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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 96.8–98.7 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 92–96 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.

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

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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.

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

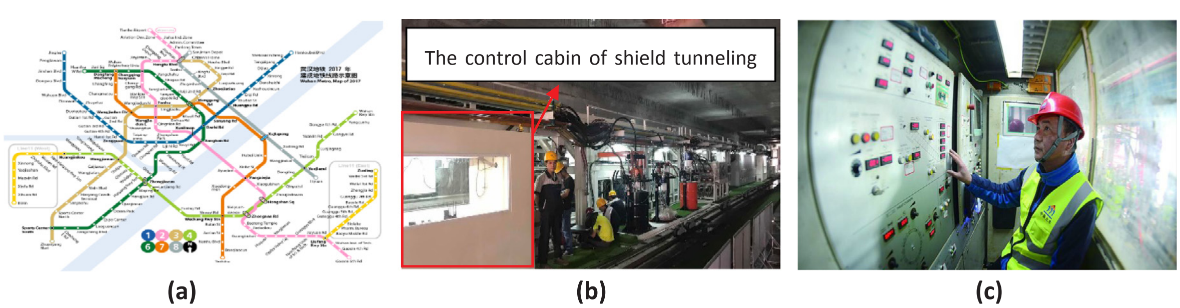

Fig. 1. The survey site for this study. (a) Wuhan metro map 2017; (b) control cabin of a shield tunneling machine; (c) shield tunneling machine driver.