

Drivers' physiological response and emotional evaluation in the noisy environment of the control cabin of a shield tunneling machine

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Abstract: Being a driver in the control cabin of a shield tunneling machine is a high-pressure career. The physiological responses and mood swings of a driver are vital to his occupational health and construction safety; however, a driver's emotional intensity and physiological reactions in a noisy environment have not been considered. This study aims to investigate how a driver's emotional intensity and physiological responses in a noisy environment can be altered. On-site measurements were conducted in an urban metro system, and an emotional survey was performed. A wearable device was used as a physiological measurement tool to obtain heart rate data from a driver. Results indicate that the driver pays considerable attention to the noisy environment. The sound pressure level in the control cabin was in the range of 96.8 to 98.7 dBA. The driver's emotion is influenced when the sound pressure level increases to 94.5 dBA. The relationship was significant between the emotional intensity and the sound pressure level. The fear was highly evident with the sound pressure level increase given that the drivers were concerned about operational errors. The heart rate of the driver was significantly influenced in the noisy environment for a long time. The increased heart rate at 92 to 96 dBA was faster than at other ranges of sound pressure level. The emotional intensity had impacts on the heart rate of the driver. The disliking influenced the heart rate more obviously than the other two emotional types. The driver's emotion has a relationship with social background.

Keywords: Emotional evaluation, Emotional intensity, Physiological response, Noisy environment, Control cabin of shield tunneling machine

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1. Introduction

Noise is undesired sound, which is a pollutant that affects human health [1]. The health effects of noise can be divided into two categories, namely, auditory health effects and non-auditory health effects [1]. In terms of auditory health effects, hearing loss is a significant health effect [2]. In a construction site, construction noise is the most common source of noise pollution, which can cause several risks to workers' health and safety[3]. When a worker is exposed to noise in a construction site for a long time, his hearing loss is induced either temporarily or permanently, and the hearing loss will adversely affect his perception and localization of environmental sounds, such as the alarm of a construction vehicle. Data

corroborate that 667 construction workers were killed after being struck by construction vehicles from 1982 to 1992, in addition, according to the incident reports by Centers for Disease Control (CDC), one of the major problems in a construction site is that construction workers fail to hear the alarm of construction vehicles [4]. Noise-induced hearing loss (NIHL) is common among construction workers due to construction. Studies found considerable evidence between the relationship of construction noise and workers' hearing loss through a questionnaire [5-7]. Meanwhile, non-auditory health effects include annoyance [8-12], cardiovascular disease [13, 14], cognitive performance [15, 16], human behaviors [17, 18], mood swings, and sleep disturbance [19, 20]. In recent years, researchers have paid considerable attention to non-auditory health effects [1]. The communication of workers on-site may be made less efficient in quality and quantity due to construction noise. Another problem is that workers induce excessive fatigue because of prolonged noise exposure, which will lead to an increase in errors resulting from a predictable cognitive failure [6]. Thus, construction noise is a fatal factor in accidents given that work-related accidents represent significant capital and productivity losses for the construction industry.

With the growth of urban population, the capacity of public transports and road surfaces is unable to meet the requirement of human transportation. Metro systems had been considered as an important factor to improve the quality of transportation and relieve congestion by filling the gaps of insufficient public transports and road surfaces capacity [21]. In the construction of metro systems, a shield tunneling machine is the most common machinery used for constructing metro lines. The quality and safety of tunnel constructions were considered to achieve the important results of the construction progress of metro systems. However, the quality and safety of tunnel construction were dependent on certain factors, i.e., real-time attitude measurement of the shield tunneling machine, which can control the shield tunneling machine that can directly affect the construction precision of the tunnel, which is an important safety protocol of the shield tunneling machine [22]. Furthermore, the cracks and grouting holes on tunnel concrete segments were referred to as tunnel quality defects [23]. The sources of defects were incorrect grouting pressure, insufficient foam raw material, and oil seepage. In addition, during the shield tunnel construction, the effect of soil deformation around the tunnel was the key factor to ensure the safety of the tunnel and buildings adjacent to the project [24]. For the abovementioned factors, their status would display on the operational screen in the control cabin of the shield tunneling machine, and the drivers must observe the change in the status of the factors continuously. Thus, the driver of the control cabin of the shield tunneling machine is a key artificial factor to ensure the safety and quality of metro constructions, and being a driver is a high-pressure underground work in metro constructions. The subjective reports had indicated that underground workers were less satisfied with their surroundings given that their environment hindered their work and that their emotions were extremely anxious, depressed, and hostile [25]. In an underground environment, thermal comfort, noise, and lighting were the most salient factors as environmental stressors [26]. In addition, some researches show evidence about the relationship between the sound environment and human emotions. Hong et al. [27] used pleasantness as a factor to construct a structural equation model of urban soundscapes. Galbrun et al. [28] discovered that human's emotional assessment showed significant correlations with water sound in outdoor environments. Benfield et al. [29] discovered that either 45 dBA or 60 dBA of the natural sound in the park had a significant effect on the positive emotion of the visitors through the Positive and Negative Affect Schedule (PANAS). The role of the negative affect is key in understanding how negative environmental characteristics, such as the noise of a wind turbine, can cause health issues [30]. In addition, the emotional fluctuation of the shield tunneling machine driver exposed to a noisy environment for more than eight hours was the potential hazard to safety and quality in the process of metro constructions. However, the researches confirm less investigation about the relationship between the emotions of a shield tunneling machine driver and the noisy environment.

On the basis of the analysis of the above research methods, questionnaire surveys or interviews are used more frequently

than the epidemiological methodology. However, a self-reporting measure has certain disadvantages. For example, some people may be less sensitive to small changes in stimuli than others [31]. Therefore, the use of physiological measurements in addition to questionnaires would be beneficial to the study of the effects of a noisy environment on humans. Considerable research has investigated the effects of a noisy environment on humans using physiological measurements [32, 33]. However, studies investigating the relationship between a shield tunneling machine driver's emotion and physiological responses under a noisy environment have been limited [32, 34]. In addition, previous studies did not investigate the effect of a driver's physiological response and emotional evaluation in a noisy construction environment, which varies according to the social characteristics of drivers and may lead to different levels of reaction and evaluation.

This study therefore aims to investigate a shield tunneling machine driver's physiological response and emotional evaluation in a noisy environment. The research questions in this paper include five aspects: 1, determine a driver's overall evaluation of a noisy environment. 2, investigate the relationship between sound pressure level in the control cabin of the shield tunneling machine and the drivers' emotional evaluation. 3, investigate the relationship between a driver's physiological response and emotional evaluation in noisy environment. 4, investigate the relationship between a driver's physiological responses and sound pressure level in the control cabin. 5, determine the effects of a driver's social background on a driver's emotional evaluation in a noisy environment. A typical Wuhan metro line was chosen as the case site, and the noise level measurements and a self-administered questionnaire survey were used for data collection.

2. Methodology

2.1 Survey site

The development of Chinese metro systems is currently boosting, reaching a historically high level in terms of construction speed, scale, and investment [35]. The Wuhan metro system is an elevated and underground urban metro system in the city of Wuhan, Hubei, China. To accommodate the increasing cross-borough traffic and provide commuter services to suburban satellites, the Wuhan metro system has planned to pursue ambitious expansion projects to connect Wuhan's three boroughs divided by the mighty Yangtze River and Han River. By 2017, seven urban transit lines and two suburban lines with a length of 273.1 km in total are expected to serve Wuhan. Wuhan metro lines, which are under construction through the shield tunneling machine, were chosen at the case site. There are 60–70 shield tunneling machines working for Wuhan metro lines on a daily basis. Approximately 2–3 shield tunneling machine drivers in each shield tunneling machine alternate work for one day. Therefore, enough shield tunneling machine drivers as subjects were available for this study. Fig.1 shows the survey site for this study.

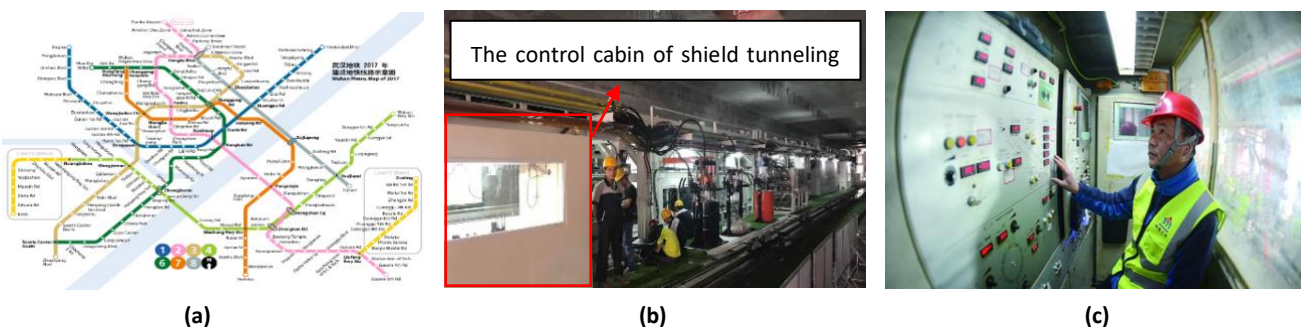


Fig. 1. The survey site for this study. (a) Wuhan metro map 2017; (b) control cabin of a shield tunneling machine; (c) shield tunneling machine driver.

2.2 Noise level measurement

The measurement of the noise level was conducted immediately when each subject began to fill out the questionnaire. In this study, a class I (IEC 61672:2013) sound level meter was used for the data acquisition, measuring the sound pressure level (SPL). For noise assessment, the construction noise level was quantified using the equivalent continuous sound level (L_{Aeq}), because the metric was useful to describe the average noise level during an entire phase of construction [36]. For the assurance of the accuracy of the obtained data, sound calibration was performed in a quiet environment before each measurement. The place of measurement was in the shield tunneling machine's control cabin. During the measurement, the microphone of the sound level meter was positioned over 1 m away from any reflective surface and 1.2–1.5 m above the floor to reduce the effect of acoustic reflection. The sound level meter was set in slow mode and A-weighting, and reading was acquired every 3–5 second. A total of 5 minute data were obtained in each shield tunneling machine's control cabin, the 5 minutes data was used for identifying relationships with emotional factors, i.e. short duration measurements of heart rate and emotional responses, which discussed from Section 3.2.

Simultaneously, the overall measurement of the noise in the environment in the shield tunneling machine's control cabin was conducted, where measurement process was from 9:00 in the morning to 17:00 in the afternoon. In each half an hour 10 A-weighted SPLs were measured, each based on the average of 3 minutes. To ensure accuracy of the mean value, the measured noise level data in the highest and lowest values were removed, then the average of the remaining values was taken. The long term measurement was only used in Section 3.1 to identify variations across the day. In addition, other environmental factors, including air temperature, relative humidity, and luminance, were measured for further analysis.

2.3 Physiological response measurement

Psychologists have used physiological measures to differentiate human emotions, such as anger, grief, and sadness [37]. Researchers in human factors have used physiological measures as indicators of emotional stress and effort [38]. With the increasing popularity of wearable devices equipped with the various physiological sensors have been used in physiological measurement, which could be divided into two categories: (1) brain physiological activities, i.e., electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) and (2) peripheral physiological activities, i.e., galvanic skin response (GSR), skin temperature, respiration, and heart rate [39]. The emotional responses have been frequently investigated using the spectral power of EEG signals. However, the emotional responses to the environmental stimuli were relatively easy-to-capture peripheral signals [40]. In recent years, indices of heart rate (HR) have received considerable attention in emotion literature. HR reflects acute changes in self-regulation and emotional states in physiological responses [41]. Particularly, HR reflected not only physiological regulation but also emotional regulation [42, 43]. In addition, HR is an easy-to-use measure that can be tested using inexpensive equipment. Hence, when the driver as the subject whose physiological response was measured through the physiological measurement device was ensured of convenience in the operation, the wearable device was selected. In this study, a physiological signal to measure HR expressed in beats per minute (BPM) was available. The data of the physiological signals were recorded on the wearable device using the Apple Watch Series 2.

To obtain the best results, each subject should start with a good fit. The Apple Watch Series 2 in the subject's right wrist was snug but comfortable. In addition, no tattoos were found on the subject's wrist, which could not impact the sensor performance. Motion was another factor that could affect the sensor performance; however, the subjects were usually sitting still in the control cabin and rarely moved. These factors ensured the acquisition of reliable data for physiological responses.

Notably a delay at the onset of the stimulus-evoked physiological activity emerged. This study only focuses on analyzing the changes in response following such a delay. The physiological data was collected for the last 18 seconds, excluding the first 5 seconds immediately after each subject began to fill out the questionnaire.

2.4 Design of emotion survey

Emotions are pervasive, an inseparable part of the human experience and life. Emotions shape perceptions and direct behavior and influence interactions with others [44]. Watson et al. [45] divided personal emotion into two categories: positive emotions and negative emotions. Glomb et al. [46] developed the Discrete Emotions Emotional Labor Scale (DEELS) according to staff's self-authenticity and Watson's emotional classification. Fourteen emotional words are included in the DEELS. Before the formal questionnaire was formatted, this paper took a test to indicate whether the drivers' emotion were influenced by the noisy environment in the control cabin as one influencing factor, 20 drivers were stochastically selected to answer whether their emotions changed when 20 drivers worn hearing protections or not. A correlations analysis was used. The result exhibited that there was a significant correlation between the hearing protection worn and drivers' emotional responses (2-tailed significant value is 0.025, $p < 0.05$). The result also indicated that the noisy environment in the control cabin influenced the drivers' emotions. Subsequently, the current study chose three words of negative emotions: anxiety, fear, and disliking. These three words served as the different types of emotional evaluation of the shield tunneling machine driver in the emotion survey as discussed by the psychologists, the managers of the shield tunneling machine, and the drivers in accordance with the DEELS. In terms of the evaluation of the emotions, a five-point emotional intensity scale was used in the questionnaire design. The evaluation of emotion intensity was divided into five levels: 1 = never, 2 = rarely, 3 = sometimes, 4 = most of the time, and 5 = always.

Before the formal investigation was conducted, questionnaire reliability and validity were tested to assess the suitability of the final questionnaire [47]. In this study, factor analysis was performed on the emotional evaluation item results from the questionnaire, resulting in a KMO (Keiser-Meyer-Olkin) = 0.735, where values greater than 0.6 are normally acceptable [48]. Accordingly, two factors were extracted with characteristic roots greater than 1, and their cumulative contribution to all eight variables was 53.2%. Bartlett's Test of Sphericity indicated $p < 0.001$, which met the requirement for validity [49]. Moreover, SPSS software reliability analysis was used to perform a confidence test on the questionnaire's emotional evaluation type questions, resulting in Cronbach's α of 0.723, which was within an acceptable range.

A total of 112 shield tunneling machine drivers took part in the experiment. All subjects were males. None of the subjects reported hearing disabilities, and the physical and psychological aspects of the subjects were also good. The subjects in all the field surveys were randomly selected, and their educational and social backgrounds were proven to be representative [50]. Given that the shield tunneling machine drivers' social background may also influence their evaluation of emotion, the subjects were sorted into four categories in terms of age: ≤ 24 , 25–30, 31–35, and ≥ 36 years old; three categories in terms of educational levels: senior middle school, technical school, and college graduates; and four categories in terms of years of service: ≤ 2 , 3–5, 6–8, ≥ 9 years. Before the questionnaire survey, the subjects were told to spend 3–5 minutes to evaluate the environment of the shield tunneling machine's control cabin. Given that the subjects need time, approximately 20–30 minutes to accommodate the sound environment in the spaces [51], the drivers who were in the shield tunneling machine's control cabin for less than half an hour were not interviewed.

The emotional survey was conducted immediately after every SPL measurement. For the investigation of the influence of

noise in the shield tunneling machine's control cabin on the evaluation of the drivers' emotions, a questionnaire survey was also conducted at the case site [52]. The questionnaire survey was conducted immediately after the noise measurement, and every questionnaire survey was generally done by the interviewer in 3–5 minutes [53]. In terms of subjective investigation, 103 valid questionnaires were obtained from the survey site, and the number of questionnaires was determined on the basis of prior studies in which 100–150 soundscape survey questionnaires could be considered to be representative [54].

2.5 Statistical analysis

Statistical analyses were performed using SPSS for windows (version 23.0, SPSS Inc. Chicago, IL). The data were analyzed using the following: chi-square correlations for factors with three or more categories of ranked variables and chi-square contingency correlations (two-tailed) for factors with three or more categories for categorical variables. In this study, p values less than 5% ($p < 0.05$) were considered statistically significant, as well as the mean differences using t-test (two-tailed) for factors with two categories. Linear and nonlinear correlations were considered.

3. Results and discussion

3.1 Evaluation of the overall environment in the control cabin

The physical environment in the shield tunneling machine's control cabin, such as noise, luminance, temperature, and humidity, has an impact on the emotion of the shield tunneling machine drivers. Through the questionnaire, the drivers ranked the physical environment of the control cabin of a shield tunneling machine. Table 1 shows environmental influence on the drivers' emotion. It can be seen that the drivers considered temperature in the control cabin as the most significant factor that impacts their emotion, successively followed by the noise, humidity, and luminance factors. Notably, the noise factor in the control cabin had a major influence.

Table 1

Compositor of the environmental influence on the drivers' emotions.

	Noise	Temperature	Humidity	Luminance
Mean of ranking	2.07	1.88	2.75	3.30
Standard deviation	0.93	1.02	0.91	1.00

In this study, the SPL of four control cabins working on four metro lines were stochastically selected to conduct the measurement. Fig. 2 shows the SPL value at different times in four shield tunneling machines, where it can be seen that the mean daily values of the measured day-long noise level at the central points of the four control cabins from 9:00 a.m. to 5:00 p.m. were between 96.8 and 98.7 dBA. Generally, a minimal value of the SPL during every two hours through the measurement process was observed. The reason was that the speed of shield tunneling machine operated was slowed down every 1.5–2 hours, when it was ready for transporting the soil to the ground. In this case, an independent sample t-test was applied to any two control cabins to assess the differences between every pair of corresponding minimal SPL values. Consequently, no significant differences ($p > 0.1$) were found, making the performance of the emotional evaluation possible.

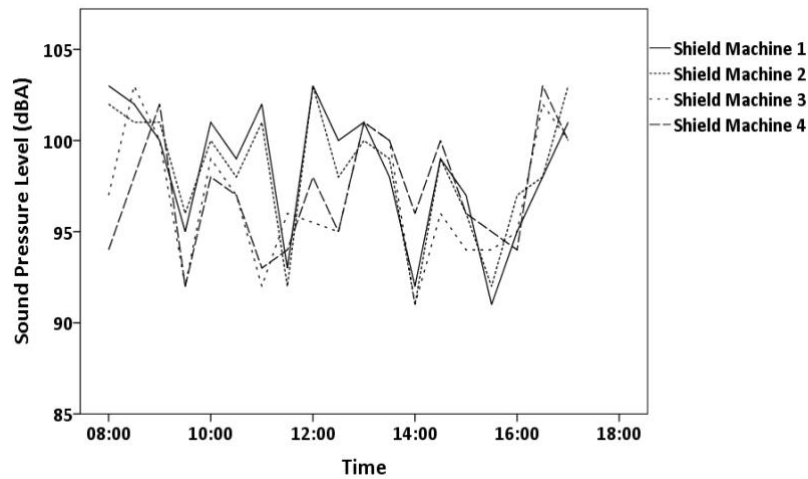


Fig. 2. SPL value at different times in four shield tunneling machines.

3.2 Relationship between SPL in control cabin and emotional evaluation

Several graphs were presented to show the emotion evaluation results. Fig. 3 shows different emotions corresponding to the range of SPL, where it can be seen that the shield tunneling machine drivers were more likely to reflect the anxiety emotion than the other two emotional types when the value of the SPL was between 92 and 100 dBA. However, the fear and disliking emotions of the drivers tended to take place in a scope from 96 to 102 dBA and from 96 to 100 dBA, respectively.

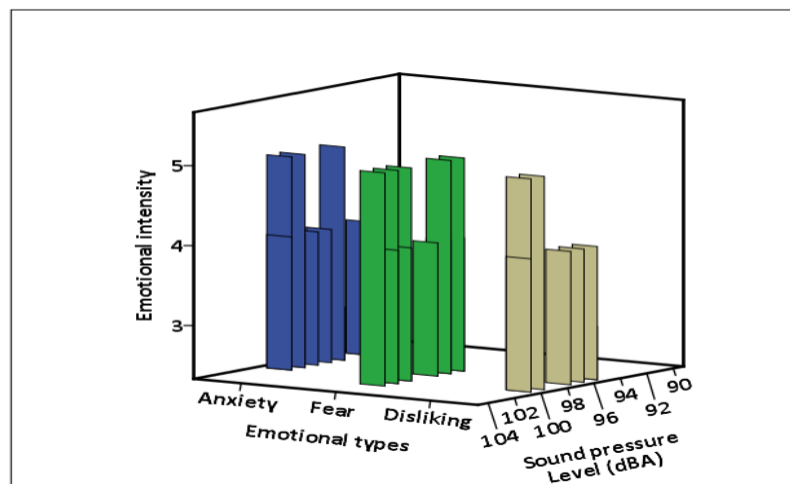


Fig. 3. Different emotion corresponding to range of SPL.

Fig. 4 shows the relationship between the degree of emotion on SPL in the control cabin and the measured SPL synchronous with the questionnaire. The degree of emotion evaluation was expressed by mean of emotional intensity, which corresponded to the mean of “anxiety”, “fear” and “disliking” results. As the mean value of SPL increased, the degree of emotion evaluation showed an upward trend. The correlation coefficient between them was $r = 0.7$ ($p < 0.01$). The average SPL value corresponded to approximately 93.6 dBA when the emotion evaluation was “Rarely.” When the emotion evaluation was “Sometimes”, the average SPL value was 94.5 dBA. When the emotion evaluation was “Most of time”, the average SPL value was 97.8 dBA. The average SPL value was 99.1 dBA when the emotion evaluation was “Always.” Producing a higher emotional intensity would be easy when an SPL value exceeded 98 dBA in the control cabin. Evidently, the noise factor influenced the emotion.

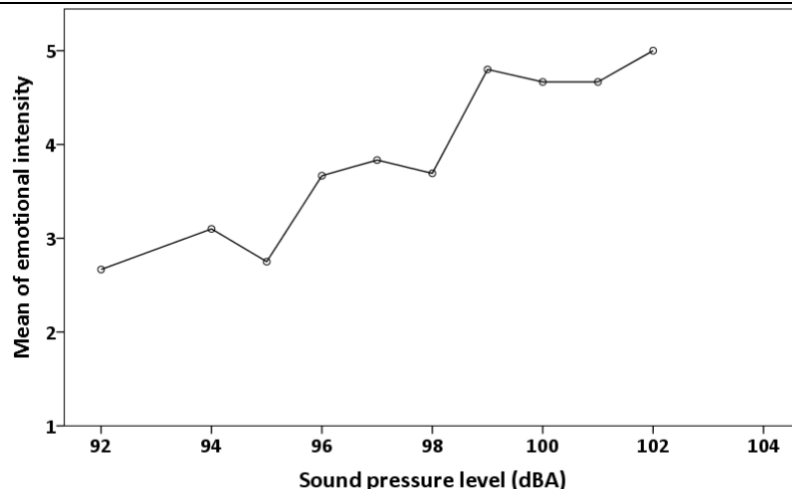


Fig. 4. Mean of emotional intensity as a function of SPL.

Notably a general correlation between the SPL and the three emotional types exists ($p < 0.001$). Fig. 5 shows the relationship between emotional intensity and SPL of the drivers' different emotional types. It can be seen that the drivers' emotional intensity of the anxiety, fear, and disliking emotion increased with SPL increased. The coefficients of determination R^2 was 0.49, 0.534, and 0.805, respectively. This result confirmed that the rate of the emotional intensity increase in the fear emotion was the fastest among the three emotional intensities. According to the interview, some drivers said, "Driver is a high pressure career." Other drivers said, "The environment of the control cabin is noisy, this environment makes me fearful most of the time." Some drivers also said, "The operational error is the biggest concern." Hence, the reason was that the drivers were concerned about operational errors, and the fear emotion was highly significant as the SPL increased in the noisy environment.

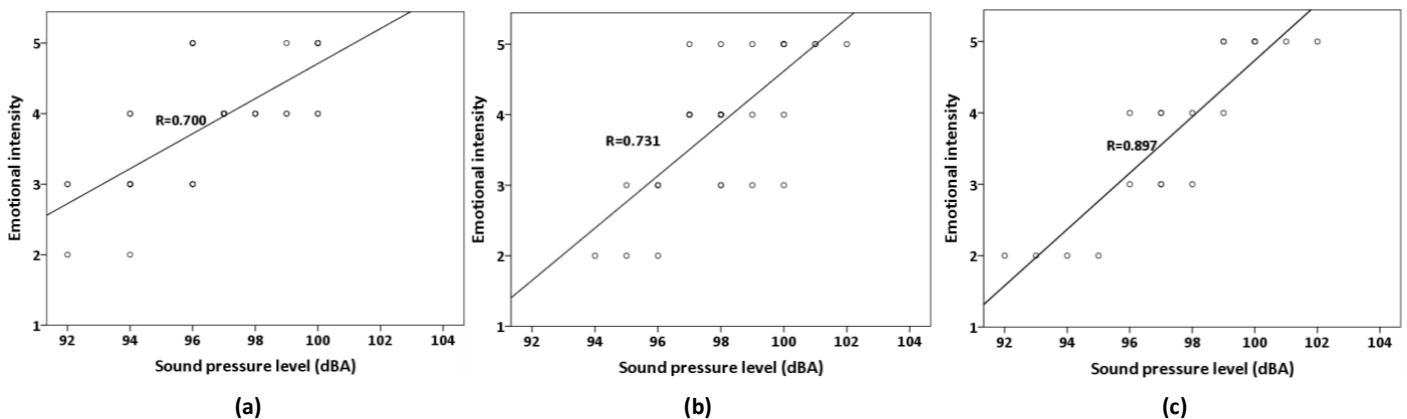


Fig. 5. Relationship between emotional intensity and SPL of the drivers' different emotional types: (a) anxiety; (b) fear; and (c) disliking.

Whether the SPL corresponding to the different emotion categories was different, which was the prerequisite for the relationship between SPL and emotional intensity, an independent sample t-test (two-tailed) was used. Table. 2 is the independent sample t-test for every two emotional types based on SPL, which exhibits significant difference occurred in every two emotional types ($p < 0.05$).

Table 2

Independent sample t-test for every two emotional types based on SPL.

Dependent variable: sound pressure level			
(I) Emotional type	(J) Emotional type	Mean difference (I-J)	Sig.
Anxiety emotion	Fear emotion	-2.00*	0.000
Disliking emotion	Anxiety emotion	-1.19*	0.035
Fear emotion	Disliking emotion	0.82*	0.049

*The mean difference is significant at the 0.05 level.

3.3 Relationship between physiological response and emotional evaluation

Several laboratory and field studies have addressed the associations between mood swings and physiological responses. The endocrine system and nerve conduction substances would react to the phenomenon of rapid heartbeat acceleration when emotions swung [55]. In this study, HR emerged as an objective measure of the physiological response. Fig. 6 shows mean of emotional intensity as a function of HR, where it can be seen that the mean value of HR increases when the degree of emotion evaluation shows an upward trend. Repeated measures of ANOVA were used to estimate the significance of differences in HR changes across different emotional types and emotion evaluation. The emotional type had no significant effect on HR responses. However, the emotion evaluation impacted HR ($p < 0.01$).

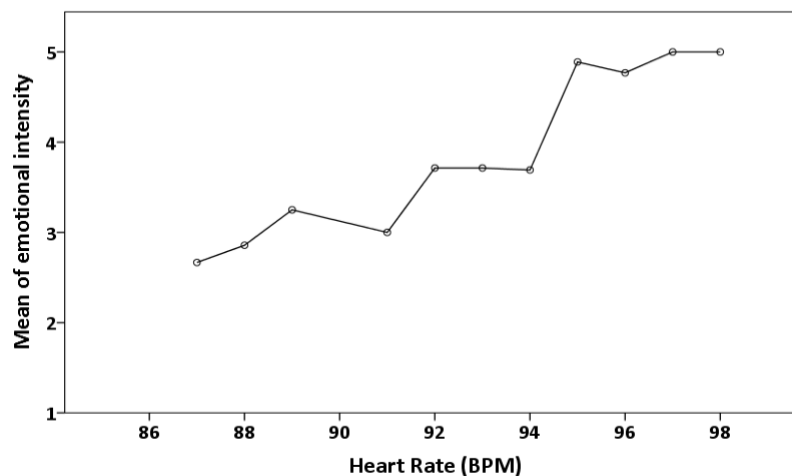
**Fig. 6.** Mean of emotional intensity as a function of HR.

Fig. 7 depicts the relationship between emotional intensity and HR of the drivers' different emotional types. It can be seen that the findings of the correlation analysis corroborated that, for the anxiety emotion, HR was influenced by emotion evaluation ($R = 0.906$, $p < 0.01$); for the fear emotion, HR was correlated with emotion evaluation ($R = 0.868$, $p < 0.01$); and for disliking emotion, the emotion evaluation impacted HR ($R = 0.877$, $p < 0.01$). Consequently, the relationship between HR and emotion evaluation was significant. This result also verified that the rate of the emotional intensity increase in the disliking emotion was the fastest among the three emotional intensities.

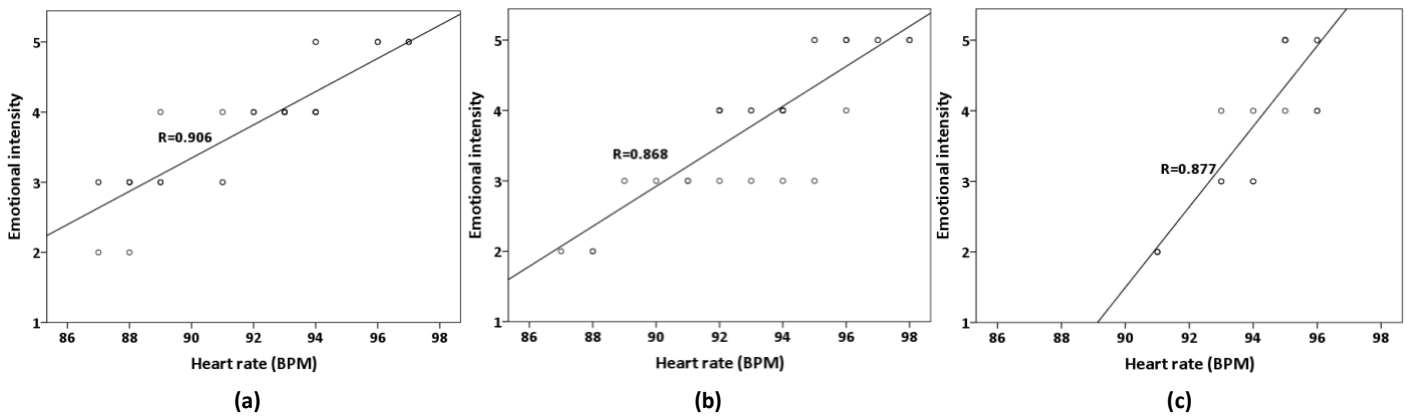


Fig. 7. Relationship between emotional intensity and HR of the drivers' different emotional types: (a) anxiety; (b) fear; and (c) disliking.

Whether the HR corresponding to different emotion categories was different, which was the prerequisite for the relationship between HR and emotional intensity, an independent sample t-test (two-tailed) was used. Table 3 shows independent sample t-test for every two emotional types based on HR, which exhibits significant difference in every two emotional types occurred ($p < 0.05$).

Table 3

Independent sample t-test for every two emotional types based on HR.

Dependent variable: heart rate			
(I) Emotional type	(J) Emotional type	Mean difference (I-J)	Sig.
Anxiety emotion	Fear emotion	-2.69*	0.000
Disliking emotion	Anxiety emotion	-1.95*	0.012
Fear emotion	Disliking emotion	0.74*	0.027

*The mean difference is significant at the 0.05 level.

3.4 Relationship between physiological response and SPL in the control cabin

Several field study findings have reported that physiological responses were related to the SPL of the stimuli. The field studies dealing with long noise exposure affirm that HR was influenced by sound pressure level. Fig. 8 shows the mean of HR as a function of the SPL, where it can be seen that the mean of HR increased when the SPL showed an upward trend. The change range of HR was from 87 to 98 BPM in the noisy environment of the control cabin. In addition, when the range of change in SPL was from 92 to 96 dBA, the upward trend of HR was faster than when the change in SPL was from 97 to 102 dBA. The reason was that the SPL in the control cabin showed an upward trend in the range of 92 to 96 dBA. The HR of the driver increased according to a certain rate. However, when the SPL in the control cabin exceeded 96 dBA, the increased rate of the driver's HR was slower than the range of 92 to 96 dBA. In addition, the result confirmed that several studies using highly arousing noise stimuli reported HR accelerations according to a model indicating the relationship between physiological responses and arousal intensity [56]. For instance, Gomez et al. [33] used 30-s noise stimuli varying from 52.2 to 77.5 dBA, whereas Holand et al. [57] presented 0.15-s noise at 110 dBA to the subjects.

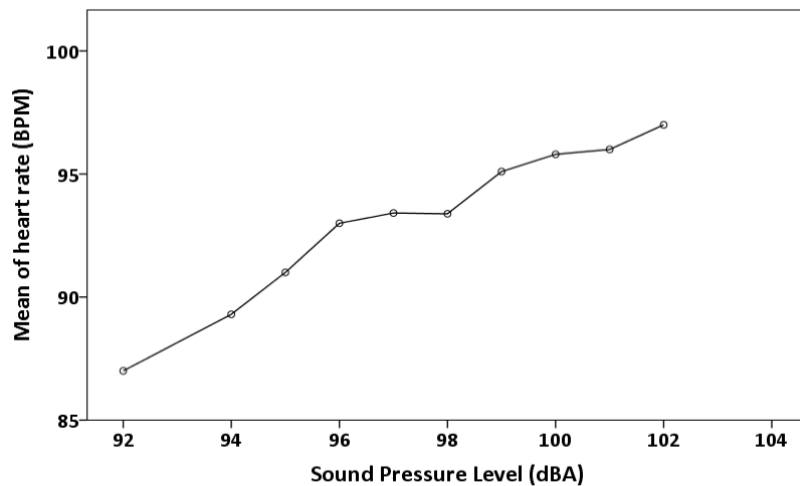


Fig. 8. Mean of HR as a function of SPL.

Fig. 9 depicts that the findings of the correlation analysis validated that, for the anxiety emotion, HR was influenced by SPL ($R = 0.728$, $p < 0.01$); for the fear emotion, HR was correlated with SPL ($R = 0.613$, $p < 0.01$); and for the disliking emotion, SPL impacted HR ($R = 0.861$, $p < 0.01$). Consequently, the relationship between HR and SPL was significant. The result asserted that the HR increase in the anxiety emotion was the fastest among the three emotional types in the noisy environment.

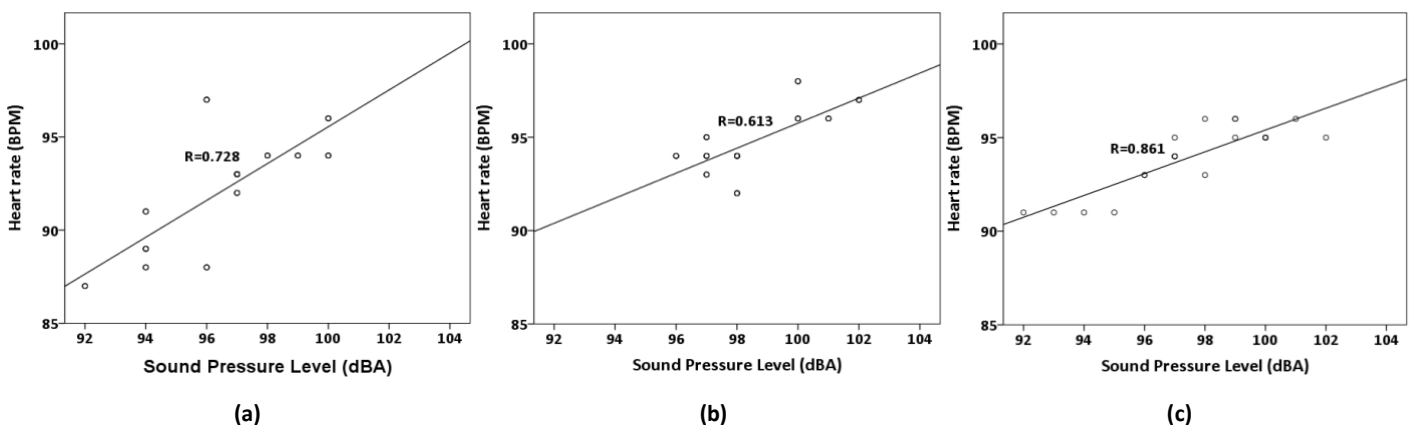


Fig. 9. Relationship between SPL and HR of the drivers' different emotional types: (a) anxiety; (b) fear; and (c) disliking.

3.5 Effect of drivers' social background

The difference in the drivers' emotional intensity was determined through their social background for every emotional type. The results of the relationship between emotional intensity and social background of drivers are shown in Table 4. The age difference was significant ($p < 0.05$) with the correlation coefficient ranging from 0.16 to 0.26. For anxiety and fear emotions, emotional intensity was higher when the drivers were younger, except for the disliking emotion. The reason may be that the drivers' work experience was insufficient when their age was less, the drivers showed anxiety and fear emotions in the noisy environment. However, with the increase in age and enough work experience of the drivers, the drivers showed a higher disliking. Interestingly, the difference in the educational level and years of service was also significant ($p < 0.05$) in the drivers' emotional intensity, with the correlation coefficient ranging from 0.34 to 0.51 for the educational level and 0.24 to 0.44 for years of service. Evidently, the drivers' emotion showed a higher disliking with a

high educational level or a long service. The result proves that the drivers who had strong cognitive ability and long years of service easily show the disliking emotion in a noisy environment.

Table 4

Pearson correlation coefficient (two-tailed) between emotional intensity and social background of drivers.

	ANXIETY	FEAR	DISLIKING
Age	-0.21*	-0.16*	0.26*
Educational level	0.34*	0.37*	0.51*
Service year	0.24*	0.31*	0.44*

4. Conclusions

This study investigated drivers' emotional estimates and physiological responses in the noisy environment of the control cabin of the shield tunneling machine. The findings confirmed that the driver of the control cabin of the shield tunneling machine took considerable attention to the noisy environment when the shield tunneling machine was operating. In the control cabin, the average range of sound pressure level was 96.8 to 98.7 dBA during the daytime. In addition, the sound pressure level of the control cabin was very high during the operation of the shield tunneling machine. However, the sound pressure level decreased with the shield tunneling machine transporting the soil to the ground.

The drivers' emotions were influenced by the average sound pressure level value in the control cabin when it increased to 94.5 dBA. The emotional intensity was increased with increased sound pressure level. Fear was highly evident as sound pressure level increased due to the drivers' concern about operational errors. The emotional intensity of every emotional type was independent.

The emotional evaluation had significant impacts on the drivers' heart rate. The degree of emotional evaluation showed an upward trend with the rise of heart rate. The drivers' heart rate was influenced by the disliking emotional intensity more than the other two emotional intensities.

The long noise exposure in the shield tunneling machine's control cabin had a significant influence on the drivers' heart rate. The rise in heart rate with the sound pressure level indicated an upward trend. The increased rate of Heart rate in 92 dBA to 96 dBA was faster than other ranges of sound pressure levels. The drivers' heart rate increased as the sound pressure level value increased gradually, and the increase in anxiety was faster than the other two emotions.

The drivers' emotion had a significant relationship with the social background. With a high educational level, increased age and long years of service, showed a higher disliking emotion.

On the basis of this research, the conclusions can be regarded as the effect standard of noise reduction in the control cabin of a shield tunneling machine, the conclusions can be also regarded as a pattern to ensure the safety and quality of metro constructions through controlling drivers' emotion in the noisy environment of the control cabin of a shield tunneling machine. Future research is required to further investigate the long-term effects of a noisy environment on the emotional evaluation and physiological responses based on drivers' operational procedures for a shield tunneling machine.

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