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Biomechanical analysis of risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers

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ABSTRACT

Work-related musculoskeletal disorders (WMSDs) represent major health issues for construction workers yet risk factors associated with repetitive lifting tasks remain unexplored. This study evaluates the effects of lifting weights and postures on spinal biomechanics (i.e. muscle activity and muscle fatigue) during a simulated repetitive lifting task undertaken within a strictly controlled laboratory experimental environment. Twenty healthy male participants performed simulated repetitive lifting tasks with three different lifting weights using either a stoop (n = 10) or a squat (n = 10) lifting posture until subjective fatigue (a point in time at which the participant cannot continue lifting further). Spinal biomechanics during repetitive lifting tasks were measured by surface electromyography (sEMG). Results revealed that (1) increased lifting weights significantly increased sEMG activity and muscle fatigue of the biceps brachii (BB), brachioradialis (BR), lumbar erector spinae (LES), and medial gastrocnemius (MG) muscles but not the rectus femoris (RF) muscle; (2) sEMG activity and muscle fatigue rate of the LES muscle were higher than all other muscles; (3) a significant difference of sEMG activity of the RF and MG muscles was observed between lifting postures, however no significant difference of muscle fatigue was apparent ($p > 0.05$). These findings suggest that risk factors such as lifting weights, repetitions and lifting postures may alleviate the risk of developing WMSDs. However, future research is required to investigate the effectiveness of using ergonomic interventions (such as using team lifting and adjustable lift equipment) in reducing WMSDs risks in construction workers. This work represents the first laboratory-based simulated testing conducted to investigate work-related musculoskeletal disorders (WMSDs) primarily caused by repetitive lifting tasks and manual handling. Cumulatively, the results and ensuing discussion offer insight into how these risks can be measured and mitigated.

1. Introduction

Extant literature reports that work-related musculoskeletal disorders (WMSDs) are among the most prevalent occupational health problems affecting manual workers [1]. In the United States, WMSDs account for 32% of all injury and illness cases that lead to absence from work for all industries [2]. While in construction and civil engineering, Schneider [3] reported that WMSDs account for over 37% of all injuries. Construction workers (e.g., rebar workers, bricklayers and roofers) are by virtue of their occupation frequently exposed to elevated physical risk factors such as repetitive motions (lifting/lowering), awkward postures and lifting weights, which represent the major causes of WMSDs [4]. Symptoms of WMSDs are myriad but may include lower back pain, neck/shoulder pain, tendonitis and carpal tunnel syndrome [5]. Fung et al. [6] found that musculoskeletal symptoms are particularly common in the upper extremities and lower back region of the human torso. Notably WMSDs not only lead to worker ill-health but also to reduced productivity and concomitant financial loss [7]. Therefore, risk factors associated with WMSDs should be identified in order to develop effective ergonomic interventions to prevent WMSDs in construction workers.

Radwin et al. [8] found that biomechanical and anthropometric parameters are significant determinants of the risk factors that instigate the development of WMSDs but their true extent remains unclear. Other researchers such as De Looze et al. [9] and Norman et al. [10] demonstrated a causal link between developing WMSDs and physical

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work exposure parameters. Specifically, Norman et al. [10] identified four risk factors for lower back disorders in automotive workers, namely: i) load moment; ii) hand forces; iii) peak shear force; and iv) peak trunk velocity. However, these studies only reported upon a specific body part (e.g., lower back and shoulder) and on an isolated risk factor (e.g., repetitions and lifting postures). In contrast, construction workers may sustain multiple injuries during repetitive lifting tasks [11]. The most important WMSDs risk factors relate to lifting weights and awkward postures because such requires maintaining muscle force over an extended period of time [12–14]. Repetitive and prolonged lifting tasks cause muscle fatigue and discomfort for a worker and invariably this activity increases the risk of developing WMSDs. Even though previous studies have widely advocated appropriate lifting postures (e.g., stoop and squat) [15,16], their effect upon spinal biomechanics remains unclear. Therefore, laboratory-based simulated repetitive lifting tests are needed to gain a better understanding of spinal biomechanics and in turn, develop effective lifting procedures and processes which may elevate the risk of developing WMSDs. Given this contextual background, this study seeks to evaluate the effects of lifting weights and postures on spinal biomechanics (i.e. muscle activity and muscle fatigue) during a laboratory-based simulated repetitive lifting task. To mitigate the risks of construction workers developing WMSDs, the research culminates by suggesting a number of potential pragmatic ergonomic interventions such as team lifting and adjustable lift equipment.

2. Research background

2.1. Current state of practice in WMSDs prevention

To reduce the risk of developing WMSDs among construction workers, general ergonomic practices have been promoted by safety and health organizations such as the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH). Instead of focusing on hazards to lower back disorders, general ergonomic practices typically focus on risk exposures associated with all WMSDs. For example, NIOSH published guidance which contains simple and inexpensive methods to help prevent injuries [17]. In a similar vein, OSHA offers training materials and programs to help workers recognize, avoid and control safety and health hazards in their workplaces [18]. Despite these efforts, current ergonomic practices designed for general manual handling tasks still lack practicality for repetitive lifting tasks because: i) most guidelines are presented in a brief and generic manner that is largely inappropriate to WMSDs prevention practices [19]; and ii) differences in work settings (e.g., repetitive lifting tasks, the weight being lifted and worker postures adopted during the lift) are often overlooked.

2.2. Risk assessment methods to identify potential risk factors of WMSDs

Within contemporary construction practice, techniques for assessing exposure to risk factors associated with WMSDs include self-reports, observations, direct measurement and remote sensing methods [20]. Despite the usefulness of these techniques, several limitations are apparent [21]. For instance, self-reports (e.g., the Borg Scale) vary from the inter-rater difference of workers' perception and are consequently imprecise and unreliable [22]. An extensive array of observational tools for ergonomic and posture analysis have also been developed and include: Quick Exposure Check (QEC) [23], the Assessment of Repetitive Arts (ART) [24], the Manual Handling Assessment Chart (MAC) [25], the Rapid Upper Limb Assessment (RULA) [26,27], the Rapid Entire Body Assessment (REBA) [28], Washingston State's ergonomic rule (WAC 296-62-051) [29], Posture, Activity, Tools and Handling (PATH) [30], Strain Index [31], The Liberty Mutual Manual Material Handling Tables (SNOOK tables) [32], the NIOSH lifting equation [33,34] and 3D Static Strength Prediction Program (3DSSPP) [35].

The RULA observational tool is a postural targeting method for estimating the risks of work-related upper limb injuries based upon the positions of upper arms, wrists, neck and upper trunk; while the REBA estimates the entire body's risks according to the positions of arms, wrists neck, trunk and legs. All risk assessment methods provide an expeditious, systematic and quantitative assessment of the worker's postural risks with regard to major body joints and angles between joints [7]. However, these posture assessment approaches usually collect data through observations, questionnaires or scorecards which are subject to the assessor's individual bias and judgement [36], as well as being inefficient and inaccurate [37,38]. Remote sensing methods are potentially an attractive solution for assessing biomechanical risks and ill-health [39–41]. For example, Weerasinghe and Ruwanpura [41] proposed infrared cameras for identifying worker activity status based upon heat emitted from the worker's body in conjunction with video images and acoustic data. However, remote sensing methods use expensive cameras and have difficulties with moving backgrounds and varying light conditions as experienced within the dynamic and inclement construction environment [22]. Direct laboratory measurements provide accurate and reliable data by using relatively simple instruments such as surface electromyography (sEMG) sensors [42]. Moreover, sEMG sensors are useful for biomechanical studies in laboratory settings [43]. Hence, this study adopts sEMG sensors to supplement existing methods to identify risk factors of WMSDs.

2.3. Theories and models of WMSDs

There are several theories and models of WMSDs causation that have been discussed in the literature, however, based on the scope of the current study only biomechanical theories and models of risk factors for WMSDs causation were reviewed. During the 1970s, Chaffin and his colleagues [44–47] and others developed simple, 2- and 3-D, static biomechanical models to estimate compressive and shear forces on lumbar spine as well as static strength requirements of jobs in occupational settings. These static biomechanical models generally tend to underestimate stresses on the low back predominately because they ignore the inertial loads [9,48] as well as muscle cocontraction [49,50]. Using a multiple internal muscle model, Schultz and Andersson [51] demonstrated that lifting of weights could generate large spinal forces due to the coactivation of trunk muscles. However, this modelling approach led to muscle contraction force calculations that were statistically indeterminate; therefore, optimisation techniques were used to make those calculations [52,53]. Dynamic, 3-D, anatomically complex and sEMG driven models were also developed to predict individual lumbar tissue loads [16,54–58]. Most of these models overcame limitations such as static or isokinetic mechanics, inaccurate prediction of muscle coactivity, static interpretation of myoelectric activity and physiologically unrealistic force per unit area. These models employ dynamic load in the hands, kinematic input, moment about the three orthopaedic axes of the low back normalized sEMG, muscle-cross section area, a gain factor to represent muscle force per unit area and modulation factors describing EMG and force behavior as a function of muscle length and velocity to determine tensile load in each muscle. The model developed by McGill and colleagues [50,59,60] also accounted for passive spinal and ligamentous forces. These theories and models represent significant improvements in biomechanical modelling to predict loads on the lumbar spine under different loading conditions.

Similarly, extant literature indicates that many factors with a biomechanical impact are strong risk factors for WMSDs to the upper extremities. Repetitiveness of the work activity has been shown to be a strong risk factor for cumulative trauma disorders (repetitive strain injury) [61–67]. Repeated load application may result in cumulative fatigue, reducing the stress-bearing capacity of the upper extremities muscles. Besides, forcefulness/overexertion of job activities has similarly been strongly associated with these upper extremities injuries [61,62,65,66,68,69]. In summary, Kumar [70] reported that relatively