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Impact of pulling direction and magnitude of force exertion on the activation of shoulder muscles

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ABSTRACT

Shoulder musculoskeletal disorders (MSD) are frequently associated with the work activities that demand forceful arm exertions in pushing and pulling directions. Considering the ability of shoulder joint to exert forces in nearly any direction, our understanding of the shoulder muscles activation as affected by pushing and pulling exertions is limited. In this study the activation of seven shoulder muscles were studied for 10 male participants during pulling exertions performed in five directions (pull right, pull left, pull back, pull down and pull up) using three force levels (22.24 N, 33.36 N and 44.48 N). Exertions performed in pulling right and pulling up directions produced higher activation and received higher perceived exertion ratings than the exertions performed in the other directions. Rotator cuff and middle deltoid muscles activation were consistently higher during pulling up and pulling right exertions compared to the other muscles. A high correlation was found between the activation of rotator cuff and deltoid muscles and the perceived exertion ratings. The rotator cuff and middle deltoid muscles activation observed during the pulling up and pulling right exertions can be explained by the concavity compression mechanism which stabilizes the glenohumeral joint of shoulder.

Relevance to industry: The muscle activation data expressed in terms of Maximum Voluntary Contraction (MVC) and perceived exertion ratings are widely used by the ergonomic practitioners to design and/or evaluate workplace exertions. This study provides such data for several shoulder muscles during pulling exertions performed under different conditions.

1. Introduction

Musculoskeletal disorders (MSD) place a substantial burden on both the employer and worker in terms of healthcare costs, human suffering, and the resulting socioeconomic impact. In particular, MSDs of the shoulder are a major cause of morbidity and pain in the modern working population. Shoulder pain is a common musculoskeletal problem with an estimated prevalence rate between 16 and 26% in the primary care setting (House and Mooradian, 2010). In 2011, shoulder disorders were the second most prevalent type of MSD but were the most severe requiring 21 median days away from work compared to 11 days for all other MSD combined (Bureau of Labor Statistics, 2012). In addition to lost workdays, shoulder MSD also generate expensive medical costs. For compensation claims data spanning from 1997 to 2005, the average total direct cost of a work-related shoulder disorder was US $16,092 per claim in the state of Washington (Silverstein and Adams, 2007). In addition to the immediate and highly visible direct costs, these disorders also cause not so evident indirect costs such as reduced health, impaired task ability, and decreased productivity (Lötters et al., 2005; Östör et al., 2005).

Multiple epidemiological investigations have proposed several work-related exposures that are associated with shoulder disorders. These exposures include, but are not limited to awkward and prolonged sustained postures of the upper extremities, and repetitive and forceful arm exertions (da Costa and Vieira, 2010; Larsson et al., 2007; Putz-Anderson et al., 1997; Walker-Bone, 2005). Occupations such as nursing, material handling, janitorial work, transportation, and manufacturing have been found to have workers who suffer from shoulder MSDs as they are frequently engaged in work activities that exposes them to these factors; in particular, forceful arm exertions in pushing and pulling directions (Bureau of Labor Statistics, 2012; Dunning et al., 2010; Putz-Anderson et al., 1997). A significant dose-response relation between pushing and pulling exertions and shoulder complaints was also reported in a previous study (Hoozemans et al., 2002).

The shoulder complex consists of three joints including the Glenohumeral joint (GHJ), Acromioclavicular joint (ACJ) and

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Sternoclavicular joint (SCJ). While ACJ and SCJ provide passive strength to the shoulder complex, GHJ is responsible for the shoulder mobility and force generation during workplace exertions. The GHJ is a ball-and-socket joint between the humeral head and the scapula's glenoid fossa. The surface of the glenoid fossa is only one third of the humeral head, meaning a small part of the humeral head is in contact with the glenoid fossa. While such arrangement of humeral head and glenoid fossa facilitates generation of pushing/pulling forces of varying magnitude in nearly any direction it puts significant burden on the shoulder muscles to stabilize the GHJ joint during such exertions.

Previous studies on the shoulder muscle activation primarily focused on the effect of factors such as hand gripping, load, and posture. Increased shoulder muscles activation with an increase in the hand gripping force was reported by Sporrong et al. (1995, 1996) and Antony and Keir (2010). Brookham et al. (2010) studied the effect of different postures during light tool usage and forward pushing exertion on the activity of shoulder muscles, and reported a positive relationship between activation of shoulder muscles and shoulder flexion angle. Chopp et al. (2010) evaluated shoulder muscle activation during overhead exertions performed using different work configurations and hand locations and reported that overhead pulling back exertion produced the highest muscle activation. Similar results were also reported in Cudlip et al. (2016) for female participants.

Considering the ability of shoulder joint to exert forces in nearly any direction and its reliance on the shoulder muscle to achieve stability during such exertions, our understanding of shoulder muscles activation as affected by the direction and magnitude of pushing and pulling exertions performed in different directions is limited. In this study inter-individual differences in the activation of shoulder muscles were studied during pulling exertions performed in different directions using three force levels. Understanding such differences would assist in knowing the contributions of shoulder muscles in stabilizing the GHJ joint during pulling exertions.

2. Methods

2.1. Approach

A laboratory-based study was performed using human participants who performed isometric pulling exertions in five directions using three force levels. Surface electromyography (SEMG) data were recorded from seven shoulder muscles: supraspinatus, infraspinatus, middle deltoid, anterior deltoid, posterior deltoid, biceps and triceps.

2.2. Participants

Ten healthy, right-hand dominant male participants free from any type of musculoskeletal, degenerative or neurological disorder were recruited for this study. Participants were graduate college students, and their average height, weight and age were 173.5 ± 5.4 cm, 76.24 ± 8.25 kg and 26.9 ± 2.4 years, respectively. Participants' assent to participate in the study was obtained using a consent form approved by the local Institutional Review Board (IRB).

2.3. Equipment

2.3.1. Custom-made force exertion device

This device consists of a wooden chair equipped with a four-point harness to secure participants in a standard sitting posture. The chair was mounted on the base of a column and base assembly. The column was fitted with a height-adjustable peripheral assembly which consist of a set of perforated steel tubes fitted with pulleys. A rope was used to hang weights of different magnitudes from the pulleys, and human participants pulled the other end of the rope using a D-handle. A set of perforated steel tubes and pulleys allow the experimenter to control the direction of pulling. Fig. 1 illustrates the force exertion device and different force exertions directions tested in the current study.

2.3.2. Surface electromyography (SEMG) system

A Telemyo 2400 T G2 EMG system (Noraxon Inc., AZ, USA) was used for data collection. The system consists of a Telemyo 2400R G2 receiver, Telemyo 2400T G2 transmitter with 16 channels, pre-amplified lead wires and disposable, self-adhesive Ag/AgCl snap/clips electrodes. The bipolar Ag/AgCl pre-gelled surface electrodes were of 1 cm diameter, with an inter-electrode distance of 2 cm. The pre amplifier on the lead wires has a band-pass of 10–1000 Hz (gain of 500), Common Mode Rejection Ratio (CMRR) $>$ 100 dB and input impedance $>$ 100 MΩ. The electrodes were attached to the pre-amplified lead wires and then connected to the Telemyo 2400T G2 transmitter. The Telemyo 2400T G2 transmitter was mounted on the participants using a pouch and belt clip. The G2 transmitter transmitted the EMG data wirelessly to the Telemyo 2400R G2 receiver. The EMG data was sampled at a frequency of 1500 Hz.

2.3.3. Strength measurement device

HUMAC NORM (Computer Sports Medicine, Inc., MA, USA) system was used for conducting Maximum Voluntary Contraction (MVC) data collection. The system consists of an adjustable chair with a four-point seatbelt harness, a dynamometer with adjustable range of motion stops and multiple adapters for variety of force exertion. During data collection, the participants were seated and secured in the chair and appropriate adapters were attached to the dynamometer to assist with muscle specific MVC force exertion.

2.4. Experimental design and data collection procedure

A two-factor experimental design was used: factor 1, direction of pulling exertion, was treated at five levels: Pulling Right (PR), Pulling Left (PL), Pulling Back (PB), Pulling Down (PD) and Pulling Up (PU); factor 2, force exertion level, was treated at three levels: 22.24 N, 33.36 N and 44.48 N. Upon arrival for data collection to the laboratory participant's demographic (height, weight, and age) data were recorded and the participant was informed of the basic procedure to be used for the data collection process. Participant's consent was then obtained using IRB approved consent form. To prepare the participant for SEMG data collection, the locations of SEMG electrodes were shaved and cleaned using 70% rubbing alcohol. Table 1 shows the electrode location used to collect SEMG data from the shoulder muscles (Decker et al., 1999; Hintermeister et al., 1998; Sporrong et al., 1998; Xu et al., 2014).

Next, SEMG data were recorded using MVC for each muscle. HUMAC NORM system was used to control muscle specific postures during MVC trials. Each MVC trial (7–9 s) consist of building the force/strength to maximum (2–3 s), holding the maximum strength (3 s) and gradually returning to a level of no force (2–3 s). Table 2 describes the exertion used to record the MVC for each muscle (Decker et al., 1999; Hintermeister et al., 1998; Xu et al., 2014). Adequate rest time of 2–5 min was provided to the participant between the MVC measurements. The participant then began the experimental trials. First, the participant was seated and secured into the wooden chair of the force exertion device using four-point harness. A few practice trials were then performed to get the participant acquainted with the setup. During the actual trials, the position of the pulley, rope and D-handle were adjusted such that the participant could grasp it using a 15°–20° flexed shoulder joint and a 70°–80° flexed elbow joint. The flexion angles are relative to the standard anatomically neutral – normally relaxed – posture. In each trial, the participant was required to hold the D-shape handle attached to one of the weight levels for 60 s. Each experimental condition was repeated twice, thus each participant performed a total of 30 randomized experimental trials (5 force directions × 3 force levels × 2 repetitions). A 2-minute rest time was provided between the trials. The SEMG data was recorded continuously during the exertion. In addition, after the completion of each experimental trial, the