to examine the influence of a structural intervention and layout change in a NICU by measuring the equivalent sound pressure levels and by collecting indicators of noise perception of the healthcare staff, before and after the intervention. The NICU under study was transferred to another building of the hospital which underwent several structural reorganizations to improve the clinical response.

2. Materials and methods

This study was carried out in a NICU located in the north region of Portugal and was conducted in two main phases: before and after a structural/layout change intervention. Both phases (pre and post-intervention) included a walkthrough inspection to characterize the built environment and indoor spaces of the NICU, measurements of the sound pressure levels and assessment of health care professional's noise perceptions. The study was conducted after institutional authorization. All ethical and confidential issues were addressed and staff were informed about the study. Since this study only gathered environmental data no approval was needed by institutional board on human subjects' protection.

2.1. NICU pre-intervention

Before structural and layout intervention, the NICU (A1) consisted of two main areas as shown in Fig. 1a. There were other support areas, such mother's room, nurses' room, etc., which were not included in this study. The areas A1.1 (nursery room) and A1.2 (incubators room), were divided by a glass wall with a corridor that allows communication between the two. The area of the spaces was 27.47 m^2 (295.70 ft^2) (A1.1) and 27.83 m^2 (299.60 ft^2) (A1.2). The floor was concrete with vinyl covering and walls and ceiling were in plasterboard coated with washable paint. A1.1 and A1.2 were equipped with 5 incubators and 6 nurseries as well as a workstation, which supports both areas.

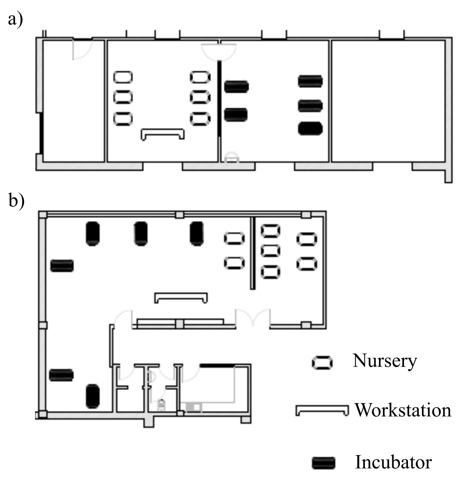

Fig. 1. Layout of NICU before (a) and after (b) the intervention.

2.2. NICU post-intervention

In this phase, the NICU (A2) was designed as an open-bay model (Fig. 1b). The NICU was transferred to another building of the hospital which underwent several structural reorganizations to improve the clinical response. The materials used were consistent with the ones used before intervention and the main difference between pre and post-intervention was an increase of the space area and the inexistence of a glass wall separating the rooms. Additionally, the ventilation system was designed considering the sound attenuation in the space. The floor was concrete with vinyl covering and walls and ceiling were in plasterboard coated with washable paint. The area (A2.1) was an open space with 116.30 m^2 (1252 ft^2), 6 incubators and 7 nurseries improving the maximum capacity up to 13 bed spaces, spread along a rectangular configuration. It had a workstation devoted to the preparation of medication and parenteral nutrition. During the measurements five new-borns were admitted in the NICU (three in incubators and two in nurseries),

The installed equipment was the same in both phases, namely: cardiopulmonary monitors, blood pressure monitors, ventilators (attached to an endotracheal tube or to continuous positive airway pressure (C-PAP) tubes), oximeters, Bili lights, etc. It was possible to verify that NICU had some preventive measures to reduce noise levels, mainly maintenance programmes of the equipment.

2.3. Noise measurements

Pre-intervention noise level measurements were performed using a sound level meter class 1 (01 dB®, model Solo-Premium). Post-intervention noise level measurements were performed using a sound-level meter class 1 (Brüel, Kjær, models 2250). In accordance with Robertson *et al.* (1998), a preliminary survey was performed in order to identify noise sources. In both phases, measurements were made continuously over 24 hours at least 1m away from the walls at a height between 1 m and 1.65 m. Noise was also determined inside an incubator. The measurements of peak sound pressure level ($L_{p,\mathrm{Cpeak}}$) were made using the C filter, since peak noises can lead to the alteration of physiological response from the newborn (Romeu *et al.*, 2016) and can affect patients experiencing long restorative periods, with noise interruption (Wiese *et al.*, 2009). The A-weighted equivalent sound pressure level (L_{Aeq}) was obtained using the A filter, which is a frequency weighting filter that simulates human hearing. Slow response time averaging (1 s) was also used as it is the most appropriate response for the majority of the applications in hospitals and provides stable readings (Philbin, Gray, 2002). To ensure accurate measurement, recording was preceded by calibration of the sound level meters (Kent *et al.*, 2002), with the respective acoustic calibrators class 1 (RION®, model NC-74 and Brüel, Kjær, model 4231). The analysis and interpretation of results reference values given by WHO were used (Berglund *et al.*, 1999). Spectral analysis of sound frequency was performed, since protocols for measuring NICU noise should also include a spectral analysis of the sound frequency (Lahav, 2015).

2.4. Health care staff perceptions

The NICU has three fixed shifts (morning: 8:00 am – 3:00 pm; afternoon: 3:00 pm – 10:00 pm; night: 10:00 pm – 8:00 am). The team is composed of nurses, operational assistants and physicians. The analysis of noise perception of health care staff in their workplaces involved the application of a questionnaire, in order to characterize working conditions, comfort and the main noise sources. The developed questionnaire, already tested in previous studies (Carvalhais *et al.*, 2015; Santos *et al.*, 2018), was divided into three main sections containing a total of 11 questions:

1) demographic information (sex, age, profession, years of work in NICU, shift);
2) judgment of personal acceptability of noise and comfort; and
3) judgment of the noisiest shift and main sources of noise in the NICU.

The personal acceptability statement and the tolerance scale consisted of judgements made about the local noise environment. Furthermore, there was no contact between the researchers and the survey participants during the time the questionnaires were being filled in. The survey was distributed and collected by a nurse to maintain anonymity. At the end of the shift, they were collected by the responsible nurse who sent it to the researchers.

2.5. Statistical analysis

The processing and data analysis involved descriptive statistics, with analysis of L_{Aeq} and $L_{p,\mathrm{Cpeak}}$ values. All tests considered a 95% confidence interval. The normality Shapiro-Wilk test, the Student's t test for paired samples and the Student's t test for independent samples, were applied. The software IBM SPSS™ (Statistical Package for the Social Sciences) 25th version and MS Excel® 2019 were used for the analysis.

3. Results

The noise levels obtained in the NICU before (A1) and after (A2) the intervention are shown in Table 1, as well as the frequencies spectrum in octave bands.

Table 1. Values of mean L_{Aeq} [dBA] (p = 0.800) and L_{Cpeak} [dBC] (p = 0.313).

NICU	Room	Area	L_{Aeq} mean ± SD (min–max) [dBA]	L_{Cpeak} [dBC]	Frequencies [Hz] 63	125	250	500	1000	2000	4000	8000
					[dBA]							
A1 pre intervention	A1.1	Work station	53.3 ± 2.74 (46.2–79.1)	112.2	48.8	42.4	45.3	50.1	47.1	47.8	41.8	40.4
	A1.2	Work station	57.8 ± 1.32 (42.6–77.4)	109.2	50.8	49.5	48.3	55.1	53.2	51.1	44.8	42.3
		Inside incubator	46.6 ± 0.23 (41.2–63.4)	104.6	56.1	50.0	52.0	41.1	39.2	34.2	32.1	30.3
A2 post intervention	A2.1	Work station	54.0 ± 2.01 (40.7–69.4)	106.9	23.7	32.6	41.1	49.9	46.9	47.6	44.0	34.2
		Inside incubator	52.0 ± 0.36 (50.7–53.3)	67.4	37.7	41.5	41.8	46.2	48.6	40.0	33.9	26.8

SD – standard deviation.

In NICU pre-intervention L_{Aeq} [dBA] mean values were 53.3 dBA (room A1.1) and 57.8 dBA (room A1.2), post-intervention L_{Aeq} [dBA] mean value was 54.0 dBA (room A2.1). No significant differences (p = 0.800) were found between the two phases – pre and post structural intervention in the NICU. The highest L_{Cpeak} [dBC] value was found in the "work station" area of room A1.1 (112.2 dBC). Data showed that no significant differences were found between L_{Cpeak} [dBC] values (p = 0.313). Except in room A2.1 – inside incubator, 500 Hz was the frequency which had higher levels in the areas under study. The demographic characteristics of the sample of health care staff who participated before and after structural intervention in this study are presented in Table 2.

The number of valid questionnaires included in the study is 43 (23 pre-intervention and 20 post-intervention). However only 15 participants responded before and after the intervention, so further analysis was made considering those participants. More than a half of the sample was composed of nurses, followed by operational assistants and physicians. Also, most of the staff have worked in NICU between 5 to 20 years. At the time of the questionnaire survey, workers who participated in the study were mainly from the morning shift. The responses of the relevant questions of the questionnaire are shown in Figs 2–5.

As presented in Fig. 2, pre-intervention perception regarding the acceptability of the working environment, 4.3% of the participants rated noise as "Clearly acceptable" on their workplace, 48.4% as "Acceptable", 40.0% as "Unacceptable" and 8.4% as "Clearly unacceptable". In the post-intervention phase, 78.9% classified the working environment as "Acceptable" and 21.1% as "Unacceptable". These results show an improvement on the acceptance of healthcare staff regarding noise after changing NICU. Concerning the main sources of noise presented in Fig. 3, in pre-intervention phase, 69.6% of staff reported "equipment", including

Table 2. Characteristics of the healthcare staff before and after the intervention.

	Before N [%]	After N [%] Completed	Final
N	23	20**	15* (drop out n = 8)
Sex			
Male	0	5 (25.0)	0
Female	23 (100)	15 (75.0)	15 (100)
Age in years			
18–39	6 (26.1)	4 (20.0)	4 (26.7)
40–59	15 (65.2)	16 (80.0)	11 (73.3)
≥ 60	0	0	0
Missings	2 (8.7)	0	0
Professional group			
Operational assistants	8 (34.8)	4 (20.0)	4 (26.7)
Nurses	13 (56.5)	12 (60.0)	9 (60.0)
Physicians	1 (4.3)	4 (20.0)	2 (13.3)
Missings	0	0	0
Years at NICU			
<5	6 (26.1)	4 (20.0)	3 (20.0)
5–20	11 (47.8)	10 (50.0)	8 (53.3)
>20	4 (17.4)	5 (25.0)	3 (20.0)
Missings	2 (8.7)	1 (5.0)	1 (6.7)
Shift			
Morning	12 (52.2)	10 (50.0)	7 (46.7)
Afternoon	6 (26.1)	3 (15.0)	3 (20.0)
Night	5 (21.7)	2 (10.0)	1 (6.7)
Missings	0	5 (25.0)	4 (26.7)

Notes: * 15 participants filled the questionnaire before and after the intervention (drop out after intervention n = 8 (34.8%)), ** those participants only responded after the intervention and were not included for T-test for paired samples analysis.

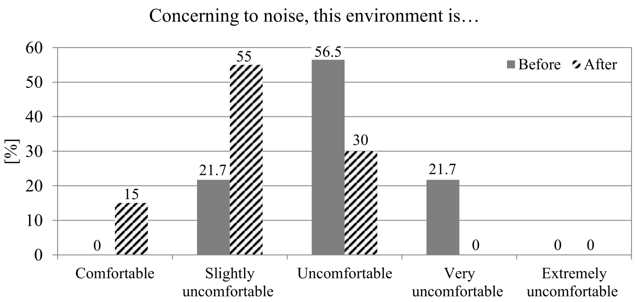

Fig. 2. Workers' responses regarding acceptability.

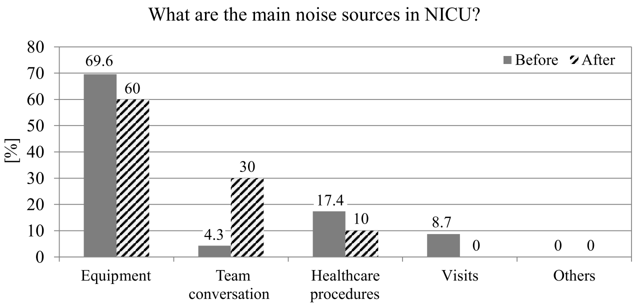

Fig. 3. Workers' responses regarding noise sources in NICU.

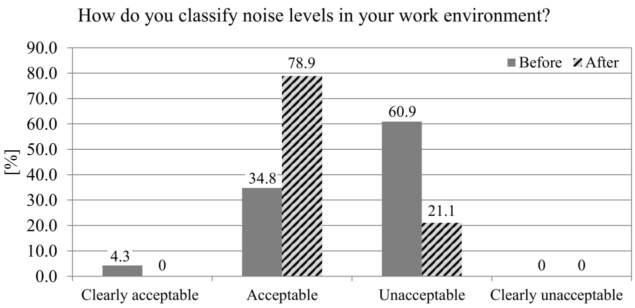

Fig. 4. Workers' perceptions of comfort of the work environment.

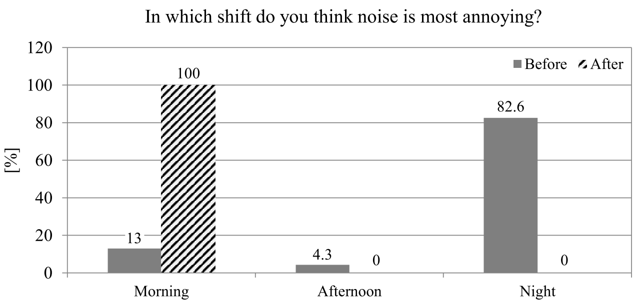

Fig. 5. Workers' perceptions regarding the noisiest shift.

telephones and the signals and sounds from medical devices, as the most annoying noise sources in NICU. The "team conversation" was rated by 4.3% of professionals, "healthcare procedures" by 17.4% and 8.7% for "visits". Post-intervention, participants found, once again, equipment as the most annoying source of noise (60.0%), but also recognized "team conversation" (30.0%) and "healthcare procedures" (10.0%) as sources with potential to increase annoyance in NICU. Figure 4 refers to the perception of comfort in relation to the work environment. Pre-intervention results showed that 41.1% of health professionals considered the work environment as "Slightly uncomfortable", 21.7% "Uncomfortable", 56.5% "Very uncomfortable" and 21.7% "Extremely uncomfortable". After the intervention in NICU, 15.0% felt that NICU was "Comfortable", 55.0% "Slightly uncomfortable" and 30.0% "Uncomfortable". The results suggest that after the alterations made in the NICU, the healthcare staff perceived the working environment as more comfortable than before. Finally, health staff reported about the most annoying pre-intervention shift (Fig. 5), 82.6% of respondents considered the morning shift as the most uncomfortable, followed by night shift rated by 13.0% of the participants. In contrast, the post-intervention survey, showed that all participants (100%) found that the morning shift as the noisiest. Statistical differences ($p < 0.05$) between the two groups of workers (pre and post-intervention), were found for all the relevant questions, except for the question regarding the main sources of noise ($p > 0.05$).

4. Discussion

After structural intervention and layout changes which were performed in the NICU, L_{Aeq} sound levels and L_{Cpeak} slightly decreased, in contrast with other studies (Krueger *et al.*, 2007; Philbin, Gray, 2002). Noise levels pre and post-intervention were higher than the recommended by WHO, which proposes that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed (Berglund *et al.*, 1999), and by other organizations such the United States Environmental Protection Agency (45 dBA daytime/35 dBA night) (U.S. Environmental Protection Agency, 1974) and the American Academy of Pediatrics (45 dBA) (American Academy of Pediatrics: Committee on Environmental Health, 1997). Results inside incubators showed the same pattern, maybe due to the healthcare procedures/activities during measurements. Other studies found noise levels significantly above the recommended during routine clinical procedures (Carvalhais *et al.*, 2017; Parra *et al.*, 2017). Data analysis revealed that low frequencies tend to have more influence on noise produced in the NICU than higher frequencies, both pre and post-intervention. These results are in agreement with the work reported by Gray and Philbin (2000), who stated that low frequencies are predominant in sound pressure levels in nurseries. Nonetheless, the presence and impact of high frequency noise in NICU is real and the exposure of a normally developing new-born by high frequency noise, may potentially result in abnormal auditory development (Lahav, 2015).

In the work developed by Kellam and Bhatia (2008) it is suggested that human speech contributes to increased sound levels at 500 Hz. In fact, this was the frequency with the highest level in the majority of measurement places. There is some evidence showing a reduction in sound pressure levels predominantly above 400 Hz during the night. During this time there is a tendency to decrease conversation and alarm sounds (Carvalhais *et al.*, 2015; Livera *et al.*, 2008; Santos *et al.*, 2018), suggesting that staff activity and conversation are noise sources with impact on noise production. The questionnaire survey revealed that most staff considered equipment and conversation between the team as the main sources of noise, especially after the intervention in the NICU. Despite that, one observes a tendency to perceive NICU environment as more comfortable and the noise levels more acceptable after the structural modification. Morning shift was considered the noisiest after intervention, as stated by other authors (Santos *et al.*, 2018).

Philbin (2004) acknowledged that every NICU has its own design and location, and that sound measurement can never be the ideal, but stressed that sound can be minimized when reconstructing a NICU. The homogeneity of results pre and post-intervention can be explained by the fact that the structural interventions were minor, despite the fact that NICU was placed in another building of the hospital, and basically the building materials and furnishings were identical, as well as the healthcare procedures and most of the healthcare staff. The most significant change was the layout of the NICU and the area increase. Carvalhais *et al.* (2019) considered a good practice to include sound control and noise as important factors when purchasing new equipment or making infrastructural modifications at a NICU. As Krueger *et al.* (2007) stated, the fact that the study occurred in one NICU is a limitation, but the opportunity to compare sound levels before and after a structural intervention is unique. Another limitation is the fact that the structural modifications aimed firstly to the reorganization and improvement of the clinical response of many units and not only the NICU. This means that some other structural measures to reduce noise levels were not implemented such as the use of materials with an improved sound absorption rate or the option for other NICU design, as opposite to the chosen open-bay model. Indeed, there is evidence that smaller rooms with less incubators/nurseries or even single-family rooms promotes a quieter environment (Domanico *et al.*, 2011; Kol *et al.*, 2015; Ramm *et al.*, 2017), despite the fact that noise levels still exceed the recommended ranges in the majority of the cases. In our study, NICU had two smaller rooms equipped with five incubators and six nurseries, respectively, and now it has one room with thirteen incubators/nurseries. Data showed no significant differences between noise levels based on layout design. In this case, our results in both assessment phases, are in agreement with the findings of Basner *et al.* (2014) that noise levels in hospitals are typically more than L_{Aeq} 15–20 dB higher than those recommended. Also, Smith*et al.* (2018) recognized the inability of NICUs to comply with current noise level ranges, and propose changes in NICU noise level recommendations. Indeed, the noise reduction strategies implemented or tested in the last years hasn't resulted in the impact needed, even though some improvements (e.g. noise levels decrease) have been observed (Ahamed *et al.*, 2017; Carvalhais *et al.*, 2015).

5. Conclusions

This study aimed to confirm the influence of physical/structural changes within NICU space on noise reduction. Our results showed that no significant differences on noise levels occurred before and after those changes. These results must be framed considering the type of intervention made, since, when structural intervention or layout rearrangement are performed with noise attenuation in mind, significant attenuation is expected. The studied NICU (pre and post-intervention) presented higher sound pressure levels than recommended by international organizations. However, the perceived environment of the NICU by healthcare staff, improved after the structural modifications. A combined approach to reduce noise in those spaces must be addressed. Continuous education aiming at a cultural change of the staff should be a priority, keeping in mind the newborns health and recovery.

Acknowledgements

This work is part of the "NeoNoise" project, which is being conducted and supported by the Health and Environment Research Center (CISA), School of Health of Polytechnic Institute of Porto (ESS|P.Porto). The authors would like to thank the participants of the study and the assistance given by the Occupational Health Service of the studied hospital.

Conflicting Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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