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Effects of overhead work configuration on muscle activity during a simulated drilling task

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ABSTRACT

Overhead work is a known catalyst for occupational shoulder injury. Industrial workers must often adopt awkward overhead postures and loading profiles to complete required tasks, potentially elevating injury risk. This research examined the combined influence of multiple overhead working parameters on upper extremity muscular demands for an industrial drilling application.

Twenty-two right-handed males completed 24 unilateral and bilateral overhead work exertions stratified by direction (upward, forward), point of force application (15, 30 and 45 cm in front of the body), and whole-body posture (seated, standing).

The dependency of electromyographic (EMG) activity on several factors was established. Significant two-way interactions existed between point of force application and direction ($p < 0.0001$) and direction and whole body posture ($p < 0.0001$). An average increase in muscular activity of 6.5% maximal voluntary contraction (MVC) occurred for the contralateral limb when the bilateral task was completed, compared to unilateral tasks, with less than a 1% MVC increase for the active limb.

These findings assist evidence-based approaches to overhead tasks, specifically in the construction industry. A bilateral task configuration is recommended to reduce glenohumeral stability demands. As well, particularly for tasks with a far reach distance, design tasks to promote a forward directed exertion. The considerable inter-subject variability suggests that fixed heights are not ideal, and should be avoided, and where this is not possible reaches should be reduced.

1. Introduction

Exertions are frequently performed in an overhead position in occupational settings. Overhead work is generally defined as working with the hands above the acromion, or over 60° shoulder flexion or abduction (Grieve and Dickerson, 2008). These postures reduce work capacity and joint strengths, while concomitantly increasing inaccuracy and task completion time (Grieve and Dickerson, 2008). Overhead work is prevalent in several occupational settings, including manufacturing and construction (Forde and Buchholz, 2004). Often geometric workspace constraints require workers to frequently adopt awkward and overhead postures to complete required tasks (Bjelle et al., 1979; Chaffin, 1973), with overhead work exposure frequencies ranging from 6 to 21% within a construction population, based on an observation of construction ironwork (Forde and Buchholz, 2004).

Myoelectric activity has frequently been used to quantify physical demands associated with overhead work. For instance, amongst experienced welders the supraspinatus is susceptible to fatigue during overhead work, and has the greatest strain, determined by the increase in EMG signals present during tasks involving overhead positions (Herberts and Kadefors, 1976). Specific to a drilling task, close overhead reaches have reduced biceps brachii and anterior deltoid activation (Anton et al., 2001). Increased muscular activity also results from farther overhead work locations when force is directed upwards (Chopp et al., 2010); however, when hand force was produced in other directions in this study (backward, forward, or downward), a modest forward reach (15–30° in front of the body) required lower overall muscular demand than directly overhead. This demonstrates the complex interactions present in the muscular demands of overhead work.

There is a greater risk for injury risk during overhead work. A strong relationship has been demonstrated between working with the arms above shoulder height (approximately 90° of elevation) and the development of pain and injury (Bernard, 1997; Grieve and Dickerson, 2008; Herberts et al., 1981; Punnett et al., 2000; van Rijn

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et al., 2010). In particular, subacromial impingement syndrome, which results from a reduction in the acromiohumeral interval width of the shoulder, is recognized as the predominant injury resulting from these awkward overhead postures (Miranda et al., 2005; Svendsen et al., 2004; van Rijn et al., 2010). Impingement accounts for approximately 50% of clinically diagnosed shoulder dysfunctions (van der Windt et al., 1995) and leads to several additional shoulder pathologies, including rotator cuff tears, subacromial bursitis, and SLAP lesions (Braman et al., 2014).

Research on overhead work has largely focused on unilateral tasks, and thus provides little insight into how bilateral strategies influence exposures. Occupational activities are often performed using both arms, particularly in the construction industry. The non-dominant limb generally acts as a whole-body stabilizer, while the dominant limb completes gross movements (Wang and Sainburg, 2007). The modification of exposure on both limbs in overhead work for bilateral tasks is unstudied, and therefore it is unknown if there is additional overexertion risk present, or a shifting of risk.

The purpose of this research was to compare muscular demands during unilateral and bilateral overhead simulated industrial drilling. It was hypothesized that a reduction in average muscular demands during the bilateral tasks would occur in the dominant arm, due to symmetric distribution of the required loads. Several scenarios were evaluated with the intention of developing evidence-based recommendations for overhead drilling to keep shoulder muscular demands as low as possible.

2. Methods

Surface electromyographic (sEMG) data was collected from university-aged males, during simulated drilling tasks. Participants performed 24 static overhead trials with a hand-held drill in one testing session while sEMG was recorded. For the purposes of this study the right (dominant) upper limb will be referred to as the active limb, and the left upper limb will be referred to as the contralateral limb.

2.1. Participants

Twenty-two right hand dominant males (21 ± 1.1 years, 1.80 m ± 0.08 m, 81.0 kg ± 8.5 kg) participated. Gender was restricted to reflect construction sector demographics (Forde and Buchholz, 2004). Exclusion criteria were reported upper extremity or back discomfort or injury within the past year. The protocol was approved by the institutional research ethics board.

2.2. Equipment

Upper extremity muscle activity and force applied by the drill were measured during experimental trials. Six upper extremity and back muscles were monitored bilaterally using sEMG with the Noraxon T2000 telemetered system (Noraxon, Arizona, USA): anterior deltoid, middle deltoid, upper trapezius, infraspinatus, supraspinatus, and lumbar erector spinae. Prior to electrode placement, the skin overlaying the muscles was shaved and cleaned with alcohol to reduce impedance. Noraxon bi-polar Ag–AgCl dual surface electrodes, with a fixed 2 cm inter-electrode spacing were placed over the described muscles using published placements (Cram and Kasman, 1998). Additionally, a ground electrode was placed over the clavicle. sEMG was recorded at 1500 Hz within the VICON Nexus 1.7.1 software (VICON, Oxford, UK). Subjects exerted a force using a hand-held drill (~2.3 kg), which was not turned on to eliminate vibration, against a multi-axis load cell (MC3A, AMTI, Watertown, MA, USA). Visual force feedback was provided through custom Labview software (National Instruments, Austin, Texas, USA). This system provided real-time feedback to the participants, and verified the desired level of force was maintained against the force transducer.

2.3. Experimental protocol

Prior to the drilling trials, participants completed eleven standardized muscle-specific maximum voluntary isometric contractions (MVC) (Table 1) to normalize signals measured during drilling trials (Criswell, 2011). MVCs were performed twice for each muscle group to improve reliability of the results (Fischer et al., 2010) with a minimum of two minutes rest between MVCs (Chaffin, 1975). Five minutes of rest was provided between the MVC and drilling tasks. The max of each muscle was found from peak signal during MVCs, and considered 100% MVC.

Twenty-four randomized trials were completed with each trial representing a unique combination of the four parameters (Table 2, Fig. 1). Participants exerted a total force of 30 N with the drill against the multi-axis transducer in the desired force direction. Each trial was approximately 10 s in duration with 60–90 s of rest provided between trials. A force magnitude of 30 N was chosen in order to elicit moderate muscular demand, emulate plausible work tasks, and be unlikely to generate fatigue during the experimental session.

Participants were verbally encouraged to remain in an upright posture and to maintain consistent arm flexion angles. They were instructed not to lean backwards or forwards, with the exception of the far reach trials for which it was necessary for some participants to lean in order to reach the target. A guard rail was placed directly in front of the participant to mimic a workplace barrier and to assist in limiting foot placements. Whole-body posture was otherwise unrestricted to encourage realistic postural selections.

2.4. Data and statistical analysis

All EMG data were processed in the amplitude domain to compare inter-task differences. Raw EMG signals were band pass filtered from 10 to 500 Hz and differentially amplified (CMRR >100 dB at 60 Hz, input impedance 100 MΩ). Signals were A/D converted using a 16-bit card with a ±3.5 V range and then linear enveloped using a second order dual pass Butterworth filter with a 4 Hz cutoff. For each trial, an average of the last five seconds of the trial for each muscle was computed and normalized to the peak magnitude obtained during the muscle-specific MVC exertions to allow for inter-subject comparisons. The last five seconds was selected to allow for force generation and to enable participants to reach and maintain the required force level (30 N) within ±5 N. Additionally, the last five seconds were more stable than that of the first five. If the participant did not maintain the force level, the trial was repeated. Additionally, an arithmetic average of the individual normalized muscle activity magnitudes was computed for each trial to compare overall muscle demand between trials.

A four way repeated measures ANOVA (technique, whole-body posture, point of force application and direction) with two-way interactions was used to determine the influence of each of the working parameters on both individual and average muscle activity of the active limb. A p-value of 0.05 was used to determine significance, and post-hoc analyses performed using Tukey's HSD statistics. Statistical analyses were completed using JMP software (SAS, Cary, North Carolina, USA).

3. Results

Muscular activity was influenced differentially by the tested parameters, for individual muscles as well as total muscular effort