EPiC Series in Built Environment
Volume 4, 2023, Pages 488–496
Proceedings of 59th Annual Associated Schools of Construction International Conference

Workers' Fatigue in Construction Projects, Assessment, Detection, and Mitigation, A Review

Mohammadsoroush Tafazzoli, Ph.D., LEED AP
Washington State University
Pullman, WA

Mostafa Namian, PhD
East Carolina University
Greenville, North Carolina

Ahmed Al-Bayati, PhD
Lawrence Technological University
Southfield, Michigan

Despite the increased focus on safety management in recent years, the construction industry's accident rate remains extraordinarily high. High physical demands and difficult work environments, which lead to physical and mental fatigue in construction workers, are one of the key causes of the continuous high rate of construction accidents. This study begins with a description of the causes and effects of fatigue among construction workers. In the second section, the subjective and objective evaluation methods for physical fatigue are discussed. The advantages and drawbacks of fatigue measurement technologies such as self-reporting and on-body sensors are reviewed. Thirdly, the major approaches for predicting and quantifying fatigue, as well as their limitations, are discussed. In addition, mitigation and management of fatigue in construction projects, as well as successful methods such as work-rest people scheduling, are discussed. The paper concludes by highlighting the fragmentation and inconsistencies in the available research as well as the opportunity for future studies to fill the existing gaps. The study is designed to give an effective evaluation of the available information on defining, assessing, detecting, quantifying, mitigating, and managing fatigues, as well as shed light on the recommended and required future steps in research for each category.

Key Words: Fatigue, Assessment, Detection, Prediction, Mitigation

Introduction

The construction industry had the greatest accident rate of any sector in the US economy in 2016 which equated to 19% of all industrial deaths (Hallowell & Hansen, 2016). Injuries in the construction sector are a leading cause of hospitalization, disability, and death. Over sixty thousand fatalities are reported annually from building projects around the world (Lingard, 2013). The cost of project accidents has a major influence on profit margins, negatively affects project success, and in certain cases poses a threat to the continued existence of construction enterprises (Zou & Sunindijo, 2015).

A great deal of effort has been put into the research to identify and comprehend the causes of construction incidents (Rajendran & Gambatese, 2009). Workers in the construction industry need to maintain a state of constant vigilance and attention to the ever-changing environment surrounding them at all times in order to identify potential dangers and avoid accidents and injuries. Because of the excessive amount of work, a worker has a greater risk of engaging in construction tasks when under the influence of fatigue (Xing et al., 2020).

Causes and Effects of Construction Workers' Fatigues

Construction workers are required to maintain a state of constant alertness and attention to the ever-changing environment surrounding them at all times in order to identify potential dangers and avoid accidents and injuries. Because of the excessive workload, a worker has a greater propensity to engage in construction activities while in a fatigued state, which results in a poor cognitive condition, including a slowed reaction time, reduced vigilance, reduced ability to make decisions, task distraction, and loss of situational awareness.

According to Lewis and Wessley (1992), a general definition of fatigue is "the lassitude or exhaustion of mental and physical power that occurs from muscular effort or mental activity. The consequence of sustained work, weariness, or exhaustion of physical or mental strength that might result in a temporary lack of ability to work are all examples of fatigue. Constantly, construction work necessitates lengthy shifts without proper breaks, as well as working in difficult climatic conditions and/or restricted areas. These conditions can raise the likelihood of physical fatigue. Table 1 shows the causes of construction fatigue in the literature.

Table 1

Effective factors in construction fatigue in the literature

Causes	Authors/ investigators
Climate (temperature and humidity)	• Al-Bouwarthan et al., 2019
Working at Heights	• Hsu et al., 2008; • Chang, 2009
Overtime shifts	• Fang et al., 2015
Sleep deprivation	• Powell & Copping, 2010
Mental exertion	• Xing et al., 2020
Muscular exertion	• Jebelli et al., 2020
Work environment factors (light, vibration, noise, etc.)	• Jiao et al. (2004)
Motivation factors (rewards, voluntary vs. compulsory tasks, etc.)	• Van der Hulst & Geurts, 2001 • Beckers et al., 2008
The social environment at the workplace	• Bültmann et al. (2001)

Construction fatigue could be categorized into physical, mental, and emotional fatigue. Physical fatigue, which is reduced physical functioning capacity, is the primary type of fatigue that the literature has focused on. The research in this field could be categorized into studying the causes and consequences, as well as detection and prevention techniques. Measuring mental and emotional fatigue requires more complex neurophysiological tools. Mental fatigue is a phenomenon that is experienced by people who have been involved in a protracted period of demanding mental effort which causes a feeling of being fatigued or inactive and leads to low job efficiency and even lifethreatening behaviors (Xing et al., 2019). It should be noted that mental factors could play a significant role in determining the level of fatigue in situations that have a common cause. For instance, when fatigue is driven by working overtime, different levels of fatigue could be observed based on the type of overtime work. For instance, mandatory, low reward, low autonomy, and highly demanding overtime work could lead to a higher level of fatigue when compared with voluntary overtime which is highly rewarded, and included less demanding tasks (Techera, 2017). Bültmann et al. (2001) found that relationships with coworkers, bosses, and subordinates play a significant impact in the development of mental fatigue. Additionally, environmental elements such as temperature, light intensity, vibration, and noise are all associated with increased levels of fatigue (Krause et al. 1997).

The Consequences of Construction Workers' Fatigue

Some of the effects of worker fatigue cannot be precisely measured. For instance, fatigue lowers the quality of life and impairs the immune system of workers, which might in turn have a broad range of ripple effects. The construction industries, particularly those in developed nations or regions, should pay more attention to fatigue detection and prevention due to a number of workforce difficulties that may impede the sector's growth. Among these problems are rising labor wages, an aging workforce, and a shortage of labor (Yu et al., 2019).

Table 2

Consequences of construction fatigue in the literature

Consequences	Authors/ investigators
Musculoskeletal disorders (MSDs)	• Merlino et al., 2003
Work errors	• Aryal et al., 2017
Reduced Productivity and poor performance	• O'Neill & Panuwatwanich, 2013
Loss of motivation	• Hallowell, 2010; DeVries et al., 2003
Compromised Safety (job site accidents)	• Namian et al., 2021; Swaen et al., 2003
Cognitive degradation (attention, vigilance, responsiveness)	• Van Dongen & Dinges, 2005 • Tixier et al, 2014
Reduced client satisfaction	• Dall'Ora et al., 2016

Quantification of the outcomes of fatigue in construction projects is complicated as it is difficult to attribute the negative outcomes such as lost productivity only to fatigue. However, According to the National Safety Council (NSC, 2018), a typical company with 10,000 workers incurs a cost of more than $1 million per year as a result of fatigue. This cost is broken down as follows: $272,0 0 0 is due to absenteeism, and $776,0 0 0 is due to working while fatigued. In another study, Rosekind et al. (2010), found that reduced productivity due to fatigue costs companies between $1,293 and $3,156 per employee annually.

Assessment of Construction Workers' Fatigues

Considering the numerous consequences of fatigue in construction assessing the level of physical fatigue experienced by construction workers is an essential first step in reducing the likelihood that these workers may become physically fatigued. Despite its significance, fatigue is frequently only discovered after a serious accident (Reiner and Krupinski 2011).

Fatigue monitoring methods

There are two primary methods for evaluating fatigue: subjective and objective. The subjective evaluation of exhaustion is based on an individual's impression of the symptoms associated with fatigue. Among these symptoms are drowsiness, loss of energy, and physical limitations. The seeming inability to directly evaluate these subconstructs led to their subjective evaluations as the most accurate methods for measuring weariness. Recently, new technologies have enabled the direct assessment of specific physical factors, such as neuronal activity or cardiorespiratory parameters, that vary under the influence of weariness. These technologies have made objective measurements possible. . Figure 1 shows some fatigue assessment methods and their corresponding tools or technologies(Yu et al., 2019). Recent advancements in wearable sensing and computing have contributed to the development of novel methods for enhancing the health and safety of construction workers. However, there is no agreement on how fatigue should be quantified due to the complicated physiological nature of fatigue (Techera et al., 2018).

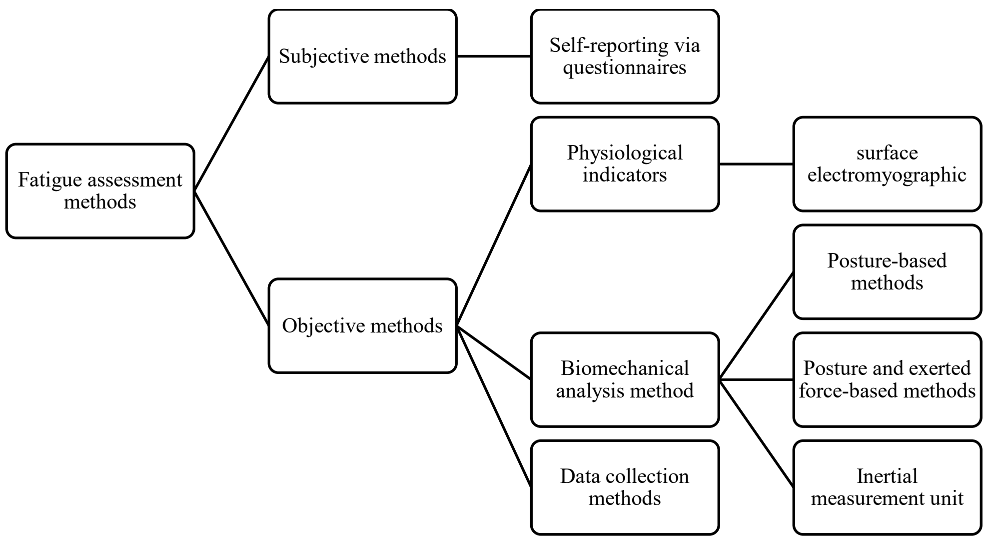

Figure 1. Fatigue assessment methods and their corresponding tools or technologies

Self-reporting via Subjective questionnaires. Subjective techniques rely on the workers' own self-reporting of how they feel in terms of their physical fatigue. Self-reporting has always been the foundation upon which fatigue monitoring in the construction industry is built. These approaches are inefficient for continuous fatigue monitoring since they call for the manual gathering of responses.

On-body sensors. Indicators of cardiovascular health include the heart rate, the temperature of the skin, and breathing rate, all of which often rise when the body is subjected to a significant amount of physical stress (Cheng et al., 2013; Gatti et al., 2014; Kirk & Sullman, 2001). The indicators are measured using sensors, which are often fastened closely to the worker's body to assure the accuracy of the readings but can be a nuisance for the workers while they go about their daily job routine. Examples of these assessment technologies are surface electromyography (sEMG) sensors and heart rate monitors. Even though these gadgets provide the impression that they will be beneficial, they could be unpleasant and disturbing because they require sensors to be placed on the body of the worker (Yu et al., 2019).

Management of Construction Workers' Fatigue

The management approaches to handle construction workers' fatigue could be categorized into detection/ prediction and mitigation techniques as shown in figure 2. Detection of fatigue is the primary step in mitigating the outcomes of workers' fatigue. Detection methods were discussed in the previous section. This section reviews some of the techniques used in mitigating fatigue for construction workers.

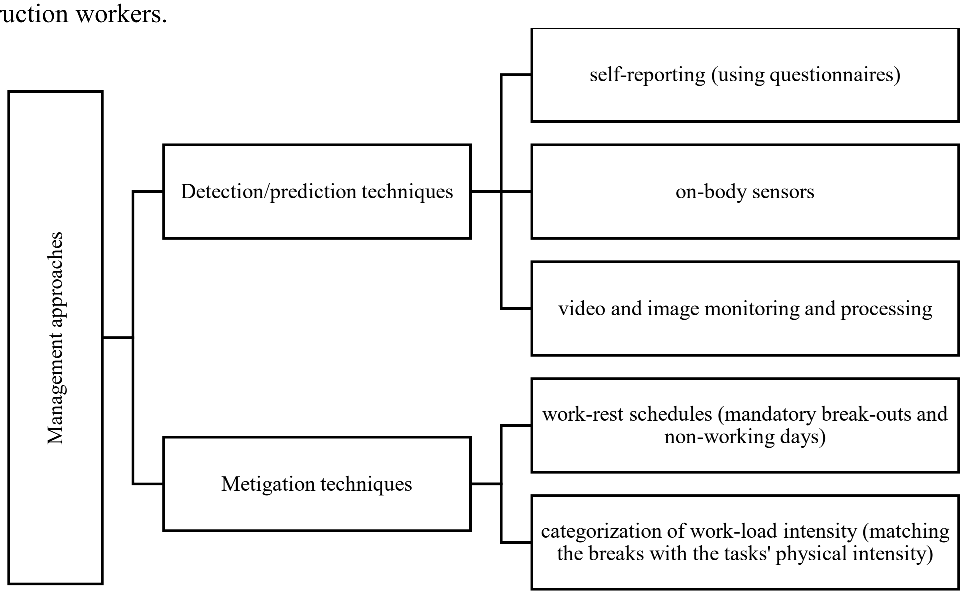

Figure 2. Management approaches to handle the construction workers' fatigue

Personnel scheduling for Construction Fatigue Mitigation

Significant labor issues are jeopardizing the continuous growth of the construction industry in the coming years. These issues include increasing labor wages, an aging workforce, and a lack of personnel in the workforce. Without addressing construction workers' fatigue, it can be expected that labor-related issues exacerbate. Scheduling the work to mitigate fatigue could serve as a motive to improve the willingness and morale of workers to join or stay in this industry.

Fatigue, and particularly its physical type, has close ties with how intensively workers must work, the duration of continuous work, and how break times and nonworking days are scheduled. By studying these links more effective schedules that can contribute to mitigating worker's fatigue can be developed. In doing so, based on prior sleep patterns (Dawson & McCulloch, 2005) devised a methodology to assess fitness for duty. According to the prior sleep/wake model (PSWM), if a worker's shift lasts longer than the quantity of sleep, they received in the previous 48 hours from the time they woke up, they are more likely to make mistakes. The same study also found that in order to be at least minimally fit, a worker must have at least 5 hours of sleep the day before work and 12 hours in the night before. The research efforts in this area seem to be limited and more empirical examinations to assess the impacts of work-rest schedules on mitigating fatigue and boosting workers' productivity are recommended.

Since physical fatigue is highly dependent on the load and intensity of the construction tasks, using universal work shifts for all construction laborers with various levels of physical intensity is questionable. Additionally, the high tendency in the construction industry to complete tasks at faster rates is in contrast with the idea of enforcing break-out intervals to prevent laborer fatigue since the breaks will reduce the project's delivery speed. Identifying a physical-intensity score, particularly for hazardous construction tasks, such as working at heights, can be tested in empirical studies and if proven effective, they can be mandated through construction regulations.

Existing gaps in Managing Construction Fatigue

Even though many researchers agree that fatigue is a major cause of accidents, it is rarely mentioned in injury reports and is usually not talked about until a major accident happens in the industry (Reiner and Krupinski 2011). The current body of information regarding fatigue remains fragmented and confused. Researchers have concentrated on diverse facets of exhaustion, gaining a deeper grasp of specific components, but the scientific community as a whole does not share a common concept of fatigue. In addition, according to our research, very few studies have compared the many causes and effects of fatigue; hence, it is difficult to determine the relative relevance of these causes and effects. This significantly lowers the industry's capacity to effectively manage fatigue.

There are five central gaps in the literature focusing on fatigue in construction projects: 1) Fragmented and various definitions of fatigue in the industry, 2) clear comparison of the causes and effects of fatigue in the workplace, 3) Objective quantification of the impact of fatigue's causes and effects, 4) empirical studies on the various construction trades, 5) an accurate and reliable method for measuring and predicting construction worker fatigue (Techera, 2017).

All of the fatigue causes that have been examined provide means for objective assessment and prediction. Based on the current level of knowledge, objectifying and quantifying these parameters at the same time should result in powerful predictive models. The ability to manage and regulate the onset of fatigue would be improved if a system could be developed to objectively forecast the possibility of exhaustion before work even starts (Techera et al., 2018).

To validate predictors, fatigue must be quantified as a dependent variable (predictand) using cutting-edge techniques. On fatigue measurement, there is a vast and abundant corpus of literature. Given the physiological complexity of weariness, there is no consensus regarding its measurement. Thus, researchers have relied on surrogates for weariness, frequently viewing it as a result of its causes (e.g., workload) and effects (e.g., moving slowly).

The indirect outcomes of fatigue, require more research to assess possible links between fatigue and safety perception and hazard recognition. Research studying the impacts of fatigue has significant overlaps with the studies focusing on multitasking, ergonomics, and the connection between scheduling and productivity. This creates a potential for multidimensional studies that combine the impact of fatigue, particularly those that are more relevant to construction projects. Also, the possible impacts of mitigation methods, such as 1) work-rest schedules (mandatory break-outs and non-working days), and 2) categorization of work-load intensity (matching the breaks with the tasks' physical intensity) need further empirical studies for assessment. If these studies can show the effectiveness of these measures, mandating them through construction codes and standards should be pursued.

Summary and Conclusion

High physical demands and harsh work situations are one of the root causes of construction accidents. Fatigue is a major contributor to occupational injuries and fatalities, especially in physically intensive tasks. Despite the plethora of research on the topic, fatigue knowledge is dispersed and disorganized. Researchers have concentrated on different components of fatigue to gain greater knowledge, but no overarching explanation exists. Due to a lack of rigorous methods for real-time fatigue monitoring, it is difficult to quantify the direct effects of tiredness on construction safety, resulting in a paucity of fatigue-related studies in occupational safety studies. This hinders the industry's ability to control fatigue. Effective fatigue management strategies for construction workers are an immediate necessity if we are to enhance the way safety is managed on construction sites. Effective fatigue management strategies for construction workers are an immediate necessity if we are to enhance the projects' safety. A proper assessment of fatigue aids in decreasing worker injuries and minimizing associated expenses, as well as in establishing suitable work-rest schedules and shift designs.

References

Al-Bayati, A. J., Tafazzoli, M., York, D. D., & Umar, T. (2020). Cyclical construction workforce shortage: an evaluation of the current shortage in Western North Carolina.

Al-Bouwarthan, M., Quinn, M. M., Kriebel, D., & Wegman, D. H. (2019). Assessment of heat stress exposure among construction workers in the hot desert climate of Saudi Arabia. Annals of work exposures and health, 63(5), 505-520.

Aryal, A., Ghahramani, A., & Becerik-Gerber, B. (2017). Monitoring fatigue in construction workers using physiological measurements. Automation in Construction, 82, 154-165.

Beckers, D. G., Van der Linden, D., Smulders, P. G., Kompier, M. A., Taris, T. W., & Geurts, S. A. (2008). Voluntary or involuntary? Control over overtime and rewards for overtime in relation to fatigue and work satisfaction. Work & Stress, 22(1), 33-50.

Bültmann, U., Kant, I. J., Schröer, C., & Kasl, S. (2002). The relationship between psychosocial work characteristics and fatigue and psychological distress. International archives of occupational and environmental health, 75(4), 259-266.

Chang, F. L., Sun, Y. M., Chuang, K. H., & Hsu, D. J. (2009). Work fatigue and physiological symptoms in different occupations of high-elevation construction workers. Applied ergonomics, 40(4), 591-596.

Cheng, T., Migliaccio, G. C., Teizer, J., & Gatti, U. C. (2013). Data fusion of real-time location sensing and physiological status monitoring for ergonomics analysis of construction workers. Journal of Computing in Civil engineering, 27(3), 320-335.

Dall'Ora, C., Ball, J., Recio-Saucedo, A., & Griffiths, P. (2016). Characteristics of shift work and their impact on employee performance and wellbeing: A literature review. International journal of nursing studies, 57, 12-27.

De Vries, J., Michielsen, H. J., & Van Heck, G. L. (2003). Assessment of fatigue among working people: a comparison of six questionnaires. Occupational and environmental medicine, 60(suppl 1), i10-i15.

Fang, D., Jiang, Z., Zhang, M., & Wang, H. (2015). An experimental method to study the effect of fatigue on construction workers' safety performance. Safety science, 73, 80-91.

Ferjani, A., Ammar, A., Pierreval, H., & Elkosantini, S. (2017). A simulation-optimization based heuristic for the online assignment of multi-skilled workers subjected to fatigue in manufacturing systems. Computers & Industrial Engineering, 112, 663-674.

Gatti, U. C., Schneider, S., & Migliaccio, G. C. (2014). Physiological condition monitoring of construction workers. Automation in Construction, 44, 227-233.

Hallowell, M. R. (2010). Worker fatigue: Managing concerns in rapid renewal highway construction projects. Professional safety, 55(12), 18-26.

Hsu, D. J., Sun, Y. M., Chuang, K. H., Juang, Y. J., & Chang, F. L. (2008). Effect of elevation change on work fatigue and physiological symptoms for high-rise building construction workers. Safety science, 46(5), 833-843.

Jebelli, H., Seo, J., Hwang, S., & Lee, S. (2020). Physiology-based dynamic muscle fatigue model for upper limbs during construction tasks. International Journal of Industrial Ergonomics, 78, 102984.

Jiao, K., Li, Z., Chen, M., Wang, C., & Qi, S. (2004). Effect of different vibration frequencies on heart rate variability and driving fatigue in healthy drivers. International archives of occupational and environmental health, 77(3), 205-212.

Kirk, P. M., & Sullman, M. J. (2001). Heart rate strain in cable hauler choker setters in New Zealand logging operations. Applied Ergonomics, 32(4), 389-398.

Krause, N., Lynch, J., Kaplan, G. A., Cohen, R. D., Goldberg, D. E., & Salonen, J. T. (1997). Predictors of disability retirement. Scandinavian journal of work, environment & health, 403-413.

Lewis, G., & Wessely, S. (1992). The epidemiology of fatigue: more questions than answers. Journal of epidemiology and community health, 46(2), 92.

Merlino, L. A., Rosecrance, J. C., Anton, D., & Cook, T. M. (2003). Symptoms of musculoskeletal disorders among apprentice construction workers. Applied occupational and environmental hygiene, 18(1), 57-64.

Mohamed, S., & Srinavin, K. (2002). Thermal environment effects on construction workers' productivity. Work Study.

Namian, M., Taherpour, F., Ghiasvand, E., & Turkan, Y. (2021). Insidious Safety Threat of Fatigue: Investigating Construction Workers' Risk of Accident Due to Fatigue. Journal of construction engineering and management, 147(12), 04021162.

NSC (2018). How you could pay the price for exhausted employees. Report, Available at: https://www.construction business owner.com/cost-fatigue.

O'Neill, C., & Panuwatwanich, K. (2013). The impact of fatigue on labour productivity: case study of dam construction project in Queensland. Proceedings from EPPM.

Perez, J., De Looze, M. P., Bosch, T., & Neumann, W. P. (2014). Discrete event simulation as an ergonomic tool to predict workload exposures during systems design. International Journal of Industrial Ergonomics, 44(2), 298-306.

Powell, R., & Copping, A. (2010). Sleep deprivation and its consequences in construction workers. Journal of construction engineering and management, 136(10), 1086-1092.

Reiner, B. I., & Krupinski, E. (2012). Demystifying occupational stress and fatigue through the creation of an adaptive end-user profiling system. Journal of digital imaging, 25(2), 201-205.

Rosekind, M. R., Gregory, K. B., Mallis, M. M., Brandt, S. L., Seal, B., & Lerner, D. (2010). The cost of poor sleep: workplace productivity loss and associated costs. Journal of Occupational and Environmental Medicine, 91-98.

Swaen, G. M. H., Van Amelsvoort, L. G. P. M., Bültmann, U., & Kant, I. J. (2003). Fatigue as a risk factor for being injured in an occupational accident: results from the Maastricht Cohort Study. Occupational and environmental medicine, 60(suppl 1), i88-i92.

Tafazzoli, M., & Shrestha, P. (2017, October). Factor analysis of construction delays in the US construction industry. In International conference on sustainable infrastructure (pp. 111-122).

Tafazzoli, M., Kermanshachi, S., Shrestha, K., & Kisi, K. (2020, November). Investigating the relative importance barriers to sustainable construction related to owners, contractors, and government. In Construction Research Congress 2020: Infrastructure Systems and Sustainability (pp. 341-350). Reston, VA: American Society of Civil Engineers.

Techera, U. D. (2017). Measuring and managing construction worker fatigue (Doctoral dissertation, University of Colorado at Boulder).

Techera, U., Hallowell, M., Stambaugh, N., & Littlejohn, R. (2016). Causes and consequences of occupational fatigue. Journal of occupational and environmental medicine, 58(10), 961-973.

Tixier, A. J. P., Hallowell, M. R., Albert, A., van Boven, L., & Kleiner, B. M. (2014). Psychological antecedents of risk-taking behavior in construction. Journal of construction engineering and management, 140(11), 04014052.

U.S. Bureau of Labor Statistics, Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, (2016). https://www.bls.gov/news.release/osh2.toc.htm (accessed October 29, 2022).

Van der Hulst, M., & Geurts, S. (2001). Associations between overtime and psychological health in high and low reward jobs. Work and stress, 15(3), 227-240.

Xing, X., Li, H., Li, J., Zhong, B., Luo, H., & Skitmore, M. (2019). A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers. Automation in Construction, 105, 102836.

Xing, X., Zhong, B., Luo, H., Rose, T., Li, J., & Antwi-Afari, M. F. (2020). Effects of physical fatigue on the induction of mental fatigue of construction workers: A pilot study based on a neurophysiological approach. Automation in Construction, 120, 103381.