RESEARCH ARTICLE

International Journal of Civil, Environmental and Agricultural Engineering

DOI: 10.34256/ijceae2213

# Risk Assessment Methods of Low Back Pain among Masonry Apprentice

P.S. Kothai [a,*], D. Ambika [a], S. Suchithra [a], T. Indrajith [a]

[a] Department of Civil Engineering, Kongu Engineering College, Perundurai, Erode-638060, Tamil Nadu, India

* Corresponding Author: pskothai68@gmail.com

Received: 07-03-2022; Revised: 10-05-2022; Accepted: 12-05-2022; Published: 16-05-2022

**Abstract:** Work-related musculoskeletal disorders (WMSDs) are primary cause of non-fatal injuries in construction. They involve instant or persistent stress on a worker's body (muscles, tendons, ligaments, bones) that may affect a worker's ability to perform his work or even cause chronic disability. This review helps the construction sectors in better understanding the intensity of WMSDs and the risks associated with them. This paper provides a layout for research community with a comprehensive overview of existing technique, their drawbacks, and the need for more study in order to achieve automated evaluations on construction sites. Despite the fact that assessing vulnerability to WMsSD risk factors has proven to be possible in order to reduce the rate of this injury, the area remains undeveloped due to a lack of awareness among professionals about the facilitating techniques, as well as their efficiency and limitations. This paper examines the current WMSD risk evaluation methods and outlines their convenience and disadvantages. This study helps the construction sector in better understanding the extremity of WMSDs and the risks associated with them. This review imparts the researchers with an integrated view of available methods, their drawbacks, and the need for study in order to achieve automated evaluations on construction sites.

**Keywords:** Construction Safety, Work Related Musculoskeletal Disorder, Masonry Workers, Low Back Pain, Remote Sensing, Wearable Sensors

## Introduction

Work related musculoskeletal disorder (WMSDs) is a common disorder or injury among construction workers. The most common factors of WMSDs is due to repetitive motion of muscle activity, in construction related activities (rebar workers, roofers & bricklayers) it is reported that 37 % of injuries related to WMSDs [1]. Overextension is also one of the factors contributing to WMSDs and the back was the foremost body part affected which accounts for about 40% of WMSDs in construction and it is also costs in loss of wages and salary about $46million in 2014[2]. In 2013 construction chart book it is reported a decrease in the number of cases in WMSDs. Despite this, they are however 16 percent higher than the average of all other sectors [3]. In the year 2017 it is reported 970 fatal and 200,000 nonfatal injuries in the United States. The losses and injuries claim about $49 billion dollar [4]. Low back pain (LBP) is one of the severe and common injuries in WMSDs. The contributing factors are manual material handling (51%), lifting (53%), static posture (55%), awkward working stance (70 %) and repetitive work (61 %) and repeated bending and twisting (51%) [5]. In addition with the LBP the knee pain, shoulder pain, spine and neck pain is also considerable parts of body where the WMSDs might affect a worker. In a recent survey among the construction workers reported prevalence of low back pain (50%) which followed by knee pain (20%) [6]. In the year 2011 the indirect cost or workers compensation about 29% is claimed as a results of WMSDs [7]. This study describes risk factors in the construction sectors and provides a comprehensive outline of current evaluation method, including their benefits, drawbacks, suitability, performance, cost, and requirements of labour. Furthermore, the intensity of WMSDs on construction sites is disclosed, as well as the research accomplishments of the construction community. In the following section the symptom and causes of musculoskeletal disorders are discussed, which followed by risk factors and severity of low back pain among brick mason in construction sector.

## Work-Related Muscular disorder

Musculoskeletal disorders are caused by set of disorders of muscles, nerves and tendons. The WMSDs progress from mild to severe stage and it is not always everyone goes through these stages in same way and most WMSDs affect the hands, wrists, elbows, neck and shoulder [8]. Most WMSDs develop over time and it is categorized into sprains, strains, cumulative trauma disorders [9]. The general WMSDs among construction apprentice are carpal tunnel syndrome, tendonitis, tennis elbow, trigger finger and low back pains [7, 8]. In 2017 the sprain and strains among construction workers contributes about 68% (13550 reported cases) of all typical injuries [7, 10]. About 41.4% is reported injuries while performing construction works and the leading five injuries where by object (36.9%), lower back pain (35.6%), falling injury (23.3%), skin injury (20.1%) and eye problem (18.2%) [6]. A deeper flexure and elevated muscle activities were found in quick-paced manual material handling and lifting [11]. In addition with the manual material handling workers the masons also suffer from WMSDs in regions of low back, shoulder, wrists/hands, knees and it is reported that 65% have atleast one symptoms of musculoskeletal pain [12]. Figure. 1 shows the tasks that associated with high WMSDs incident rates, the helpers have high incident rate than the other typical construction activities [10]. In a current one-year follow-up study, 750 bricklayers were randomly selected and surveyed, and it was found that 67 percent of respondents had indications of WMSDs. The back, knee and upper arm are the most common body regions where the pain is experienced [8, 12].

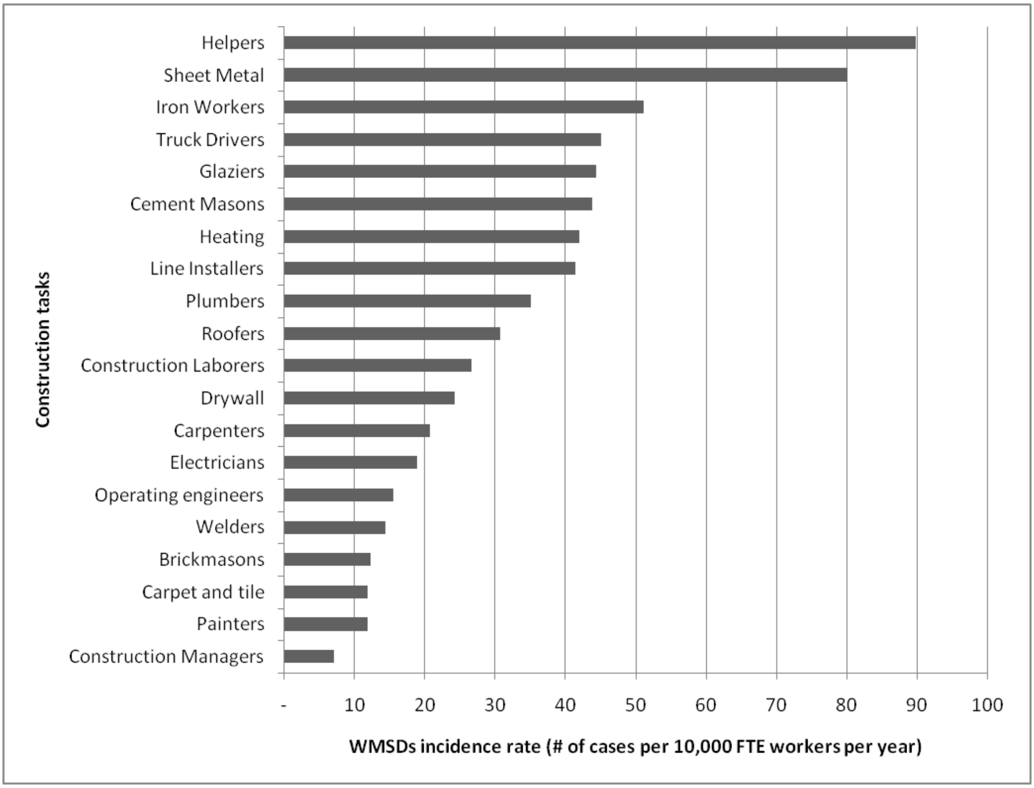


Figure 1. Incidence rates of musculoskeletal disorder among various construction tasks [10]

## Severity of Low Back Disorders Among masonry workers

Brick masons, painters and helpers generally spend more time physically handling work objects than any other manufacturing occupation in construction industry [13]. The prevalence of back injuries among masonry workers was 22.0 per 10,000 FTEs, compared to 16.2 per 10,000 FTEs in general sectors [10]. Overexertion is identified to be 33.4 per 10,000 FTEs among masonry workforce, compared to 21.5 per 10,000 in all industries combined [14].

Although, many construction employees are unaware of ergonomic solutions as well as critical risk factors linked to MSDs [15]. Furthermore, masons often report musculoskeletal symptoms as a result of their work [16]. Masons often record injuries to other body regions besides the low back, such as the spine, shoulders, wrists/hands, and knees [17]. These high injury reports shows the physical nature of masonry work [18]. About 65% of brick masons have had at least one musculoskeletal complaint in the last six months, and 81% claim their symptoms are related to their job [14]. Nearly 40% of construction labour in the study had abnormal lung function. According to the Building Trades National Screening Program pulmonary function test; the figure was closer to 50% among truck drivers, brick masons, and concrete workers [3]. In addition to these direct costs due to injuries, contractors may include a number of indirect costs. The indirect costs includes compensation paid to injured employees during their absence, costs associated with time lost due to work interruption, and employee training and replacement costs [2, 8]. Among all types of injuries the back injuries is most affected body part by WMSDs in construction. From Figure 2 the back injury is accounts for about 41.7% of WMSDs in 2017. The shoulders are the second leading part affected by WMSDs in construction industry [10].

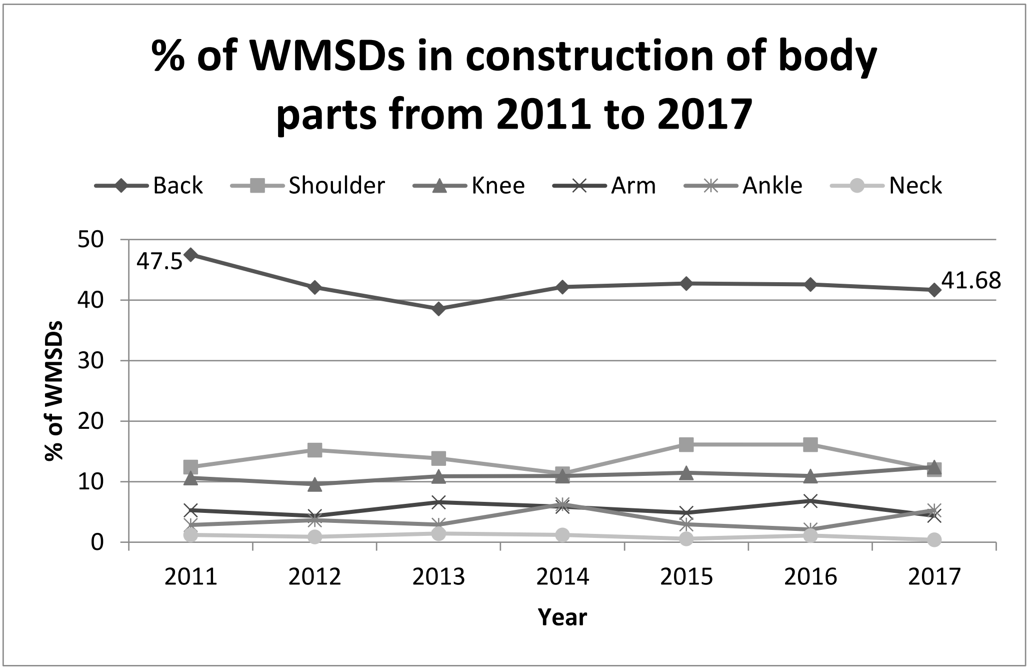


Figure 2. WMSD incident rates in construction of body parts from 2011 to 2017 [10].

The figure 3 represents the exposure score of selected occupation in construction works. The brick masons are exposed to higher rates of repetitive motions and bending tasks [3, 10]. The long term exposure to the work related musculoskeletal disorder risk which may reduce their career span and increase the chances of chronic disability among brick masons [15]. Ergonomic training is the key that can help brick masons in minimizing exposure to these risk factors [19].

## Solutions

In developed countries like United States and European countries the ergonomic practices is encouraged by safety and health organizations like OSHA, NIOSH and HSE [20]. There are several programmes available for identifying and minimizing risk factors in various occupations [8]. In construction the risk management is majorly categorized into workplace controls, engineering controlling factors and personal protective equipment for self protection [21]. The engineering controls involve redesign of tools and work methods and workplace controls deals with job rotation and work cycles [8, 21]. The National Institute for Occupational Safety and Health (NIOSH) has implemented a recent technique called "Safe – Skilled – Ready Workforce Initiative". It helps to teach the workers to identify and minimize the injuries and illnesses in working environment [15]. The Occupational Safety and Health Administration (OSHA) and NIOSH also provide guidelines for avoiding WMSDs risks in hospital employees, shipyards workers and other workplaces concerned with manual material handling [8, 15]. In conjunction with the NIOSH initiative the OSHA 10-h course is developed for construction apprentices for gaining knowledge about safety practices in workplace [15, 22].

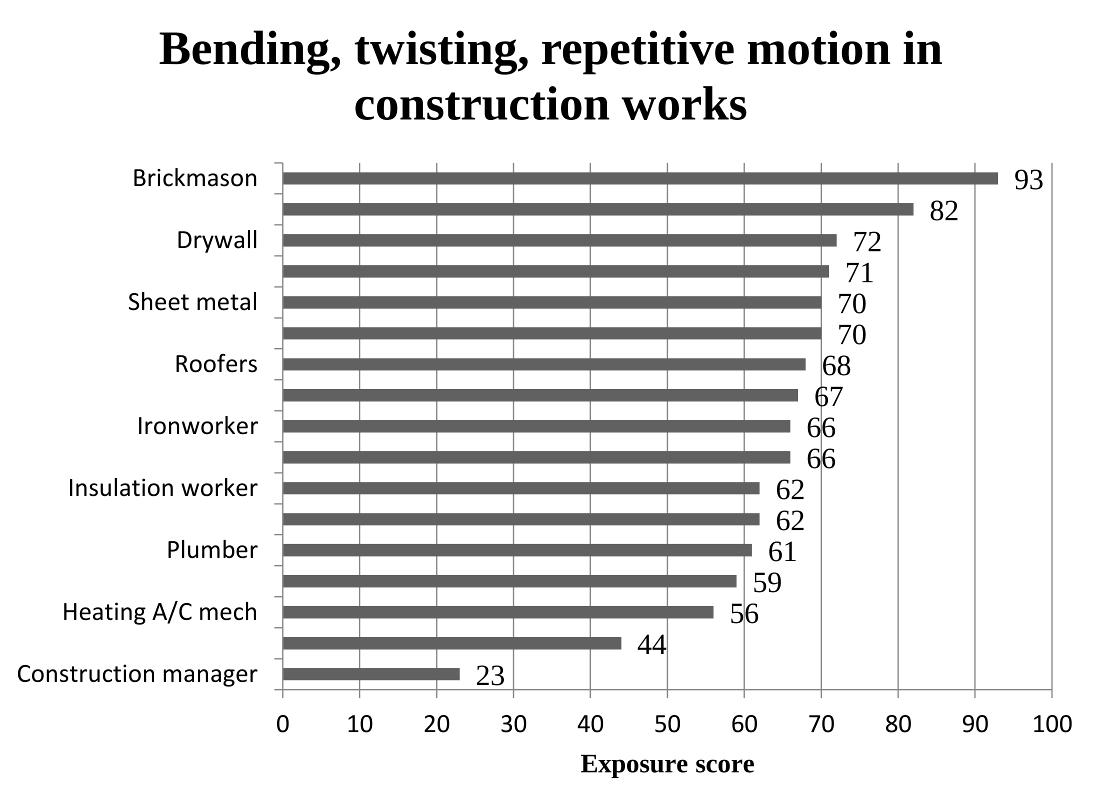


**Figure 3.** Bending, twisting and repetitive motion at construction works

The Center for Construction Research and Training (CPWR) has developed Safety Voice for Ergonomics (SAVE) program to provide necessary knowledge about the musculoskeletal injuries for masonry apprentice. The program is designed to teach problem solving skills and techniques for masonry workers [15]. SAVE program will incorporate blended learning principles [23]. It combines both traditional and face-to-face teaching with e-learning methods [24]. There's affirmation that blending conventional and e-learning is effective, mainly when providing demonstrative information such as industrial safety practices [15, 22, 23]. The major outcomes of SAVE training program is limiting of musculoskeletal disorders among masons [15]. The intermediate outcomes of SAVE are apprentice awareness and ability to converse about ergonomics and safety issues [15, 22]. The promoted guidelines and interventions according to these criteria are still ineffective. Most recommendations are written in a generalised and brief manner, causing them ineffective in directing on-site risk evaluation without the assistance of experts. Modification is necessary to make the guidelines suitable for a particular task. The approach often depends on the experts' knowledge or previous health records, leaving factors like vibration and contact force untouched [8, 25]. Despite the fact that investments in ergonomic strategies have been increasing every year, only minimal results were achieved. Figure. 2 provides statistical observation of incident rates of WMSDs in construction from 2011 to 2017 [10]. The prevalence of WMSDs in apprentice with low back pain has remained virtually constant in recent years. These show that there is a bottleneck in existing process and possibly requiring the use of advanced risk-assessment techniques.

## Risk factors in construction tasks

Construction workers have a potential to adjust to severe working conditions and also meet the expectations at the cost of their own health. As a result, WMSD risk factors in construction workplaces are difficult to detect before a high WMSD occurrence rate is identified [26, 27]. The WMSDs factors in workplace increase the risks of WMSDs. It is divided into physical factors, psychological factors and individual factors [8, 27]. Hazardous tasks or environments that expose workers or labours to musculoskeletal disorder risks are known as physical exposures, also considered as physical risk factors. Repetitive movements, high force exertions, awkward postures, and poor working conditions such as high vibration and extreme temperature are all factors related to physical factors [8, 28]. The typical physical risk factors, the injuries and activities associated with them are represented in Table 1.

**Table 1.** Physical factors in construction industry [8]

| **Risk Factor** | **Definition** | **Injury** | **Activities** |
|---|---|---|---|
| Repetition | Performing activities or similar over a period of time with no resting time | Muscle fatigue and muscle strain | Masonry workers, roofing |
| Awkward posture | Bending, twisting and overextending body over comfortable range of motion | Postural stress – neck, shoulder, wrist and back | Roofing, Manual material handling |
| Force | Amount of effort required to maintain control of an equipment while performing a task | Muscle, tendon and joint stress | Lifting, manual material handling |
| Contact stress | Impaction of injury by sharp and hard objects when balancing and grasping | Nerve and tissue injury | Masonry, carpenter |

| | | | |
|---|---|---|---|
| Vibration | Object's oscillating moment about a fixed point | Organs damaged due to absorption of high energy vibration | Operating power tools in sit and standing position on vibration surface |
| Temperature | Extremely cold or hot temperature | Cold: shivering, dilated pupils clouded consciousness<br>Hot: heat stroke, heat exhaustion | Outdoor workings |

In several cases the workers expose to WMSDs risks due to multiple risk factors. Handling of heavy equipments and repetitive lifting and lowering tasks are most common WMSDs in construction industry [8]. Brick masons are highly exposed to WMSDs than any other occupation because most of their work requires using repetitive bending motions.

Furthermore, approximately 77% of construction manufacturing and production workers are expected to work in cramped spaces and awkward stance at least once a month [3]. The individual factors also indirectly contribute to WMSDs risks [8]. The physiological factors can be family problems, safety worries, social support from colleagues and management, task demands and time pressure [29]. The individual factors differs in all aspects and it includes age, gender, previous WMSDs, physical and mental condition and bad habits [8, 29]. It has been stated that the cumulative sum of physical and psychosocial exposures over the individual factors can be used to evaluate the risk of human body injuries [30]. However, no researchers have examined into the how the factors (Psychological and individual) that contributes in the occurrence of construction WMSD risks [8].

## Risk assessment methods of WMSDs

In order to overcome the work-related muscular disorders among various field of studies for decades the researchers mainly focus on the awkward posture, high force exertion and repetitive motion. The risk assessment methods categorize into (1) self reported, (2) observation, (3) direct measurements, (4) biomechanical models, (5) machine learning and remote-sensing [8]. Table 2 outlines the typical risk-assessment techniques with corresponds to focused risks, tasks, assessment accuracy, advantages, limitations, lab/field applicability, cost, labour, and time requirement. Although there are a variety of current survey, observation, and direct measurement methods, their accuracies, targeted body parts, advantages, and limitations can differ.

## Self Reported

Self-report was developed initially to evaluate the WMSD problems and is used extensively in epidemic and ergonomic studies. The self reports methods includes face to face interview, Nordic Musculoskeletal questionnaire (NMQ) and recently the recorded videos, video conferences and internet surveys is used to improve the effectiveness of self reports [31]. The NMQ consists of information on workers background psychological health, illness history and other work related information. Each category of NMQ has several questionnaires that help to analyze the musculoskeletal disorder and about the frequency of pain concentration in overall body such as lower back, neck, shoulder. The level of pain is categorized into mild, moderate, severe and unbearable [32]. Musculoskeletal injuries related to construction workers are often tricky to detect by simple surveys. A body map (body parts graph) is used to help managers figure out where the WMSDs affects in order to obtain efficient and precise symptom description. In University of Western Ontario WMSD prevention program has developed a "Work Discomfort Survey" which has a set of questions regarding WMSD risk factors in a workplace for each part of body [8].

## Observation

Observation is method of recording postures in a workplace, for this assessment method an skilled ergonomist is essential and the evaluation forms are used to measure the WMSDs risks involved in an activity and potential proper redesign of a task and working environment will be developed [8]. The typical observational methods are Ovako Working Posture Analyzing System (OWAS), Posture, Activity, Tools, and Handling (PATH), Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA). OWAS is a technique for analysing working postures. It is developed by a steel company Ovako. The activities in a workplace is observed directly and recorded by video tape. The video and photograph is used for further investigation. This analysis gives score for the position of three major body parts (back, arm and legs) [33]. PATH is one of the observational methods to assess the posture in non-repetitive activities. The activities are divided into handling activities, public activities, hand grip and activities of specific tasks. PATH is used to evaluate three parts of the body (trunk, legs and hands), equipment and manual handling [34].

In posture analysis the REBA is used to determine the entire working posture and RULA is to determine the upper limb postures [35]. In REBA the working postures were recorded by a digital video camera with the help of frozen frame video recordings stick diagrams were drawn and analysed. The most often repeated postures and the postures that held for long time in a work cycles were selected for assessment. From the analysis it is reported that 70% of workers reported low back pain due to awkward posture [5]. In western India on a medium scale construction firm the postural analysis was performed by six skilled workers. It was carried out on construction works of brickwork, shuttering, material transportation, granite cutting and plastering works. The results of this methodology indicate that risks are involved in each task, the workers also states that pain in upper extremities [36]. In risk assessment of Filipino construction workers the analysis shows a weak correlation between RULA and REBA and their respective survey scores. It shows that subjective assessment method is insufficient in identifying risk associated to tasks [25].

## Direct measurements

The direct measurements give accurate results while comparing with the observational techniques and it is often conducted in a laboratory, occasionally wearable sensors are directly mounted on human body for recording human motions of body segments and joints. The direct measurements provide objective results than self reported surveys and observation methods. The direct measurements include electromyography, optical scanners, optical markers and goniometers are frequently used for analysis of biomechanics and joint loading [8]. Among all of the direct measurements the EMG is primarily used to evaluate the impact of exoskeleton use [31]. In a biomechanical study conducted on Noraxon USA, the surface electromyography (sEMG) is used to determine the left and right muscle activity of various body regions such as biceps brachii, brachioradialis and lumbar erector spinae [37]. Direct measurement provides comprehensive information, however the cost of equipment, data storage, and data processing time make them unsuitable for large numbers of subjects and long-term data collection [7]. In general, direct measurement has a high degree of accuracy, and post-processing of data obtained by the equipment is relatively easy [38]. To collect data on body motion and muscle function, most systems need inclusive instrumentation and lab environments [39]. The body-attached markers can also obstruct workers' ability to perform routine tasks on construction sites by interfering with their actions [8, 40]. To avoid obstruction in workers task performance the wearable sensors (single and multiple) are more effective for measuring in site conditions [41]. The results obtained from the wearable sensors may slightly vary from surface electromyography, because of its direct connection with the surface of the body [37, 42]. Furthermore, direct measurement involves a substantial capital investment in equipment. As well as the resources required to maintain and it is essential to employ qualified and skilled technicians to ensure their effective operation [43]. Overall, direct assessment is ideal for lab evaluation, examination of the features of risky postures and movements, accident investigation, and learning how injury progresses [8]. Direct measurement is limited in its ability to work properly for concurrent evaluation and monitor of on-site WMSD risks.

## Biomechanical models

The sensing based risk assessments outperform self-report and observational approaches by capturing precise and unbiased human motion data for assessing joint workloads [8]. According to the previous researches [44-46], the joint and tissue loading is strongly correlated with the severity of WMSD. Hence biomechanical model is used to evaluate human motions and predict joint loadings in various body regions. Biomechanical models are mostly aimed to measure the tissue and joint loading in accurate manner. The human biomechanics differ from one to another, therefore specific relationship are not established [8]. In a feasibility study the biomechanical model for spine loading is determined by using remote-sensing system [47]. The observation from the direct measurement and remote sensing methods are used in the post-processing of biomechanical analysis [8]. In recent years there are numerous computerized software were developed such as Three-Dimensional Static Strength Prediction Program (3DSSPP), Open Sim, Visual 3D and Any Body are existing to estimate joint loading conditions [8, 48]. So far the previous research has used a subset of 3D visualization functionalities to accomplish their objectives. The drawback of the previous studies [49] is the negligence of the typical construction works like manual material handling and repetitive movements. To overcome this gap the author interprets an automated biomechanical simulation approach for workplace using 3D visualization [35, 50]. The biomechanical models have both kinds of application; it can be used for postural analysis tool and also for independent human body movement analysis. The biomechanical models has limitation over the number of data require and errors may occur if the biomechanical skeletal model is configured with motion data from nearest joints. The external data includes gender, age, weight and the motion data are defined in the model. The complexities over the data collection increase the time and cost for analysis.

## Remote-sensing

Remote-sensing techniques are based on sensor-less biomechanics, the motion capturing sensors are used to track human body activity. The collected data can be used as for evaluation of existing assessment methods and also as a input for assessing risk levels on-site [8]. In this method there is need for direct attachment of sensors and signal receivers to human body, making them ideal for use in real-world evaluation [51]. To analyze difficult and diverse human movements, 3D-sensing technologies such as Microsoft Kinect have been developed, which collect the depth of each image pixel within the system to its corresponding position [52, 53]. The human skeleton can be derived based on the depth values by programming the 20-joint human model using the software development kit (SDK) [54].

Many previous researches have conducted experiments to investigate the viability of using video streams to perform musculoskeletal disorder evaluations. In initial stages of research studies concentrated on two-dimensional (2D) images for capturing human body motion. And the kinematic data have acquired by physically defining the position of human joint centres in each frame [51, 55]. The optical sensors can be used for both laboratory and outdoor condition. The method of processing visual data is not completely computerized because it requires manual feedback to assess posture and joint loading evaluation [8, 56]. In addition researchers have attempted to use motion training models as a baseline to equate with human models derived from recorded videos for statistically evaluating site workers' safety behaviors [57]. The effectiveness of results obtained for this method is reliant depends on comparison of training model and extracted skeleton model.

Table 2. Comparison of musculoskeletal disorder risk assessment methods

| Assessment technique | Example | Exposure | Applicable task | Instrument Accuracy | Advantages | Limitation | Lab versus field | Cost of equipment | Time/labour |
|---|---|---|---|---|---|---|---|---|---|
| Self report | [14] | Injured body part report | All types of construction tasks | Moderate | Suitable for large population; easy to use; high applicability | Personal implication; inter-related difference | Lab/field | Online availability and instrument is not required | Adequate subject required and interview process consume time |
| Observation | [33,34,36] | Whole body and limb posture risk evaluative | Masonry, Electrical, Painting, drywall, manual lifting and handling | High | Minimum work disturbance; inexpensive; practicality | Partial risk analysis; unable to detect slight movement, vibration | Lab/field | Expert employment; toolkit available online | Requires in-site visit and well trained observer is required |
| Direct measurements | [37] | Whole body risk assessment | Repetitive movements: bending, squatting and stooping | Very high | Accurate and exposure data collection; automatic | Sensors attached directly on skin; time/cost consuming | Indoor/Outdoor | Equipment cost $2000 | Require abundant subject and equipment requirement |
| Biomechanical models | [35] | Whole body joint loading and force evaluation | Analysis of static and dynamic movements | Accurate estimates during static motion tasks | User friendly interface; risky movement simulation analysis | Motion data required | Computer based | Open source | Time for algorithm development; research specialists required |
| Remote sensing | [48] | Awkward posture | Awkward posture detection | Moderate | Cost effective; automatic; applicable for real work place | subjective to illumination and complexities on post data processing | Indoor | Equipment cost $ 1500-$2500 | Qualified researchers and requires more time for development of algorithm |

In conclusion the remote sensing is more appealing for assessing outdoor construction works. But it is still difficult to convert the collected data into informative output for evaluation.

## Machine learning

Machine learning (ML) is a field of study that computer algorithms that improve themselves systematically through experience and data. It is one of the components of artificial intelligence. For more than two decades, construction expertise has considered Machine Learning [58]. Deep learning is a subset of a larger class of machine learning approaches focused on the artificial networks and representation learning. The learning can be unsupervised, semi-supervised and supervised [59]. In a research conducted in 2016, two high efficient algorithms of ML is applied Random Forest (RF) and Stochastic Gradient Tree Boosting (SGTB) to arrive large body injury reports [58]. This technique involves assessment of risk factors in indoor laboratory condition [59].

In conclusion the deep learning algorithm is used to predict the risk factors in construction that causes illness, injury and musculoskeletal pain. The outcome of the deep learning algorithm is based on the comparison of its accuracy to the existing algorithm.

## Discussion

This discussion will focus on existing assessment techniques as well as the gaps between current evaluation techniques and in-site assessment. There are still technical and methodological drawbacks in existing techniques of ergonomic assessment in construction.

Data collection on actual construction sites can be hindered by a lack of relevant activities, high equipment costs, device importability, overlap with ongoing work, time, training, labour requirements. Some marker-based approaches, such as EMG, require markers to be closely fixed to the human subjects. Although on actual sites, the sensors can have an effect on efficiency and are prone to being detached as a result of body motions, resulting in incorrect measurements. The infrared vision based techniques are sensitive to illumination and limited to outdoor environments. Existing ergonomic research often fail to take efficiency and cost-effectiveness into consideration. Furthermore, the majority of current ergonomic field evaluation methods are subjective and inadequate. As a result, several ergonomic studies concentrate on identifying and assessing risk factors in controlled laboratory environment. Therefore the construction industry requires a practical prevention of WMSDs before an injury occurs. Furthermore assessing cumulative injury risk is much more challenging since the actual nature of many disorders is still unknown, and the prevalence of musculoskeletal disorder can be influenced by a various number of aspects.

The construction sector is extremely labour-demanding. Replacing labour with machines and automation is challenging. Brick mason apprentice and manual material handlers are exposed to high WMSDs risks, particularly low back injury. A number of strategies and risk-assessment approaches have proposed and developed to prevent low back injuries. However, before implementing these approaches on real-world sites, construction professionals should be aware of their strengths and applicability. The self reported assessment and observational analysis are simple and economical to implement. The collected data from these methods are contextual, lacks accuracy and it affects the results during evaluation. Direct measurement is reliable in obtaining data, but lacks practicality in on-site works due to directly attached sensors on human skin or body parts. Motion capture systems like Vicon are expensive and restricted to laboratory conditions. As a contradiction, they are unsuitable for actual construction site. Vision-based technologies require relatively lower investment, but they still depend on manual procedures and are influenced by constraints. The machine learning assessments like deep learning provide comparable results. However, it is restricted to indoor and laboratory environment. Biomechanical models are promising and capable of converting joint loading data which can be used for post-processing [8]. The researchers have attempted to link the human motion capture with biomechanical models through conversion of data formats[35, 60].

This review shows a pattern in which researchers use remote-sensing technologies to build new WMSD evaluation methods in construction. However, a substantial quantity of researches is still needed to be developed and implement for developing a low cost automated real time risk assessment system. Based on risk evaluation functions, work discomfort levels and risks could then be measured [61]. Based on recent developments of motion capture systems it is possible to determine joint loading forces. However there are still loopholes that must be solved for risk assessment of brick mason workers. First, vision-based motion capture techniques are only capable of tracking posture-based potential risks and are unable to detect risk factors like temperature, vibration and contact stresses. Second, vision based methods are subjective to environmental interference hence further study is required to overcome factors like poor illumination and it also considers body posture as prime indicator.

Third, current methods are used to find general solutions to WMSDs and focuses only on simple tasks. Hence a specific construction activity or a real-world challenge should be used to develop a WSMD risk-assessment strategy. Fourth, when considering cost of resources, accuracy and time constraints, an integration of two or more method can yield superior results than a single method.

## Conclusion

This article analyzes WMSDs potential risk factors and severity of low back pain among brick masonry workers in the construction industry. The existing risk assessment approaches, their suitability and limitation on the construction site are summarized. Risk evaluation of WMSDs in construction is challenging because of the nature of construction works. It is implied that once the risk or risk factors for a particular construction activity are defined, a minor or major redesign of the job will be required depending on the magnitude and effects of the factor. It is improved by either making changes in the working environment setting, tools, equipment, or procedure of the operations. Furthermore for a particular task or operation, there is a possibility of alternate postures to carry out the task without distressing the workers health and efficiency. A comparative study of a particular construction activity would be helpful to identify risk involved in the operation and also for providing proper guidelines.

## References

[1] J.T. Albers, C.F. Estill, (2007) Simple Solutions: Ergonomics for Construction Workers, U.S Department of Health and Human Services, Public Health Service.

[2] J. Albers, C.F. Estill, L. MacDonald, (2006) Proceedings of a meeting to explore the use of ergonomics interventions for the mechanical and electrical trades, The National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention.

[3] A. Albert, B. Pandit, Y. Patil, Focus on the fatal-four: Implications for construction hazard recognition, Safety science, 128(2020) 104774. https://doi.org/10.1016/j.ssci.2020.104774

[4] Alghadir, S. Anwer, Prevalence of musculoskeletal pain in construction workers in Saudi Arabia, The Scientific World Journal, 2015 (2015) 1-5. https://doi.org/10.1155/2015/529873

[5] I.E. Allen, J. Seaman, Changing course: Ten years of tracking online education in the United States (ERIC), Sloan Consortium, (2013) 47.

[6] D. Anton, M. Bray, J.A. Hess, D.L. Weeks, L.D. Kincl, A. Vaughan, Prevalence of work-related musculoskeletal pain in masonry apprentices, Ergonomics, 63 (2020) 1194-1202. https://doi.org/10.1080/00140139.2020.1772380

[7] M.F. Antwi-Afari, H. Li, D.J. Edwards, E.A. Pärn, D.G. Owusu-Manu, J. Seo, A.Y.L. Wong, Identification of potential biomechanical risk factors for low back disorders during repetitive rebar lifting, Construction Innovation, 18 (2) (2018). https://doi.org/10.1108/CI-05-2017-0048

[8] M.F. Antwi-Afari, H. Li, D.J. Edwards, E.A. Pärn, J. Seo, A.Y.L. Wong, Biomechanical analysis of risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers, Automation in Construction, 83 (2017) 41-47. https://doi.org/10.1016/j.autcon.2017.07.007

[9] A. Aryal, A. Ghahramani, B. Becerik-Gerber, Monitoring fatigue in construction workers using physiological measurements, Automation in Construction, 82 (2017) 154-165. https://doi.org/10.1016/j.autcon.2017.03.003

[10] N. Asgari, M.A. Sanjari, A. Esteki, Local dynamic stability of the spine and its coordinated lower joints during repetitive Lifting: Effects of fatigue and chronic low back pain, Human Movement Science, 54 (2017) 339-346. https://doi.org/10.1016/j.humov.2017.06.007

[11] E.W.P. Bakker, A.P. Verhagen, C. Lucas, H.J.C.M.F. Koning, R.J. de Haan, B.W. Koes, Daily spinal mechanical loading as a risk factor for acute non-specific low back pain: a case–control study using the 24-Hour Schedule, European Spine Journal, 16 (1) (2007) 107-113. https://doi.org/10.1007/s00586-006-0111-2

[12] M.H. Beheshti, Z. Javan, G. Yarahmadi, Ergonomic evaluation of musculoskeletal disorders in construction workers using posture, activity, tools, handling (PATH) method, International Journal of Occupational Hygiene, 8 (2) (2016) 110-115.

[13] S.H. Binti Ismail, (2016) Musculoskeletal modelling for ergonomics: shoulder & low back loading in bricklaying.

[14] T. Bosch, J. van Eck, K. Knitel, M. de Looze, The effects of a passive exoskeleton on muscle activity, discomfort and endurance time in forward bending work, Applied ergonomics, 54 (2016) 212-217. https://doi.org/10.1016/j.apergo.2015.12.003

[15] J.S. Boschman, H.F. van der Molen, J.K. Sluiter, M.H.W. Frings-Dresen, Musculoskeletal disorders among construction workers: a one-year follow-up study, BMC musculoskeletal disorders, 13 (1) (2012) 1-10. https://doi.org/10.1186/1471-2474-13-196

[16] P. Coenen, I. Kingma, C.R.L. Boot, G.S. Faber, X. Xu, P.M. Bongers, J.H. Van Dieen, Estimation of low back moments from video analysis: A validation study, Journal of Biomechanics, 44 (13) (2011) 2369-2375. https://doi.org/10.1016/j.jbiomech.2011.07.005

[17] B.R. Da Costa, E.R. Vieira, Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies, American journal of industrial medicine, 53 (3) (2010) 285-323. https://doi.org/10.1002/ajim.20750

[18] Das, An evaluation of low back pain among female brick field workers of West Bengal, India, Environmental Health and Preventive Medicine, 20 (2015) 360-368. https://doi.org/10.1007/s12199-015-0476-0

[19] G.C. David, Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders, Occupational medicine, 55 (3) (2005) 190-199. https://doi.org/10.1093/occmed/kqi082

[20] J.J. Devereux, I.G. Vlachonikolis, P.W. Buckle, Epidemiological study to investigate potential interaction between physical and psychosocial factors at work that may increase the risk of symptoms of musculoskeletal disorder of the neck and upper limb, Occupational and Environmental Medicine, 59 (4) (2002) 269-277. https://doi.org/10.1136/oem.59.4.269
B

[21] J.A. Diego-Mas, J. Alcaide-Marzal, Using Kinect™ sensor in observational methods for assessing postures at work, Applied Ergonomics, 45 (4) (2014) 976-985. https://doi.org/10.1016/j.apergo.2013.12.001

[22] J.R.T. Domingo, M.T.S. De Pano, D.A.G. Ecat, N.A.D.G. Sanchez, B.P. Custodio, Risk assessment on Filipino construction workers, Procedia Manufacturing, 3 (2015) 1854-1860. https://doi.org/10.1016/j.promfg.2015.07.226

[23] X.S. Dong, E. Betit, A.M. Dale, G. Barlet, Q. Wei, (2019) Trends of musculoskeletal disorders and interventions in the construction industry, Centers for Disease Control and Prevention, United States.

[24] X.S. Dong, X. Wang, J.A. Largay, R. Sokas, Long-term health outcomes of work-related injuries among construction workers—findings from the National Longitudinal Survey of

Youth, American Journal of Industrial Medicine, 58 (3) (2015) 308-318. https://doi.org/10.1002/ajim.22415

[25] A. Dutta, S.P. Breloff, F. Dai, E.W. Sinsel, C.M. Warren, R.E. Carey, J.Z. Wu, Electromyography Signal Analysis of Knee Flexor and Extensor Muscles in Potential Knee Musculoskeletal Disorders during Roofing, In Construction Research Congress 2020: Safety, Workforce, and Education, (2020) 129-139, American Society of Civil Engineers Reston, VA.

[26] P. Entzel, J. Albers, L. Welch, Best practices for preventing musculoskeletal disorders in masonry: Stakeholder perspectives, Applied Ergonomics, 38 (5) (2007) 557-566. https://doi.org/10.1016/j.apergo.2006.08.004

[27] A. Golabchi, S. Han, J. Seo, S. Han, S. Lee, M. Al-Hussein, An automated biomechanical simulation approach to ergonomic job analysis for workplace design, Journal of Construction Engineering and Management, 141 (8) (2015) 04015020. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000998

[28] S. Han, M. Achar, S. Lee, F. Peña-Mora, Empirical assessment of a RGB-D sensor on motion capture and action recognition for construction worker monitoring, Visualization in Engineering, 1 (2013) 1-13. https://doi.org/10.1186/2213-7459-1-6

[29] S.U. Han, S.H. Lee, A vision-based motion capture and recognition framework for behavior-based safety management, Automation in Construction, 35 (2013) 131-141. https://doi.org/10.1016/j.autcon.2013.05.001

[30] R. J. Gatchel, (2015) Handbook of Occupational Health and Wellness, Springer, New York.

[31] J.A. Hess, L. Kincl, D.L. Weeks, A. Vaughan, D. Anton, Safety Voice for Ergonomics (SAVE): evaluation of a masonry apprenticeship training program, Applied ergonomics, 86 (2020) 103083. https://doi.org/10.1016/j.apergo.2020.103083

[32] T.M. Hlavenka, V.F.K. Christner, D.E. Gregory, Neck posture during lifting and its effect on trunk muscle activation and lumbar spine posture, Applied ergonomics, 62 (2017) 28-33. https://doi.org/10.1016/j.apergo.2017.02.006

[33] V.C.W. Hoe, D.M. Urquhart, H.L. Kelsall, M.R. Sim, Ergonomic design and training for preventing work-related musculoskeletal disorders of the upper limb and neck in adults, Cochrane Database of Systematic Reviews, 8 (2012). https://doi.org/10.1002/14651858.CD008570.pub2

[34] Hu, X. Ning, A.D. Nimbarte, The changes of lumbar muscle flexion–relaxation response due to laterally slanted ground surfaces, Ergonomics, 56 (8) (2013) 1295-1303. https://doi.org/10.1080/00140139.2013.803161

[35] S.H. Huang, Y.C. Pan, Ergonomic job rotation strategy based on an automated RGB-D anthropometric measuring system, Journal of Manufacturing Systems, 33 (4) (2014) 699-710. https://doi.org/10.1016/j.jmsy.2014.02.005

[36] N. Inyang, M. Al-Hussein, M. El-Rich, S. Al-Jibouri, Ergonomic analysis and the need for its integration for planning and assessing construction tasks, Journal of construction

engineering and management, 138 (12) (2012) 1370-1376. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000556

[37] M. Iqbal, L. Angriani, I. Hasanuddin, F. Erwan, H Soewardi, A. Hassan, Working posture analysis of wall building activities in construction works using the OWAS method, IOP Conference Series: Materials Science and Engineering, 1082 (2021) 012008. https://doi.org/10.1088/1757-899X/1082/1/012008

[38] N. Jaffar, A.H. Abdul-Tharim, I.F. Mohd-Kamar, N.S. Lop, A literature review of ergonomics risk factors in construction industry, Procedia Engineering, 20 (2011) 89-97. https://doi.org/10.1016/j.proeng.2011.11.142

[39] H. Jebelli, J.O. Seo, S. Hwang, S.H. Lee, Physiology-based dynamic muscle fatigue model for upper limbs during construction tasks, International journal of industrial ergonomics, 78 (2020) 102984. https://doi.org/10.1016/j.ergon.2020.102984

[40] V.R. Kamat, J.C. Martinez, M. Fischer, M. Golparvar-Fard, F. Peña-Mora, S. Savarese, Research in visualization techniques for field construction, Journal of construction engineering and management, 137 (10) (2011) 853-862. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000262

[41] L.D. Kincl, D. Anton, J.A. Hess, D.L. Weeks, Safety voice for ergonomics (SAVE) project: protocol for a workplace cluster-randomized controlled trial to reduce musculoskeletal disorders in masonry apprentices, BMC Public Health, 16 (1) (2016) 1-9. https://doi.org/10.1186/s12889-016-2989-x

[42] V.S Kulkarni, R.V. Devalkar, Postural analysis of building construction workers using ergonomics, International Journal of Construction Management, 19 (2019) 464-471. https://doi.org/10.1080/15623599.2018.1452096

[43] H. Lee, K. Yang, N. Kim, C.R. Ahn, Detecting excessive load-carrying tasks using a deep learning network with a Gramian Angular Field, Automation in Construction, 120 (2020) 103390. https://doi.org/10.1016/j.autcon.2020.103390

[44] X. Li, S.H. Han, M. Gül, M. Al-Hussein, M. El-Rich, 3D visualization-based ergonomic risk assessment and work modification framework and its validation for a lifting task, Journal of Construction Engineering and Management, 144 (2018) 04017093. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001412

[45] K. McKeown, M. Banerjee, J.W. Madaus, N. Gelbar, Developing an e-toolbox to facilitate universal design for instruction into online and blended learning, Educause Review, 47 (4) (2012).

[46] X. Ning, G. Guo, Assessing spinal loading using the Kinect Depth sensor: A feasibility study, IEEE Sensors Journal, 13 (4) (2012) 1139-1140. https://doi.org/10.1109/JSEN.2012.2230252

[47] I.L. Nunes, P. McCauley Bush, Work-related musculoskeletal disorders assessment and prevention, Ergonomics-A Systems Approach, (2012) 1-30.

[48] I.L. Nunes, Ergonomics: A Systems approach (InTech: Rijeka, Croatia), Human Factors and Ergonomics, (2012). https://doi.org/10.5772/2232

[49] The Center for Construction, and Training, (2013) The construction chart book: The U.S. construction industry and its workers (CPWR - The Center for Construction Research and Training: Silver Spring, MD).

[50] S.P. Schneider, Musculoskeletal injuries in construction: a review of the literature, Applied occupational and environmental hygiene, 16 (11) (2001) 1056-1064. https://doi.org/10.1080/104732201753214161

[51] J.O. Seo, R. Starbuck, S.U. Han, S.H. Lee, T.J. Armstrong, Motion data-driven biomechanical analysis during construction tasks on sites, Journal of Computing in Civil Engineering, 29 (4) (2015) B4014005. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000400

[52] S. Shankar, R. Naveen Kumar, P. Mohankumar, S. Jayaraman, Prevalence of work-related musculoskeletal injuries among South Indian hand screen-printing workers, Work, 58 (2) (2017) 163-172. https://doi.org/10.3233/WOR-172612

[53] A.J.P. Tixier, M.R. Hallowell, B. Rajagopalan, D. Bowman, Application of machine learning to construction injury prediction, Automation in Construction, 69 (2016) 102-114. https://doi.org/10.1016/j.autcon.2016.05.016

[54] H.F. Van Der Molen, P.P.F.M. Kuijer, P.P.W. Hopmans, A.G. Houweling, G.S. Faber, M.J.M. Hoozemans, M.H.W. Frings-Dresen, Effect of block weight on work demands and physical workload during masonry work, Ergonomics, 51 (3) (2008) 355-366. https://doi.org/10.1080/00140130701571792

[55] Wang, F. Dai, X. Ning, Risk assessment of work-related musculoskeletal disorders in construction: State-of-the-art review, Journal of construction engineering and management, 141 (6) (2015) 04015008. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000979

[56] Wang, F. Dai, X. Ning, R.G. Dong, J.Z. Wu, Assessing work-related risk factors on low back disorders among roofing workers, Journal of construction engineering and management, 143 (7) (2017) 04017026. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001320

[57] J. Wang, Z. Liu, J. Chorowski, Z. Chen, Y. Wu. Robust 3d action recognition with random occupancy patterns, European Conference on Computer Vision, (2012) 872-885. https://doi.org/10.1007/978-3-642-33709-3_62

[58] X. Wang, X.S. Dong, S.D. Choi, J. Dement, Work-related musculoskeletal disorders among construction workers in the United States from 1992 to 2014, Occupational and environmental medicine, 74 (2017) 374-380. https://doi.org/10.1136/oemed-2016-103943

[59] S. Warade, J. Aghav, P. Claude, S. Udayagiri, Real-time detection and tracking with Kinect, International Conference on Computer and Information Technology, (2012) 86-89.

[60] E.B. Weston, M. Alizadeh, G.G. Knapik, X. Wang, W.S. Marras, Biomechanical evaluation of exoskeleton use on loading of the lumbar spine, Applied ergonomics, 68 (2018) 101-108. https://doi.org/10.1016/j.apergo.2017.11.006

[61] K. Yang, C.R. Ahn, H. Kim, Deep learning-based classification of work-related physical load levels in construction, Advanced Engineering Informatics, 45 (2020) 101104. https://doi.org/10.1016/j.aei.2020.101104

**Conflict of interest:** The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

**Funding:** No funding was received for conducting this study.