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ORIGINAL PAPER

Psychophysiological Responses to Medium Levels of Occupational Noise: An Exposure–Response Relationships

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Abstract

Medium noise levels are very common in work environments, and few studies have addressed their effects. This study aims to investigate the effects of real noise levels from four types of workplaces on psychophysiological responses. Thirty-one normal hearing male subjects were recruited. They were asked to judge the noise annoyance (NA) and noise-induced subjective load (NISL) of four occupational environments involved cognitive functions; closed office rooms (CO:57.8–65.2 dB(A), open-plan offices (OPO:65–71.8 dB(A), control rooms (CR:68.7–75 dB(A), and industrial noise (IN:75.5–81 dB(A). Meanwhile, the electrodermal activity (EDA), heart rate (HR), and respiration rate (RR) were monitored throughout the experiments. The saliva cortisol of subjects was also analyzed before and after each trial. The results were evaluated in the view of impact of noise and moderating factors using linear and mixed models, and a dose–response relationship was found for each response. The results showed that the NA were rated 26.5%, 39.5%, 53%, and 72.2%, in the CO, OPO, CR, and IN, respectively, and NISL increase in levels ≥ 65 dB(A)(OPO). In addition to subjective effects, the medium levels of occupational noise can significantly affect the physiological responses in view of the moderating factors. In total, the EDA and RR responses increased, whereas HR initially increased and then decreased. According to the regression models, it seems that medium levels of occupational noise have significant and linear effects on EDA, RR, and HR in levels ≥ 60 (CO), ≥ 65 (OPO), and ≥ 69 dB(A) (CR), respectively. Moreover, the levels range of 60–70 dB(A) (CO and OPO) can increase mean of cortisol level more than the levels range of 70–80 dB(A) (CR and IN).

Keywords Psychophysiological responses · Medium levels · Dose–response relationship · Occupational noise

1 Introduction

Medium noise levels are very common in work environments and effects of them are unspecified. Occupational noise exposure is associated with several psychophysiological adverse effects, and these effects have been addressed somewhat in laboratory and empirical studies [1]. The sound pressure level has been identified as a crucial factor affecting these effects [2]. In addition, type of noise, duration of exposure, and individual susceptibility to noise determine the harmful effects of noise [3]. Most studies have addressed the effects due to noise in levels that can cause adverse effects such as hearing loss [3]. So that, most studies have concluded that chronic exposure to continuous noise at levels ≥ 85 dB(A) lead to hearing impairment, sleep disturbance, cardiovascular effects, higher blood pressure, and other psychophysiological responses than individuals not exposed to noise [4], whereas few studies have attempted to address these and other responses to the medium levels of occupational noise [5]. Epidemiological evidence clearly was not also established to confirm any relationship between noise of medium levels and health effects [6]. Hence, there is a relatively large body of literature concerning regarding non-auditory effects of the occupational noise medium levels [3].

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The medium levels of occupational noise are A-weighted equivalent levels (LAeq) below 80 dB(A) [7]. In other words, the medium levels are levels below those recognized as causing hearing impairment. However, the medium levels may cause serious disturbances, including annoyance responses and a general decrease in well-being, impairment in work performance, tiredness, lack of concentration, and contributes to mental workload. Several studies have tried to investigate the physiological changes and other effects due to noise for short time periods [8, 9]. However, these effects are still questionable for realistic situations with longer durations of noise exposure. Despite a number of studies that reported the noise effects on people's health, none have deal with effects of occupational noise with medium levels [10]. There are occupational environments that are exposed to medium noise levels. For example, office rooms (closed- and open-plan offices), control rooms (operator rooms and quality control rooms), and some of the industrial process or production workplaces (such as assembly and rubber factory) have a noise level of less than 80 dB(A) [1, 11].

However, most studies have reported that the contribution (effect size) of noise on many non-auditory effects is uncertain and it is partly attributable to many other stressors that exist in workplaces [12]. Therefore, assessment of the responses of the body and their trends in the exposure to noise in indoor occupational environments with medium noise levels can be very valuable to estimate of the effect size and mechanism of noise effects on the health and cognitive performance of the employees and thereby noise control [13]. Moreover, a dose–response relationship could be derived by measuring various psychological and physiological responses of body in exposure to sound levels in different work places in laboratory scale [13–17]. Explore a dose–response relationship between exposure to medium levels and various responses in different workplaces could be generalized beyond the type of workplace [1]. Thereby, a global dose–response relationship for occupational noise would contribute to the effort to reduce impairing sound levels, and in the way, dose–response curves for community noises have done [18]. Exact estimation of the effects of exposure to occupational noise on health is difficult because, in occupational environments, noise is often accompanied by other hazards such as heat or exposure to chemicals. However, developing dose–response relationships for occupational exposure to noise in workplaces at the office and industrial levels is a topic that has not been deeply studied. Topics such as response trend of the body physiological and psychological to noise, effect size or role of noise in non-auditory effects, and determining "comfort," "precaution" and "hazardous" levels are the main study areas. Therefore, studying dose–response can elucidate role of noise in non-auditory effects. Hence, the objectives of this study were (i) to examine the psychophysiological responses to medium levels of occupational noise at four types of simulated work places through laboratory experiments and (ii) to explore a general dose–response relationship between noise equivalent levels and perceived psychophysiological responses at work places exposed to medium levels of noise.

2 Methods

2.1 Noise Levels Selection and Characterization

In order to investigate the effect of noise medium levels from occupational environments on psychophysiological responses, all workplaces to medium levels (range of 60–80 dB(A)) were selected and studied. The first premise for the occupational noise' selection and inclusion in the study was occupations with medium noise level ($\leq$ 80 dB(A)), and similar frequency characteristics with dominant sound pressure levels at intermediate frequencies, especially at 500–1000 Hz. Other inclusion criteria were noise study in occupations involved cognitive functions. Thus, the LAeq during a normal workweek of 60 workplaces were characterized and recorded. In total, four categories of occupational environments with a similar circumstance (corresponding cognitive performance and metabolism) were studied; closed-plan offices (CO) ($n = 15$), open-plan offices (OPO) ($n = 15$), control rooms (CR) ($n = 15$), and industrial workplaces (IW) ($n = 15$). An averaged 1-hr equivalent continuous A-weighted sound level (LAeq(1h)) for each workplace were derived from measurements at different positions in the places (range 60–80 LAeq(1h) dB). Therefore, LAeq of the office rooms, control rooms, and some of the industrial workplaces were adjusted to cover ranges between 60 and 80 dB(A) at 5–7 dB(A) intervals with spectral adjustments. The range of noise at CO and OPO rooms were from 59 to 66.2 dB(A) and 65 to 71.2 dB(A), respectively, while the noise of CR had a variation from 65.7 to 75.2 dB(A). The noise level of IW with operator tasks varied from 75.5 to 81.0 dB(A).

2.2 Experimental Design

This was a single-blind randomized cross-over trial study that had a repeated-measures design on 31 subjects. The experiments were designed in five sessions and each participant was exposed to four noise conditions of the CO, OPO, CR, and IN and one baseline condition (background noise (BN). Noise levels tested were the same real noise levels from four mentioned workplaces. Therefore, the LAeq(1h) of selected occupational environments were recorded by Tascam DR-05 recorder. Then, the LAeq(1h) (the same real noise levels) were presented via a spherical loudspeaker (12 matched loudspeakers in a dodecahedral configuration) (OS003-BSWA

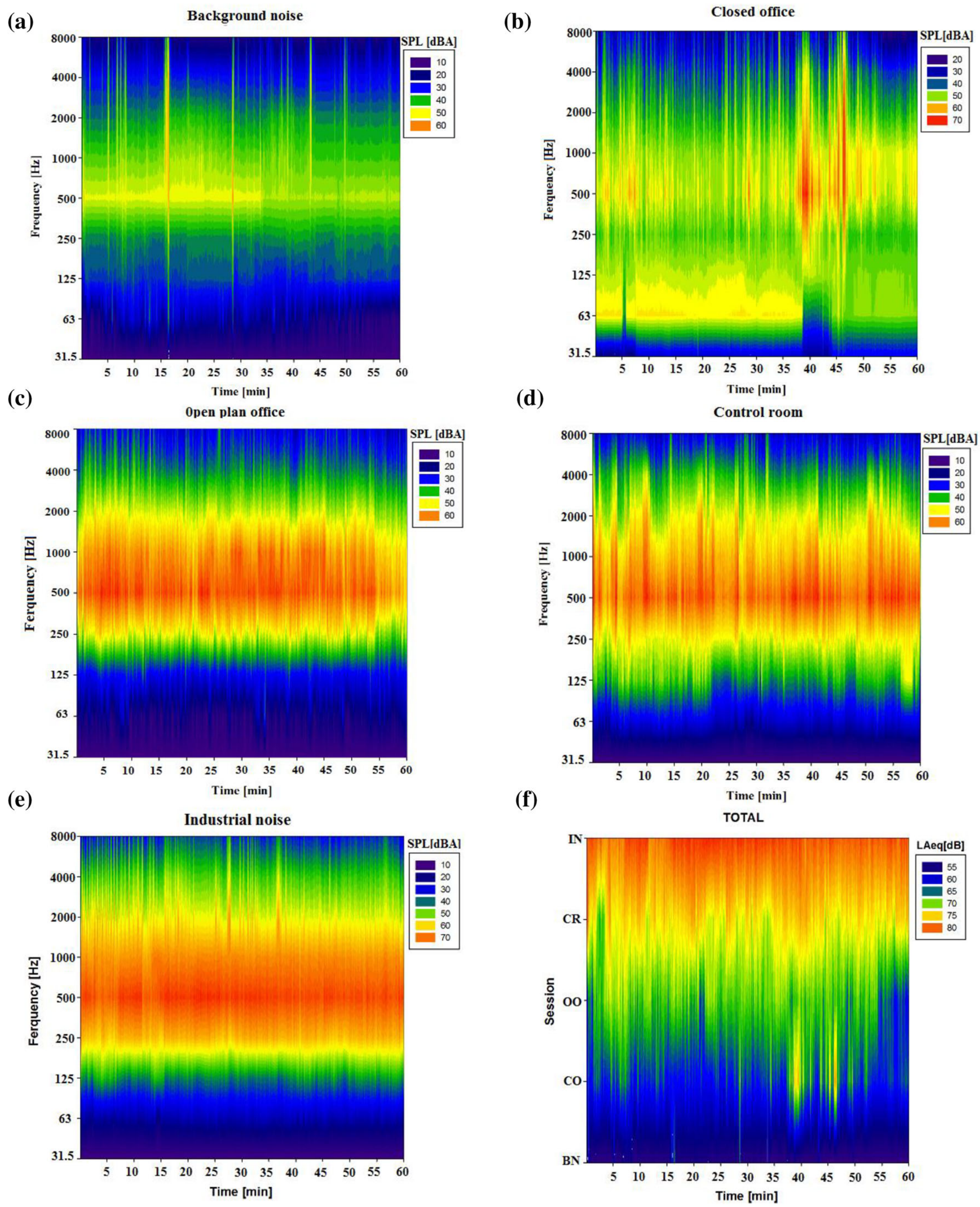

Fig. 1 Comparison of the spectrograms of five noise conditions. **a** background noise (BN), **b** closed offices (CO), **c** open-plan offices (OPO), **d** control rooms (CR), **e** industrial noise (IN), and **f** total

Technology Co) located in center of the room and behind of the listener (at height of 1.1 and distance of 1 m from the listener). The spectrograms of five noise conditions are presented in Fig. 1. Table 1 also presents the outline of the laboratory experiments and characterization of noise levels. In all sessions, the experiment conditions were the same and the psychophysiological responses were evaluated, except that the noise level was different in each session. The sessions were random in five consecutive days that each session lasted for 1 h. All sessions were performed during the morning. To design realistic noise situations in laboratory (the four sessions noisy) with real working conditions, the experiments were carried out in an air-conditioned room with dimensions: 3.4 m $\times$ 5.6 m $\times$ 3.05 m (Fig. 2). To simulate

Table 1 Outline of the laboratory experiment and characterization of noise levels

Sessions Noise conditions	1 Quiet room	2 Closed offices	3 Open-plan offices	4 Control rooms	5 Industrial noise
Noise type	Baseline	Real	Real	Real	Real
Range of SPL [dBA]	52.8–53.5	57.8–65.2	65–71.8	68.7–75	75.5–81
LASeq of the session [dBA]	53.3	64	68.9	73.8	80
Signal to noise ratio	–	7.4	6.5	6.3	6
Noise sources	C	IS, OT, PR, VS, AC, C	IS, OT, PR, VS, C, CP	IS, PR, C, WP, PBN	IS, PR, C, AC, PN
Duration of the session [min]	60	60	60	60	60
Psychological responses	NA, NISL	NA, NISL	NA, NISL	NA, NISL	NA, NISL
Physiological responses	EDA, HR, RR, and SC	EDA, HR, RR, and SC	EDA, HR, RR, and SC	EDA, HR, RR, and SC	EDA, HR, RR, and SC

OT outdoor traffic, *IS* irrelevant speech, *PR* phones ringing, *VS* ventilation systems, *AC* activity in the corridor, *CP* customer paging, *C* computer, *WP* Wireless pager, *PBN* process background noise, *PN* process noise, *NA* noise annoyance, *NISL* noise-induced subjective load, *EDA* electrodermal activity, *HR* heart rate, *RR* respiration rate, and *SC* saliva cortisol

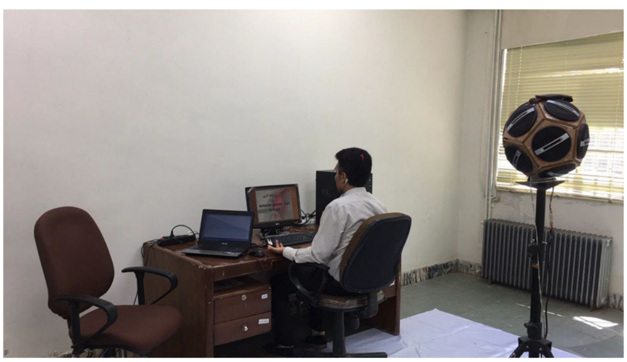

Fig. 2 Experimental setup in air-conditioned room

laboratory conditions with real working conditions, the light intensity, relative humidity, and temperature at room were set 400 Lux, 50%, and 22 °C, respectively, at all session. The coefficient of absorption of the interior surfaces of the room was corresponds with real work environments conditions. All the experimental sessions were conducted in research laboratory of the Hamadan University of Medical Sciences.

2.3 Measurements of Psychophysiological Responses

2.3.1 Psychological Responses

The psychological responses to occupational noise were assessed in two terms of noise annoyance (NA) and noise-induced mental work load (NISL). At the end of each session, the subjects were asked to rate their subjective judgment of NA using a 100-score graphical rating scale (0 = "Not at all" to 100 = "Extremely") for each noise source [19]. Also, the NISL was evaluated at the end of each session using the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) software. It is for the subjective and retrospective judgment of noise subjective load that comprises six questions concerning mental, physical, and temporal demand of the task, performance, effort and noise annoyance [20].

2.3.2 Physiological Responses

Four simple physiological responses were measured: (1) salivary cortisol (SC) expressed in micrograms per deciliter (μg/dl); (2) electrodermal activity (EDA) expressed in micro-Siemens (μS); (3) heart rate (HR), and (4) respiration rate (RR) expressed in beats per minute (bpm). Before each trial, a 3-ml saliva sample was taken to measure cortisol baseline. Also, the EDA, HR, and RR were measured using NEXUS 4 device made by Mind Media BV Company [21]. These data were recorded on a laptop via the Bluetooth. The EDA was measured through the Nexus-4 skin conductance sensor on the hand. The electrodes of this sensor were attached to the subjects' index finger and the middle finger of the non-dominant hand. The HR was gathered from the raw data of electrocardiographs (ECG), while the ECG was measured through electrodes attached to each subject's chest (the negative (black) electrode on the right chest and ground electrode was placed on the left chest in below the collarbone and the red positive electrode on the right of the sternum in the fourth intercostal space). The RR was measured via a respiration transducer belt worn around the chest, which was computed from the raw respiration data. This belt records the RR by measuring the changes in thoracic circumference when an individual breathes. The percentage change (%) of responses was calculated from the baseline to noise exposure.

2.4 Procedure

A small theory and practice training to become familiar with experiments was conducted for participants. They were mentioned to have enough sleep in the night before the experiment and refrain from drinking caffeine or any other stimulus. In each session, in order to stabilize the level of RR and HR of individuals, the subjects were asked to sit facing the desktop for around 15 min, before the experiment commenced. Then all the electrodes were attached to the subject's body (two fingers of the hand and chest). Before each trial, the SC, EDA, RR, and HR were recorded duration of 5 min (baseline). Then the LAeq(1h) were presented (with the exception of session 1 that was the background noise) and the subjects were asked to do cognitive tests (the mean of MWL resulting from tests = 46.4) during exposure to noise (1 h). A calibrated SV104 dosimeter was used to determine the LAeq (1 h) for each subject in the octave band frequency analysis. Dosimeter was attached to the subject's shoulder, close to the ear. At times 5, 15, 25, 35, 45 and 60 min (after exposure), the RR, HR, EDA were recorded. After each trial, the subjects were asked to rate the NA and MWL due to noise. The independent variables (dose) were LAeq (1 h), and the psychophysiological responses were dependent variables. Figure 3 shows a simple illustration of the implementation process of the experiments from the before, during and after exposure to noise.

2.5 Subjects

Thirty-one males by mean ± SD, 30.19 ± 6.6, (range 25–43 years old) were volunteered to participate in the experiment. The eligibility criteria for the inclusion of participants were: good general health, normal hearing, non-smoking, non-alcohol and non-drugs, low noise sensitivity, absence of sleep disorders, and no previous exposure to noise. For this objective, each participant completed the questionnaire of noise sensitivity (NS) [22], Beck Anxiety Inventory (BAI) [23], and general health questionnaire (GHQ) [24]. The participants' sleep quality was assessed using the Pittsburgh sleep quality index (PSQI) [25]. Also, auditory health screening and training of computer-assisted performance tests were conducted for each subject. The GHQ score levels of subjects were on average 15.77 ± 4.83, BMI, 24.14 ± 3.50, BAI, 4.71 ± 2.33, and NS, 57.16 ± 11.08. They had a normal hearing threshold (mean HL with at least 20 dB in the frequency range of 125–8 kHz) and free from intrinsic sleep disorders (mean PSQI $\leq$ 5). All participants had slept at least 7 h in the night before each session. Also, they were free from smoking, alcohol, and drugs. All subjects reported that they had not experienced being exposed to noises from workplaces or were not experiencing issues with noise in their current dwelling. All participants signed a consent form. The study was approved by the Medical Ethics Board at the Hamadan University of Medical Science, Hamadan, Iran.

2.6 Statistical Analysis

Descriptive analysis was performed based on mean ± SD for quantitative variables and count (%) for qualitative variables. In order to study the relationship between the NA, NISL, and SC responses with LAeq (1 h) adjusting on age, GHQ, BAI, NS, and MWL, the generalized estimating equation (GEE) model with identity link function was used. This method fits a population-specific model for correlated (and clustered) data. EDA, HR, and RR were taken continuously during the experiment. Thus, the percentage changes from the baseline to noise exposure (during 5, 15, 25, 35, 45, 60 min) for each subject were calculated. To investigate the effects of noise level on the EDA, HR and RR, adjusted on age, GHQ, BAI, NS, and MWL during the experiment, a three-level linear mixed model (3-level LMM) was used. In this study, p values less than 0.05 were considered statistically significant. Computations were performed using R version 3.4.1 [26], and SPSS 24.

3 Results

3.1 Psychological Responses

Figure 4a displays the mean ± SD of NA and NISL rating. As shown in Fig. 4a, the mean NA and NISL ratings varied entirely across the sessions. Mean NA and NISL were 6.81 and 46.48, respectively, under baseline conditions and increased under noise conditions. The NA ratings increased about 4, 5.8, 7.8, and 10.6 times relative to background noise at the CO, OPO, CR, and IN, respectively. Irrelevant speech and activity in the corridor were rated as annoying sources in office workrooms. The wireless pager and background noise in the control rooms and also process noise and activity in the corridor were rated as annoying noises in industrial workplaces. The results also showed that noise could increase the MWL. NISL rating was about 1.1, 1.22, and 1.4 times of MWL due to tests in the OPO, CR, and IN, respectively. Table 2 shows the relationship between psychological responses (NA and NISL) as a function LAeq after control-

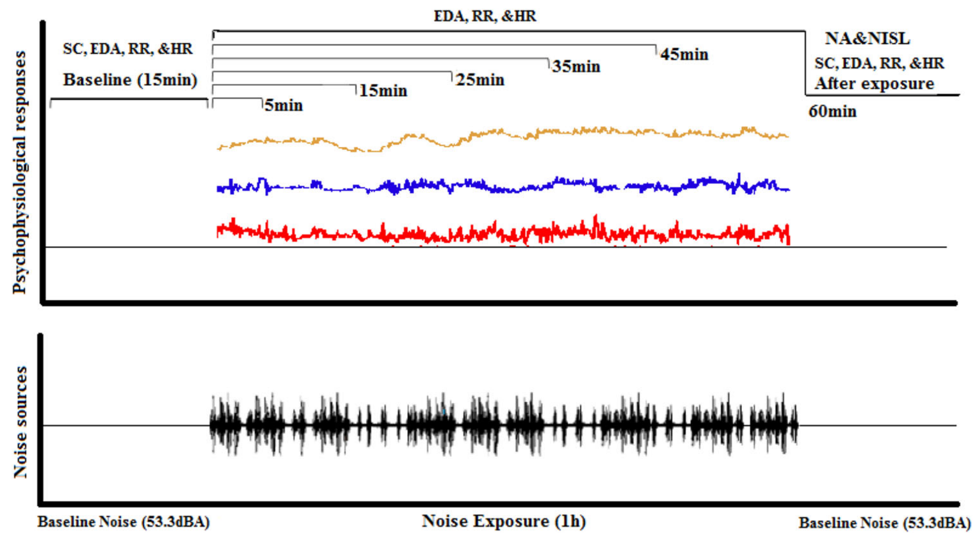

Fig. 3 Assessment of psychophysiological responses for different durations of noise exposure in each session

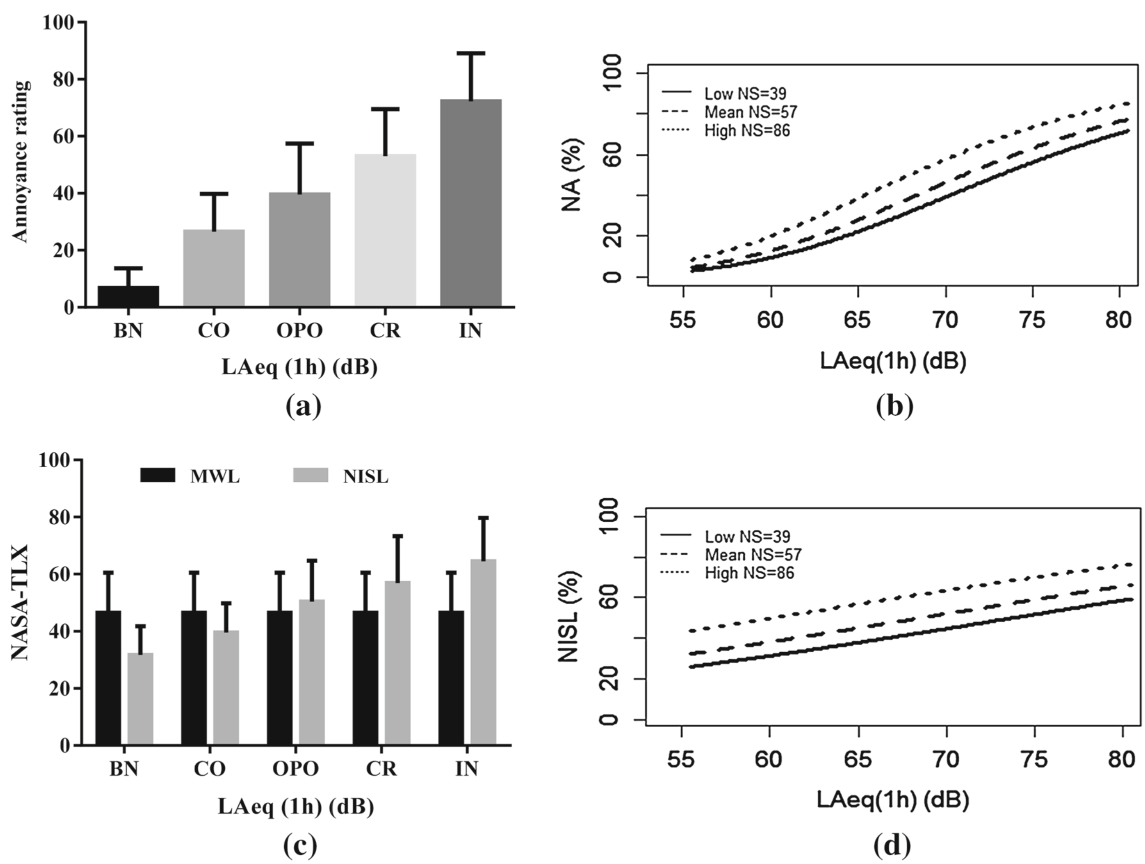

Fig. 4 Mean ± SD (**a**), and exposure–response relationships based on GEE model (**b**) for NA and NISL (BN: background noise, *CO* closed office, *OPO* open-plan office, *CR* control room, *IN* industrial noise)

ling. The population-specific linear model was fitted using the GEE method for each noise source showed that the prevalence of NA and NISL increased significantly, as the sound pressure level increased. The GH and NS were nonsignificant moderators stronger than other factors (Table 2). Figure 3b also displays exposure–response relationships using GEE model for NA and NISL ratings during 1 h exposure to LAeq for five sessions based on three levels of noise sensitivity. The regression lines of annoyance rating have a steep slope at the level higher than 65 dB(A). The highest NA and NISL rating was recorded in session 5 with the IN source. This curve takes another slope at the level higher than 68 dB(A)

Table 2 Correlation coefficients between NA-, and NISL-transformed responses* and LAeq(1h) using the GEE model

Psychological responses	NA		NISL	
Predictor	Estimate ± SE	*P* value	Estimate ± SE	*P* value
Intercept	− 2.87 ± 0.70	**< 0.001**	− 0.87 ± 0.49	0.074
LAeq (1 h)				
BN: 53.8 dB	Ref	–	–	–
CO: 64 dB	1.21 ± 0.15	**< 0.001**	0.22 ± 0.05	**< 0.001**
OPO: 68.9 dB	1.59 ± 0.15	**< 0.001**	0.50 ± 0.07	**< 0.001**
CR: 73.8 dB	1.97 ± 0.14	**< 0.001**	0.69 ± 0.08	**< 0.001**
IN: 80 dB	2.59 ± 0.17	**<0.001**	0.91 ± 0.08	**< 0.001**
Age	0.02 ± 0.02	0.256	− 0.01 ± 0.00	0.280
GHQ	− 0.03 ± 0.02	0.107	0.009 ± 0.01	0.535
BAI	0.05 ± 0.03	0.115	− 0.003 ± 0.02	0.899
NS	0.01 ± 0.006	0.107	0.01 ± 0.00	0.072
MWL	0.001 ± 0.003	0.700	− 0.000 ± 0.00	0.790

BN background noise, *CO* closed offices, *OPO* open-plan offices, *CR* control rooms, *IN* industrial noise, *NA* noise annoyance, *NISL* noise-induced subjective load

*transformed NA to $Z_{\frac{NA+0.1}{100+0.2}}$ where Z_α *is* 100αth percentile of standard Normal distribution

The bold parameters are significant at the 0.05 level

(OPO). This implies that NA and NISL ratings were affected by the source type as well as the noise exposure level.

3.2 Physiological Responses

The results cortisol changes are presented in Table 3 and Fig. 5. As shown in Fig. 5, the mean changes of the SC increased as the noise level increased for sessions 2 (CO: 46.3%), 3 (OPO: 54.02%) and 4 (CR: 38.2%). Mean changes were 14.5% under baseline conditions (BN). Mean cortisol changes for the noise of CO and OPO (60–70 dB(A)) were higher than the noise of the CR and IN (70–80 dB(A)). However, the results demonstrated that the cortisol changes were the lowest while noise levels were 75–80 dB(A) (IN: 5.85%). The SC changes during 1 h of exposure to noise was also investigated using the GEE method. The cortisol(Pre) and BAI were significant, and other factors and the interaction between cortisol(Pre) × age were nonsignificant moderators (Table 3). Figure 5b also displays an exposure–response relationship using GEE model for cortisol.

Table 3 Correlation coefficients between Saliva Cortisol and LAeq (1 h), using the GEE model

Predictor	Estimate ± SE	*P* value
Intercept	− 1.29 ± 0.62	**0.039**
LAeq (1 h)		
BN: 53.8 dB	Ref	–
CO: 64 dB	0.27 ± 0.06	**< 0.001**
OPO: 68.9 dB	0.31 ± 0.06	**< 0.001**
CR: 73.8 dB	0.21 ± 0.06	**< 0.001**
IN: 80 dB	0.12 ± 0.06	**0.050**
Cortisol(Pre)	0.93 ± 0.39	0.017
Age	0.02 ± 0.02	0.235
GHQ	0.01 ± 0.01	0.244
BAI	0.04 ± 0.02	**0.020**
NS	0.00 ± 0.00	0.320
MWL	0.00 ± 0.00	0.122
SC(Pre) × age	− 0.02 ± 0.01	0.153

The bold parameters are significant at the 0.05 level

Figure 6a also shows the mean changes of EDA, HR, and RR, before exposure, during exposure (30th min), and after exposure for CO, OPO, CR, and IN. The findings of the correlation analysis of EDA, HR, and RR for four different working environments using 3-level LMM are presented in Table 4. As summarized in Table 4, EDA responses to noise exposure were statistically significant. The three-level LMM revealed that there was a significant interaction between noise and time with EDA ($P < 0.001$). The time was also a significant moderator for EDA.

HR changes were significant under noise conditions of the CR, and IN, whereas RR changes were significant under noise conditions of the OPO, CR, and IN. The mean HR and RR decreased linearly and significantly with time. However, the interaction between noise and time and also other factors were insignificant moderators (Fig. 6 and Table 4). Figure 6b displays a dose–response relationship using three-level LMM for the changes percent of EDA, HR, and RR, as a function of LAeq relative to baseline during 1 h (for 10 min intervals) exposure to four types of occupational noise. The mean EDA changes were %12.05, %34.5, %35.2, and %22.8 in CO, OPO, CR, and IN, respectively. The HR changes were correlated with LAeq (1 h) in sessions 3 (OPO), 4 (CR), and

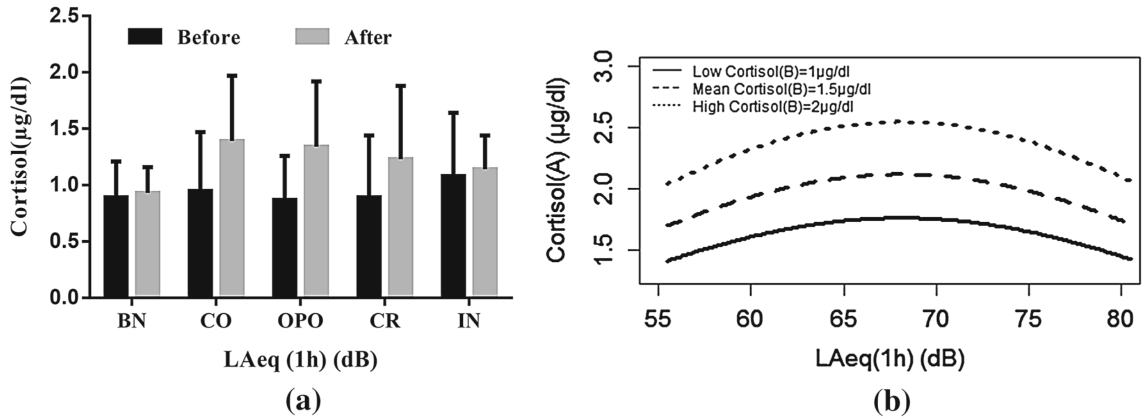

Fig. 5 Mean ± SD before and after exposure (**a**), and an exposure–response relationship based on GEE model (**b**) for cortisol (*BN* background noise, *CO* closed office, *OPO* open-plan office, *CR* control room, *IN* industrial noise, *B* before exposure, *A* after exposure)

5 (IN), and the mean changes were about %0.9, %1.2, and %2, respectively. The RR changes were also correlated with LAeq (1 h), for the OPO, CR and IN and the mean changes were about %0.2, %0.3, and %0.5, respectively. However, the relationship between HR RR with LAeq (1 h) of CO was insignificant.

4 Discussion

The current study intended to provide new data about universal relationship between noise level and prevalence of psychophysiological responses for four types of work places, despite occupational differences between them. The LAeq was used as a base for the analyses of dose–response relationships. The previous research has reported a strong relationship between the psychophysiological responses and occupational noises at the levels ≥ 85 dBA [3]. The present study expanded their findings to occupational noise in medium levels that are pervasive, background, and continuous in workplaces. In this experimental study with controlling other real environmental stressors, participants were exposed to real noise levels. The real sources of noise have different level variations. Psychophysiological responses to the exposure were measured, and individual factors moderating the responses were identified.

The NA has been identified as the most important subjective effect caused by noise in the workplace [13]. Moreover, there is a certain degree of MWL in each occupation and noise can be a crucial factor affecting MWL in the workplaces [27]. Therefore, the NA and NISL are best explained as mental effects indicators [16]. Psychological evaluations of the medium levels of occupational noise in terms of the NA and NISL indicated that ratings of the NA and NISL were highly correlated with noise level. This indicates that medium levels of occupational noise may have a significant impact on employees' subjective judgments. Moreover, the findings revealed that noise sensitivity contributes to explaining the variance NA and NISL ratings despite type of workplace. In this regard, Pedersen et al. developed a model predicting for NA at office and control rooms (levels of 55–65 dBA) [1]. Golmohammadi et al. reported that the main source of subjective annoyance among bank employees is irrelevant speech [28]. In study of Sayed Abas Ali, also percentage of annoyance caused by noise levels (75–85 dBA) in various industries, 47.1% has been reported [29]. These results are consistent with the results of previous studies. However, the findings of the present study showed that the rating of psychological responses to office rooms noise differed significantly compared to industrial workrooms in terms of both NA and NISL.

Cortisol and EDA responses to noise are best explained as stress indicators [30], as well as, the HR and RR reflects acute changes in self-regulation and emotional states that are best explained as defense reactions (physiological regulation) of the body to noise [31]. Therefore, these four physiological responses were measured in this study. A number of field and laboratory studies have addressed the associations between noise levels and physiological responses [13–16]. Several field studies have also reported a positive correlation between noise level and physiological responses. This study found that the SC levels during exposure to four types of occupational noise had significant changes compared to background noise. In this regard, Fouladi et al. reported that the industrial noise levels > 80 dB(A) have a significant effect on salivary cortisol elevation [31]. In this study, there was a significant increase in salivary cortisol at 60–70 dB(A) and a decrease in the levels of 70–80 dB(A). The dose–response relationships for the EDA, HR, and RR were moderated by age, NS, BAI, score of general health, MWL, time, and interaction effect; time and noise. The results of the assessment during five sessions showed that noise level of four types of workplaces had key

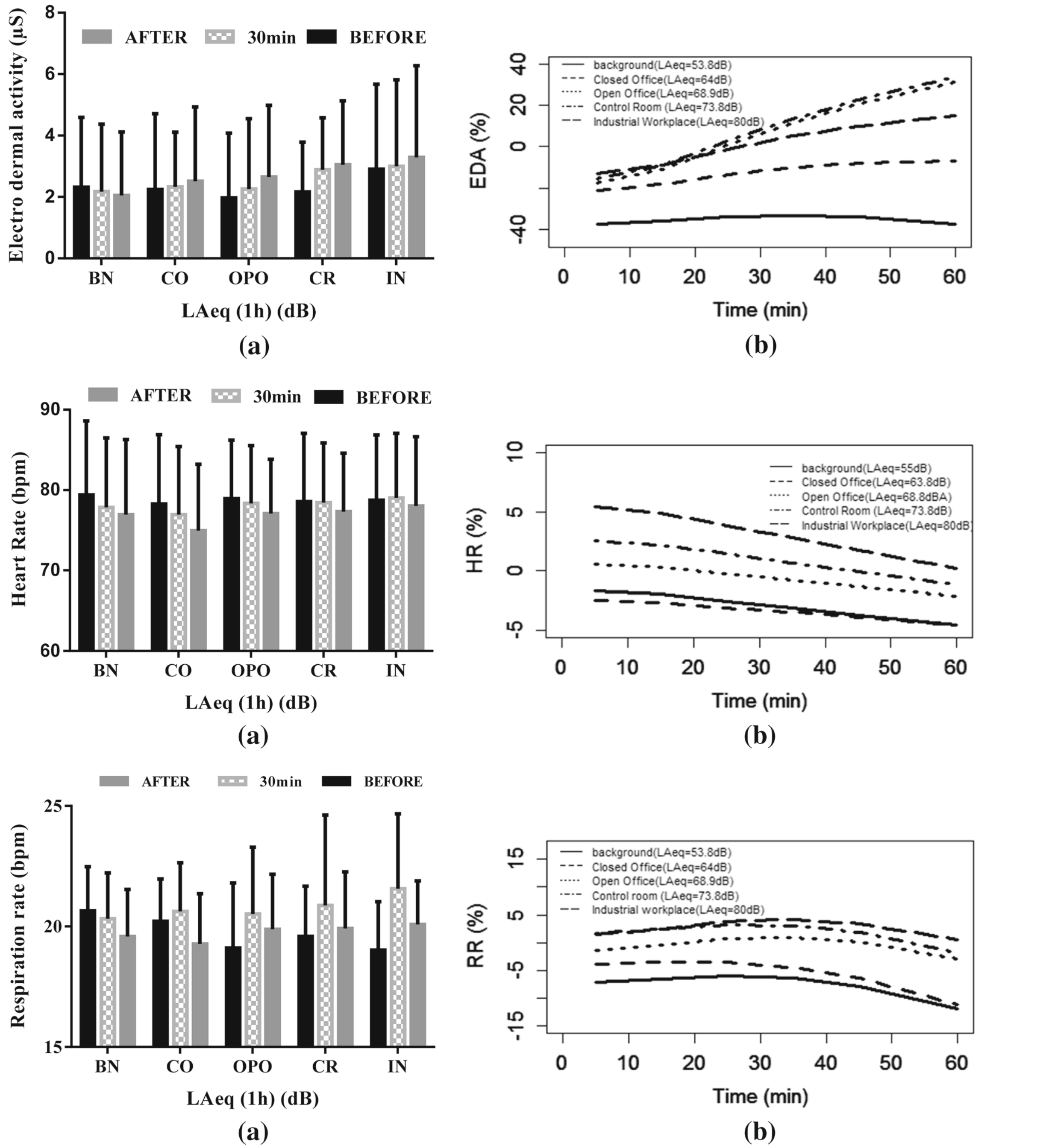

Fig. 6 Mean ± SD (**a**), and exposure–response relationships based on 3-level LMM (**b**) for EDA, HR, and RR during 1 h exposure to noise. (*BN* background noise, *CO* closed office, *OPO* open-plan office, *CR* control room, *IN* industrial noise, *B* before exposure, *A* after exposure)

effects on the mean changes of EDA, HR, and RR. In other words, the EDA, HR, and RR were correlated with noise in four type workplaces. However, the effect size of the relationships was not similar in four work environments. The majority of previous studies have mainly reported a positive correlation between noise levels and the EDA [32, 33]. This is in line with the findings of present study. This implies that not only in industrial environments, but also in OPO, noise might influence health as well as EDA confirming the conclusion of previous studies. Notbohm et al. also found accelerated EDA in exposure to traffic noise in banks [16]. Based on regression analysis, our laboratory experiment also revealed that HR has significant changes during exposure to noise ≥ 69 (CR). Park et al. reported an insignificant correlation between floor impact noise (LAFmax = 63 dBA) and HR [33]. Abbasi et al. reported the increases rate of HR relative to the baseline

Table 4 Correlation coefficients between EDA, HR and RR responses and LAeq (1 h), using the 3-level LMM

Physiological responses	EDA		HR		RR	
Predictor	Estimate ± SE	*P* value	Estimate ± SE	*P* value	Estimate ± SE	*P* value
Intercept	31.96 ± 69.50	0.650	5.43 ± 9.74	0.582	4.49 ± 8.96	0.621
LAeq (1 h)						
BN: 53.8 dB	Ref	–	–	–	–	–
CO: 64 dB	23.42 ± 10.36	**0.025**	− 0.38 ± 1.36	0.782	2.00 ± 1.44	0.160
OPO: 68.9 dB	44.50 ± 10.36	**< 0.001**	2.35 ± 1.37	0.088	7.38 ± 1.44	**< 0.001**
CR: 73.8 dB	46.85 ± 10.36	**< 0.001**	3.82 ± 1.36	**0.006**	9.47 ± 1.44	**< 0.001**
IN: 80 dB	45.02 ± 10.36	**< 0.001**	5.92 ± 1.36	**< 0.001**	10.47 ± 1.44	**< 0.001**
Age	− 1.87 ± 1.30	0.163	0.03 ± 0.18	0.860	0.04 ± 0.16	0.838
Time	0.08 ± 2.05	0.967	− 1.16 ± 0.54	**0.032**	− 1.85 ± 0.62	**0.003**
$Time^2$	− 2.70 ± 1.29	**0.037**	− 0.01 ± 0.34	0.972	− 2.00 ± 0.40	**< 0.001**
GHQ	1.81 ± 1.38	0.200	− 0.31 ± 0.19	0.121	0.11 ± 0.18	0.536
BAI	− 2.20 ± 2.44	0.370	0.26 ± 0.34	0.444	0.27 ± 0.31	0.399
NS	− 0.23 ± 0.43	0.600	0.00 ± 0.06	0.899	− 0.03 ± 0.06	0.586
BMI	0.19 ± 1.68	0.860	− 0.19 ± 0.22	0.410	− 0.27 ± 0.21	0.198
MWL	0.14 ± 0.25	0.580	0.04 ± 0.03	0.240	− 0.03 ± 0.03	0.457
LAeq (1 h)						
BN:53.8 dB × time	Ref	–	–	–	–	–
CO: 64 dB × time	5.77 ± 2.85	**0.043**	0.30 ± 0.76	0.688	− 1.04 ± 0.87	0.231
OPO: 68.9 dB × time	19.70 ± 2.85	**< 0.001**	0.10 ± 0.76	0.895	1.27 ± 0.87	0.143
CR: 73.8 dB × time	19.83 ± 2.85	**< 0.001**	− 0.32 ± 0.76	0.673	0.51 ± 0.87	0.557
IN: 80 dB × time	11.28 ± 2.85	**< 0.001**	− 0.92 ± 0.76	0.224	1.45 ± 0.87	0.094

The bold parameters are significant at the 0.05 level

in the exposer to levels ≥ 60 dB [15]. In regression analysis, the RR response was strongest during noise exposure among physiological responses and the results revealed that the RR increased due to noise exposure and changes were significant during exposure to noise ≥ 65dBA (OPO). Shafiee et al. found significant respiratory changes in staff open-plan bank offices when LAeq were ≥ 65 dBA [32]. Gomez et al. also reported an association between noise and respiratory responses [34].

The results of the evaluation of physiological responses showed that changes in physiological responses due to noise did not have the same trend despite the difference in noise levels. The inconsistency between changes in responses can be justified according to a model presented by James-Lang [35]. This model indicates the relationship between the stimuli intensity and the physiological response in a biological system. According to this model, human physiological response to stimulus consists of three stages: before exposure, after exposure, and the third stage involves active defense for eliminate reactions to secondary stimuli. The results revealed that before exposure to noise, the responses were almost calm. Immediately, after presentation of noise, the HR accelerated but gradually decreased over time (indicating defense stage), whereas EDA and RR increased during 1 h exposure to noise. The changes EDA to noise of CO and IN was lower than two other noise. It was because of low level and transient noise in the CO, and also steady, monotonous, and continuous noise in the IN (indicating the stage after the encounter), whereas the EDA accelerated during exposure to noise of OPO and CR, due to random, intermittent, and arousal noise (indicating stage of after exposure). This experimental study also revealed that RR increased during noise exposure, but it gradually declined in the final of the experiment (indicating after exposure). The SC was measured before and after of presentation of noise in each session. It increased after exposure to noise of CO, OPO, and CR (indicating stage of after exposure).

5 Conclusion

For the medium noise levels of the four categories occupational, the relationship between %NA, %NISL, and %SC with LAeq could be well described with a linear regression model (GEE model). Influences of medium noise levels on annoyance and MWL ratings depends entirely on the values of noise sensitivity and annoyance ratings between four noise sources were significantly different. Generally, most subjects were predicted to be highly annoyed ($\geq 40\%$) by the noise of OPO, CR, and IN. The MWL can also increase under the influence of noise in levels ≥ 65 dB(A) (OPO). Among various prediction models, mixed models (3-level LMM) could be an appropriate prediction for physiological changes. In addition to subjective effects, the medium levels of occupational noise can significantly affect the physiological responses in view of the moderating factors. Physiological changes due to medium levels of occupational noise were small, but consistent and significant. However, these changes were not affected similarly, between occupational groups. The EDA and SC responses most affected by the type of noise compared to the noise level. According to the regression models, it seems that medium levels of occupational noise have significant and linear effects on EDA, RR, and HR in levels ≥ 60 (CO), ≥ 65 (OPO), and ≥ 69 dB(A) (CR), respectively. Moreover, the levels 60–70 dB(A) (CO and OPO) can increase mean of cortisol level more than the levels 70–80 dB(A) (CR and IN).

References

1. Pedersen, E., Waye, K. P., and Ryberg J. B.: Response to occupational noise of medium levels at four types of work places. In: International Noise and Sustainability, pp. 1–8 (2010)
2. Basner, M., Brink, M., Bristow, A., Kluizenaar, Y., Finegold, L., Hong, J., et al.: ICBEN review of research on the biological effects of noise 2011–2014. Noise Health **75**(17), 57 (2015)
3. Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., Stansfeld, S.: Auditory and non-auditory effects of noise on health. The Lancet **383**(9925), 1325–1332 (2014)
4. Smith, A.: A review of the non-auditory effects of noise on health. Work Stress **5**(1), 49–63 (1991)
5. Hua, H., Emilsson, M., Kähäri, K., Widén, S., Möller, C., Lyxell, B.: The impact of different background noises: effects on cognitive performance and perceived disturbance in employees with aided hearing impairment and normal hearing. J. Am. Acad. Audiol. **25**(9), 859–868 (2014)
6. Walker, E.D., Brammer, A., Cherniack, Martin G., Francine, L., Cavallari, J.M.: Cardiovascular and stress responses to short-term noise exposures—a panel study in healthy males. Environ. Res. **10**, 414–439 (2016)
7. Kjellberg, A., Landström, U.: Noise in the office: part II—the scientific basis (knowledge base) for the guide. Int. J. Ind. Ergon. **4**, 401–427 (1994)
8. Belojevic, G., et al.: Recent advances in research on non-auditory effects of community noise'. Srp. Arh. Celok. Lek. **144**(1–2), 94–98 (2016)
9. Chang, L.-T., et al.: Short-term exposure to noise, fine particulate matter and nitrogen oxides on ambulatory blood pressure: a repeated-measure study. Environ. Res. **140**, 634–640 (2015)
10. Volandri, G., Puccio, F.Di, Forte, P., Mattei, L.: Psychoacoustic analysis of power windows sounds: correlation between subjective and objective evaluations. Appl. Acoust. **134**, 160–170 (2018)
11. Sim, C.S., Sung, J.H., Cheon, S.H., Lee, J.M., Lee, J.W., Lee, J.: The effects of different noise types on heart rate variability in men. Yonsei Med. J. **56**(1), 235 (2015)
12. Zhu, S.K., Sakakibara, H., Yamada, S.: Combined effects of hand-arm vibration and noise on temporary threshold shifts of hearing in healthy subjects. Int. Arch. Occup. Environ. Health **69**(6), 433–436 (1997)
13. Eriksson, C., Pershagen, G., Nilsson, M.: Biological mechanisms related to cardiovascular and metabolic effects by environmental noise. WHO Environmental Noise Guidelines for the European Region, pp. 1–19 (2018)
14. Elmenhorst, E.M., et al.: Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose-response relationships in laboratory and field'. Int. Arch. Occup. Environ. Health **83**(7), 743–751 (2010)
15. Abbasi, A.M., Motamedzade, M., Aliabadi, M., Golmohammadi, R., Tapak, L.: Study of the physiological and mental health effects caused by exposure to low-frequency noise in a simulated control room. Build. Acoust. **25**(3), 233–248 (2018)
16. Notbohm, G., Schmook, R., Schwarze, S., Angerer, P.: Patterns of physiological and affective responses to vehicle pass-by noises. Noise Health **15**(66), 355 (2013)
17. Li, Z.-G., Di, G.-Q., Li, J.: Relationship between electroencephalogram variation and subjective annoyance under noise exposure'. Appl. Acoust. **75**(1), 37–42 (2014)
18. Miedema, H.M.E., Vos, H.: Noise sensitivity and reactions to noise and other environmental conditions. J Acoust Soc Am **113**(3), 1492–1504 (2003)
19. ISO/NP TS 15666: Acoustics,—Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys. International Organization for Standardization, Geneva (2003)
20. Hart, S.G., Staveland, L.E.: Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. Adv. Psychol. **52**, 139–183 (1988)
21. Edmonds, W.A., Tenenbaum, G.: Case Studies in Applied Psychophysiology: Neurofeedback and Biofeedback Treatments for Advances in Human Performance. Wiley, Hoboken (2011)
22. Ekehammar, B.: Weinstein'S noise sensitivity scale: reliability and construct validity. Percept. Mot. Skills **70**(1), 129 (1990)
23. Beck, Aaron T., Epstein, Norman, Brown, Gary, Steer, Robert A.: An inventory for measuring clinical anxiety: psychometric properties. J. Consult. Clin. Psychol. **56**(6), 893 (1988)
24. Montazeri, A., Harirchi, A.M., Shariati, M., Garmaroudi, G., Ebadi, M., Fateh, A.: Health and quality of life outcomes | full text|the 12-item general health questionnaire (GHQ-12): translation and validation study of the Iranian version. Health Qual. Life Outcomes **1**(66), 1–4 (2003)
25. Buysse, D.J., Reynolds, C.F., Monk, T.H., Berman, S.R., Kupfer, D.J.: The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res. **28**(2), 193–213 (1989)
26. Core Team, R (ed.): A Language and Environment for Statistical Computing, vol. 2. R Foundation, Vienna (2018)
27. Darvishi, E., Maleki, A., Giahi, O., Akbarzadeh, A.: Subjective mental workload and its correlation with musculoskeletal disorders in bank staff. J Manip. Physiol. Ther. **39**(6), 420 (2016)
28. Golmohammadi, R., Aliabadi, M., Nezami, T.: An experimental study of acoustic comfort in open space banks based on speech intelligibility and noise annoyance measures. Arch. Acoust. **42**(2), 333–347 (2017)

29. Ali, S.A.: Industrial noise levels and annoyance in Egypt. Appl. Acoust. **72**(4), 221–225 (2011)
30. Fouladi, D.B., Nassiri, P., Monazzam, E.M., Farahani, S., Hassanzadeh, G., Hoseini, M.: Industrial noise exposure and salivary cortisol in blue collar industrial workers. Noise Health **14**(59), 184 (2012)
31. Zhang, L., Kang, J., Luo, H., Zhong, B.: Drivers' physiological response and emotional evaluation in the noisy environment of the control cabin of a shield tunneling machine. Appl. Acoust. **138**, 1–8 (2018)
32. Shafiee Motlagh, M., Faradmal, J., Aliabadi, M., Golmohammadi, R., Ranjbar, A.: Empirical study of room acoustic conditions and neurophysiologic strain in staff working in special open-plan bank offices. Acoust. Aust. **46**(3), 329–338 (2018)
33. Park, S.H., Lee, P.J.: Effects of floor impact noise on psychophysiological responses. Build. Environ. **116**, 173–181 (2017)
34. Gomez, P., Danuser, B.: Affective and physiological responses to environmental noises and music. Int. J. Psychophysiol. **53**(2), 91–103 (2004)
35. Lang, P.J., Bradley, M.M., Cuthbert, B.N.: Motivated attention: affect, activation, and action. Atten. Orient. Sens. Mot. Process. **97**, 135 (1997)