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Revealing the "Invisible Gorilla" in construction: Estimating construction safety through mental workload assessment

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ABSTRACT

Construction companies can accrue losses due to labor fatalities and injuries. Since more than 70% of all accidents are related to human activities, detecting and mitigating human-related risks hold the key to improving the safety conditions within the construction industry. Previous research has revealed that the psychological and emotional conditions of workers can contribute to fatalities and injuries. Recent observations in the area of neural science and psychology suggest that inattentional blindness is one major cause of unexpected human related accidents. Due to the limitation of human mental workload, laborers are vulnerable to unexpected hazards while focusing on complicated construction tasks. Therefore, the ability to detect the mental conditions of workers could reduce unexpected injuries. However, there are currently no available measurement approaches or devices capable of monitoring construction workers' mental conditions. The research proposed in this paper aims to develop a measurement approach to evaluate hazards through neural time–frequency analysis. The experimental results show that neural signals are valid for mental load assessment of construction workers, especially the low frequency bands signals. The research also describes the development of a prototype for a wearable electroencephalography (EEG) safety helmet that enables the collection of the neural information required as input for the measurement approach.

1. Introduction

Construction is one of the most dangerous industrial sectors in every country. In Hong Kong, the construction industry has one of the worst safety records compared to all other industries. In 2013, there were 3332 injuries and 37 fatalities in the construction industry in Hong Kong, which accounts for 19.68% of fatalities across all industries [29]. Most of these accidents (including injuries and fatalities) were related to labor activities (75%), including slipping (24.0%), lifting (14.7%), falling (13.1%), striking against stationary objects (9.3%), operating tools (2.8%) and other human-related activities (10%) [29]. If safety hazards are properly detected and reported, workplace safety can be significantly improved [40]. However, the biggest challenge in identifying hazards and recording accidents is the dynamic environment of construction jobsites and workers' unpredictable behavior patterns [34]. Many researchers suggest that safety hazards could be identified through a safety analysis or safety climate analysis [75]. Together with proper safety programs [3] and prospective safety performance evaluation [71], safety conditions could be significantly improved. Although safety practices such as training, inspections, motivation, enforcement, and penalties, are successfully implemented in construction projects and achieved some improvements [28], there still are a large number of unexpected accidents that occur on job sites. However, risks cannot be assessed, controlled and avoided if managers are not aware of the hazards in the first place [12]. Since preventing accidents purely through safety programs is not possible, focusing on identifying and protecting vulnerable individuals rather than attempting to identify all possible hazardous events for all possible individuals who could be impacted provides an alternative option to further improve on site safe conditions [6]. In other words, construction site safety interventions can be improved by strategically targeting individuals who are more susceptible to accidents.

A workers' ability to perceive hazards can help him or her to escape from dangerous situations, which can result in near-miss accidents. Classic psychological theories suggest that people's decision making on risk-taking behavior is negatively correlated with their risk perception [46]. Thus, individuals who are weak in risk perception or tend to misestimate the risks are vulnerable to safety hazards, which can result in injuries instead of near-miss accidents. Therefore, a worker's ability to perceive risk is an excellent indication of a worker's vulnerability. If such an ability can be quantified and monitored, more vulnerable individuals could be identified and better protected.

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Among the many factors that could impact a worker's perception ability, his or her mental condition is most important. In psychological research, mental workload has been determined to be one of the best indicators of perceptional ability [45,49] especially for people who usually conduct complicated tasks. Therefore, the measurement of individuals' mental workload can help to assess their perception ability, which in turn can then be used to identify vulnerable workers on a construction job site. The research described in this paper aims to propose an approach to quantitatively estimate mental workload and then apply the resulting estimates to identify potentially vulnerable construction workers.

2. Background

2.1. Psychological issues and construction safety

In labor-intensive industries like construction, the psychological condition of workers plays a central role in safety performance. Construction work involves inherently dangerous tasks and exposure to various psychological stressors associated with pressure due to constraints on schedules and physical hazards [38]. According to Endsley's findings (1995) [19], there are three steps that people who experience dangerous events proceed through, including (1) detection of hazardous signals, (2) perception and comprehension of risks, and (3) projection of the consequences associated with decision options. Many psychological researchers conclude that emotions greatly influence signal detection, risk perception and process of risk-based decision making [51,60]. Different from other industries, in construction, risk perception is more important because even if the hazards are identified, workers still may involuntarily behave unsafely, since most construction tasks are inherently associated with various level of risks [74]. Due to tight project budgets and schedules, construction personnel are predominately production-oriented and can suffer from high levels of physical and mental pressure [47], which can exacerbate the level of danger and increase the possibility of injury. Tixier et al. (2014) conducted an experiment on 69 construction workers and observed that the emotionally negative group (i.e. those workers who were sad, unhappy, fearful, anxious and disgusted) were subject to more risks than the positive group (i.e. those workers who were happy, amused, joyful and interested) [63]. For example, in masonry work, heavy load lifting and awkward posture requires significant physical demands. In additional to physical demands, temporal demands and mental demands play critical roles in workers' performance [43] and safety [41]. Therefore, the demands of construction tasks could be indicators of safety risk. In 2010, Mitropoulos and Namboodiri proposed a novel task demand assessment (TDA) approach to measuring construction safety based on how difficult it was to safely perform an activity [48]. With the help of wearable biological sensors, the physical demands of tasks can be detected and measured, however, there is still no meaningful quantitative assessment framework on the mental demands of construction tasks [2]. This research aims at proposing such an approach to assess the mental demands through analyzing human brain rhythms.

2.2. Risk perception and mental workload

Mental workload or cognitive load refers to the total amount of human mental effort or memory that is required for the execution of a task [62]. When a person places too much attention on one task, he or she will have less attention to focus on other stimuli. One classic example is talking on the phone while driving [55]. In these cases, when a driver's attention is mostly allocated to the phone conversation, less attention is allocated for driving, which can result in higher accident rates [50]. Therefore, when a task consumes too much attention, people can be exposed to the danger of inattentional blindness [56]. Inattentional blindness is a psychological phenomenon where an individual fails to identify stimuli due to this lack of attention [39]. One approach to studying inattentional blindness is known as the Invisible Gorilla Test [13]. In this test, subjects are asked to count the number of ball passes between several participants in a video, while a person wearing a full gorilla suit walks through the scene. After watching the video, the subjects are asked to indicate whether they saw the gorilla. Most results demonstrate that 50% of subjects did not report seeing the gorilla. Failure to see the gorilla is attributed to the high mental engagement of the counting task and results in inattentional blindness [18].

In the construction industry, when workers focus too narrowly on their work, they become inattentionally blind, which decreases their perception ability and makes them more vulnerable to dangers. Also, repetitive tasks that require a very low cognitive load can lead to accidents. Another possible issue that affects the risk perception is hazard expectation. When workers conduct certain construction activities, they expect certain things to happen and tend to block out other possibilities. For example, when a worker installs a roof, he or she knows from standard training that falls are major hazards. Because they are focused on avoiding a fall, they may not be aware that they may be also hit by an object. These types of distractions and lack of focus on safety may also lead to inattentional blindness. These examples highlight why, even though workers may participate in safety training, they still could be injured.

Another issue that is related to the mental workload of workers is work complexity [69]. Workers often face rising cognitive demands when they execute increasingly complex tasks. In these cases, their cognitive skills are more important than physical skills [16]. In the construction industry, workers obtain a considerable portion of information directly from the cognitive task, while they are concurrently performing physically demanding work [17]. For instance, in the case of electrical installation, workers not only need to accurately attach wires, but they may need to do so on top of a ladder while holding their arms up for long periods of time. In these types of situations, understanding how the physical workload impacts the mental workload is required to estimate the safety condition of the worker in executing the task. However, due to differences between individual workers, it is difficult to predict the risk level from the task complexity and individual proficiency. Therefore, a quantitative and direct monitoring approach that can estimate the mental workload of workers can help project managers to identify vulnerable workers and implement safety policies or approaches to help avoid accidents.

2.3. Quantitative neural time–frequency analysis

In order to develop a measurement of mental workload, various behavioral and physiological tests have been developed since the 1980s [27,70]. Although subjective and inaccurate, such measurements can provide a relatively continuous data record over time without obstructing execution of the task [68]. In recent years, new neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) can provide direct and quantitative alternatives for the assessment of mental workload [57]. Among these methods, EEG is the best candidate for construction implementation because it can be applied outside of a specialized laboratory. Other methods require cumbersome devices, large medical teams and immobile subjects [23]. Moreover, many studies have found a correlation between brain rhythms collected by an EEG and mental workload [52,61,66].

One popular quantitative analysis for brain rhythms of mental workload is Event-Related Potentials (ERPs). ERPs is a valid approach because it requires fewer assumptions or parameters, possesses higher temporal precision and accuracy, has been well studied, and provides fast and easy computational results [14]. However, the results of ERPs are difficult to interpret and link the continuous data to physiological mechanisms. To resolve these difficulties, a time–frequency-based analysis adopted from digital signal processing theory has been introduced for use in the analysis of brain rhythms [26,64,65]. In the research method