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Monitoring workers' attention and vigilance in construction activities through a wireless and wearable electroencephalography system

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ABSTRACT

As a sector associated with high injury and fatality rates, the construction industry requires constant caution with regard to construction laborers during project execution. Different from people in other industries, construction workers are less sensitive to hazards because of their long-term exposure to risks. Therefore, maintaining construction workers' vigilance and monitoring their attention levels are critical to successful safety management practices. However, current attention-assessing approaches are post hoc and subjective and difficult to implement in construction practice. To address these issues, we propose a wireless and wearable electroencephalography (EEG) system to quantitatively and automatically assess construction workers' attention level through processing human brain signals. To validate the proposed system, we conducted an on-site experiment to analyze the EEG signal patterns when construction workers avoid different obstacles in their tasks. The results suggest EEG signal properties such as frequency, power spectrum density, and spatial distribution can effectively reflect and quantify the construction workers' perceived risk level. Especially, lower gamma frequency bands and the frontal left EEG cluster provide the most direct and observable indications of their vigilance states. These conclusions could facilitate the future implementation of wearable EEG devices through data filtering and channel optimization.

1. Introduction

Construction safety has always been a significant concern of project success for contractors. Among the causes of accidents, the most frequent and direct reason is related to workers' unsafe behavior [1,2]. After studying >500 accident reports, Suraji et al. found that 88% of accidents were attributed to inappropriate operations in construction activities [3]. Similarly, Haslam et al. studied 100 accidents and reported that 49% of the accidents had resulted from unsafe behaviors [4]. According to Haslam et al.'s study, focus group interviews suggested three major types of unsafe behaviors: (1) overlooking safety due to heavy workloads and other priorities; (2) taking shortcuts to save effort and time; (3) inaccurately perceiving risk, with feelings of invulnerability and "it won't happen to me." Being exposed to constant potential hazards on construction sites, construction workers get used to the hazardous environment and become insensitive to risks over time [5]. Construction workers' choice of unsafe behaviors is mainly due to their incorrect estimation of and insufficient attention/vigilance toward the potential risks. Thus, such discrepancies between the actual work environment risks and workers' perceived risks result in aggressive work behaviors and unsafe activities. Encouraging construction workers to correctly assess the risk and pay attention to potential hazards is critical to mitigate such unsafe behaviors and human errors. Many training programs are designed for such purpose. The work environment risks can be assessed at organizational level through safety inspections or quantitative survey approaches, such as safety climate measurement [6], however, assessing individual construction worker's perceived risk is extremely difficult. Therefore, it is necessary to develop a quantitative and objective mechanism to evaluate the workers' perceived risks, so that these risks can be compared with the actual work environment risks to identify the mismatches.

Current studies rely on questionnaires to assess workers' unsafe behaviors and attention/vigilance levels from the perspective of behavioral psychology [7], but many researchers challenge the objectivity and reliability of the aforementioned method [8]. Therefore, it is necessary to develop an objective and quantitative approach that can monitor and measure construction workers' perceived attention/vigilance levels. The outcomes of such an approach could help to improve field monitoring, safety management, and training programs. To fill this research gap, we propose an attention/vigilance assessment model through a wireless EEG device. This proposed device can quantitatively and

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instantaneously report the assessment results, and it can be worn during construction tasks. The findings of this study could help enable more realistic and rigorous training programs and foster safer and healthier work behaviors.

2. Background

2.1. Risk perception and construction safety

Individual workers' hazard evaluations and risk perceptions in the occupational environment determine how they respond to the risks. Understanding how workers perceive the risks or risk factors to which they are exposed is of paramount importance for construction safety management [9,10]. Many studies have focused on understanding how humans perceive and respond to risk when they confront various hazards. Deery described drivers' risk perception behavior in a hazardous environment as having four major steps [11]: hazard detection, risk perception/acceptance, self-assessment, and action. People tend to take risky behavior when they perceive the hazardous signal as minor or assess themselves as skillful and able to avoid the risk with ease [2,12]. Similarly, Bohm and Harris' research on construction projects reported that workers' risk perception significantly differed from the measured "objective risk" [2].

The individual's perceived risk level depends on both external and internal factors [10]. The external factors are related to the work environment, such as construction site environment, exposure level, work group and warning signs, while the internal factors are related to individual conditions, such as experience, working memory, stress, and mode. Individual internal factors are the major reasons why construction workers neglect hazardous signals and incorrectly assess potential risks. Among those factors, working memory is the most difficult factor to quantify [13] and the major cause of accidents during the execution of construction tasks. Working memory or mental workload refers to the amount of human mental resources required to perform tasks and perceive hazards [14]. When a worker is short of working memory, he or she may fail to detect risk stimuli in the surrounding environment or underestimate the associated risks, resulting in his or her adopting unsafe behaviors [13]. Talking over the phone while driving is a typical example of this issue [15]. On the contrary, if workers were to devote more attention and vigilance to the tasks associated with higher risks, they could potentially avoid injuries and end up with near-miss accidents [16]. Therefore, mismatching of perceived risk and "objective" risk can lead to risk-taking or unsafe behaviors. Accordingly, helping construction workers develop proper hazard recognition and correcting their misunderstanding on unsafe behavior should improve safety performance at the site [12]. Many studies suggest hazard recognition and risk perception of workers can be improved through training and intervention. Rethi et al. initiated a hazard recognition training with visually degraded stimuli for the construction and mining industry [17]. Barrett and Kowalski introduced simulation exercises and three-dimensional slides in their training program and significantly improved workers' ability to recognize roof hazards [18]. Isler et al. applied a video-based road commentary training program and found that participants who received video-based training can identify more hazards than control groups [19]. Many researchers developed questionnaires to understand and promote the risk perception capacity of construction workers [20] to assist training programs; however, none of them could quantitatively and objectively assess the perceived risk level of construction workers. Therefore, the aim of this research is to develop such a feasible approach to monitor the perceived risk of workers through detecting their attention/vigilance levels with a wearable EEG device.

2.2. Construction behaviors and wearable devices

Construction projects usually involve a large number of labor-intensive and complicated tasks. Together with tight schedules and dynamic work environments, these types of tasks make it necessary to closely monitor the labor force to ensure project quality, crew safety, and productivity. Emerging information and electronics technologies show a promising potential in application at all different management levels in the construction industry. Given the construction industry is an information-intensive industry, the success of which depends on controlling huge amounts of information related to physical buildings, equipment, and construction crews, reliable and efficient information collection, storage, and transfer could dramatically improve efficiency in all aspects of project management [21,22]. Although nowadays computing systems have the capacity for processing large amounts of data, the majority of data is generated on construction sites where personnel have difficulty in gaining access to conventional computer systems [21]. As an alternative to carrying bulky equipment, wearable systems have attracted enormous research interest.

The functionality of wearable systems in construction falls into two categories: site inspection and work behavior monitoring. Wearable site inspection systems are targeted at acquiring physical building information from various sensing technologies. Yuan et al. proposed mobile phones as the means of monitoring temporary structures and collecting data based on cyber-physical systems (CPS). Similarly, mobile phones also can be used as platforms for a BIM-based augmented reality (AR) system for construction implementation [23,24]. Also, phones are excellent 2D bar code and QR code readers for building management and maintenance [25]. Recent developments in mobile laser scanners, such as light detection and ranging (LiDAR) scanners, are able to extract building features from point clouds data and create as-built models [26–29]. Cameras or RGB-D cameras also can be used as portable stereo vision systems to acquire and recognize three-dimensional (3D) structural components [30]. More recently, Nguyen et al. developed a smart shoe design to integrate multiple laser scanners and an inertial measurement unit (IMU) to map 3D construction environments [31].

Another type of wearable system mainly focuses on work behavior monitoring. The most widely used wearable devices are designed for positioning and tracking. Radio-frequency identification (RFID) is able to approximately locate the carrier's position based on the radio wave communication and signal strength between the RFID tags and readers [32]. Ultra-wideband (UWB) technology provides a short-pulse radio frequency waveform that could locate objects more accurately with higher cost [33]. For behavior monitoring, IMU-based systems are more popular [34]. Khoury et al. implemented IMUs as a tracking and navigation system in different project scenarios [35]. Yang et al. developed an automatic near-miss fall detection system based upon workers' kinematic data captured by wearable IMUs [16]. With both categories of wearable systems, project managers are able to associate the physical work environment and work behaviors. However, none of the information collected by these wearable systems can be used to assess the subjective risk perception of construction workers, which is crucial to identifying the origin of unsafe behaviors. To fill this gap, this paper proposes to bring in a new data source, EEG signals, to assess the vigilance/attention level of construction workers. The quantitative data on the vigilance/attention conditions of workers can be utilized for detecting mismatches between the perceptional risks and objective risks in future.

2.3. EEG and neural signal processing

As we mentioned before, risk perception is highly related to a human subject's working memory (mental workload), which is a cognitive resource for performing various activities [14]. When the brain allocates more working memory to work activities, less working memory will be allocated to precaution; on the contrary, higher vigilance means less attention devoted to work activities [13,36]. The purpose of safety training is to raise workers' attention to proper levels when they are exposed to hazardous environments. Therefore, it is possible to monitor the workers' attention level at risky conditions as an indirect reflection