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Spatial dependency of shoulder muscle demand during dynamic unimanual and bimanual pushing and pulling

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ABSTRACT

Work involving extensive pushing and pulling is associated with higher frequency of shoulder complaints. While reports of shoulder muscle demand during submaximal isometric tasks are abundant, dynamic submaximal push-pull exertions are not well understood. We evaluated how muscle demand (weighted EMG average) of surface glenohumeral muscles varies with task type and target. Seventeen healthy young adults performed seated unimanual and bimanual pushes and pulls to 3 thoracohumeral elevations (20°, 90°, 170°) and 4 elevation planes (0°, 45°, 90°, 135°) with loading at 15% of isometric push-pull capacity. Pulling required less demand than pushing ($p < 0.0001$). Muscle demand varied more with elevation than elevation plane. The lowest target had highest demand for pulling ($p < 0.01$), and the most elevated target had highest demand for pushing ($p < 0.0001$). Working above the shoulder is known to increase demand during isometric tasks, however, these results suggest that for dynamic tasks working against gravity has a larger effect on demand than task target.

1. Introduction

Work-related musculoskeletal disorders (MSD) place a large burden on the economy and workers' health, with MSD accounting for 29–35% of all occupational injuries and illnesses involving days away from work in private industries (Bhattacharya, 2014). Physically demanding occupations such as military service have high occurrence of musculoskeletal disorders, with active duty non-deployed service members having an injury rate of 62.8% per person-years (Hauret et al., 2010). Annual total cost from work-related MSD in the United States ranges between $45 and $54 billion (National Academy of Science, 2001). Shoulder injuries, in particular, are taxing on worker health and the economy. A study of worker compensation claims found that 30.6% of claims involving the shoulder resulted in over seven days of lost work and that shoulder claims resulted in the second highest total cost behind lumbar spine claims (Dunning et al., 2010).

Ergonomics research has identified push-pull tasks as related to shoulder complaints (Hoozemans et al., 2002). Since Hoozemans et al. (1998) identified a lack of knowledge regarding the biomechanical demands placed on shoulder muscles and joints as a result of these exertions, numerous efforts have been made to characterize such tasks. Much of the push-pull literature considers how various conditions including exertion direction and task location influence strength capacity (Calé-Benzoor et al., 2016; Chaffin et al., 1983; Chow and Dickerson, 2009, 2016; Das and Wang, 2004; La Delfa et al., 2014; La Delfa and Potvin, 2016; MacKinnon, 1998). When designing workspaces to prevent MSD, it is important to evaluate demand at the muscular level in addition to overall strength capacity. Since most modern industrial workspaces are characterized by predominantly light repetitive work (Das and Sengupta, 1996), several studies have characterized total muscular demand, a sum or average of individual EMG signals, during submaximal isometric tasks (Chow et al., 2017; McDonald et al., 2012, 2014; Meszaros et al., 2018; Nadon et al., 2016). These studies report that muscular demand during these isometric tasks including pushing and pulling are spatially dependent. In general, superiorly located tasks increase muscle demand, although exertion direction also plays a large role in determining muscular demand (Meszaros et al., 2018) and the resulting spatial dependency (McDonald et al., 2012, 2014; Meszaros et al., 2018; Nadon et al., 2016). All these studies, however, evaluated isometric tasks and the results may not be directly applicable to dynamic exertions since EMG and force exertion under dynamic conditions frequently differ (Antony and Keir, 2010; Kumar, 1995). There has been some effort to characterize muscular loading during dynamic tasks (Bennett et al., 2011; Kao et al., 2015; Lin et al., 2010), but these studies involve full-body cart pushing and may not be applicable to seated or stationary dynamics tasks, such as work on an assembly line or opening and closing hatches on military equipment, since foot placement is known to influence push-pull capacity (Rancourt and Hogan,

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2001).

Therefore, to effectively design workplaces involving dynamic force tasks to minimize work-related shoulder MSD, additional understanding of the demands placed on shoulder muscles during these tasks is needed. To characterize a workspace, a combination of task targets, i.e. target hand location at the end of motion, covering the entire space is needed. One obvious solution to reduce muscular demand at the shoulder is to perform task bimanually and split the loading over two shoulders; however, studies comparing unimanual to bimanual strength capacity report unimanual capacity as greater than 50% of bimanual capacity (Chaffin et al., 1983; Warwick et al., 1980), suggesting that there may be limited muscular demand benefits seen by switching to bimanual operation. While muscle demand during bimanual pushing and pulling has been previously evaluated (Chow et al., 2017), to the authors' knowledge no study has directly compared muscular demand between bimanual and unimanual pushing and pulling. Therefore, our objective was to quantify how muscle demand, a measure of the overall load placed on the muscular system, of superficial muscles crossing the glenohumeral joint varies with both task type (unimanual and bimanual pushing and pulling) and task target for dynamic tasks. This research aims to expand understanding of how task design contributes to overuse injuries, thereby enabling the development of preventive measures to reduce risk of shoulder MSD and lower the associated economic burden.

2. Methods

2.1. Experimental protocol

Seventeen healthy young adults (8 males/9 females) between the ages of 20 and 32 years participated in this study. The participants were recruited from the local community using the following inclusion criteria: 1) no history of injury or pathology of the upper limb, 2) no neuromuscular impairments, and 3) no physical impediments to performing the required physical exertions. Fifteen of the subjects were right-dominant, and two were left-dominant. Hand dominance was self-reported by subjects, and their dominant hand was used for all unimanual tasks. All subjects provided written informed consent in accordance with North Carolina State University Institutional Review Board. Each subject completed the testing protocol in a single session on a single day.

Unimanual surface electromyographic (EMG) recordings of the anterior, middle, and posterior deltoid, biceps brachii, lateral head of triceps brachii, latissimus dorsi, and pectoralis major were collected. The skin overlying the location of markers was shaved and cleaned with alcohol prior to electrode placement. Electrodes were placed over each muscle belly in line with muscle fibers using published placement locations (Cram and Criswell, 2011). Recordings were made at 2000 Hz using 1-cm Ag/AgCl dual electrodes with 16-channel capacity (Noraxon Telemyo DTS system, Noraxon, Scottsdale, AZ) (input impedance > 100Mohm, CMRR > 100 dB, gain 500).

Subjects performed a series of isometric joint moments on a Biodex System 4 Quick Set (Biodex, Shirley, NY), and EMG data collected during these trials was used in subsequent EMG normalization. Maximum isometric joint moments of shoulder abduction and elbow flexion for the dominant hand were collected following a previously described standard protocol (Holzbaur et al., 2007a). Subjects were seated with their torso restrained in a vertical posture with straps to prevent changes in posture during the trials. At the shoulder, maximum isometric abduction moment was assessed with the shoulder abducted to 60° and the elbow braced in full extension. At the elbow, maximum isometric flexion moment was assessed with the shoulder in neutral abduction and the elbow flexed to 90°. Three trials of each moment were obtained, and participants received standardized verbal and visual feedback to encourage MVC. To minimize the effects of fatigue, 60 s of rest was provided in between trials.

Additionally, maximal isometric push-pull capacity with the arm in 90° forward flexion was determined for each participant using a closed-chain attachment for the Biodex. This location was chosen for maximal push-pull testing as it represents a neutral baseline task location for the subsequent testing protocol. Six trials using the dominant hand were collected (three push/three pull) where subjects received standardized visual and verbal feedback to encourage maximum force production (Holzbaur et al., 2007a). EMG recordings during these trials were also used in subsequent EMG normalization. Force production was only measured along the single axis aligned with the task. The maximal push-pull force sustained for at least 0.5 s, determined by a custom Matlab script (The Mathworks, Natick, MA), during these six trials was used to determine loading for the testing protocol. Studies of sustained isometric, continuous dynamic, and intermittent isometric contractions have reported fatigue thresholds ranging from 7% to 25% maximum isometric strength (Bjorksten and Jonsson, 1977; Hagberg, 1981; Rohmert, 1973), with intermittent contractions associated with higher thresholds. Therefore, loading was set at 15% of the maximal push-pull force in the tested baseline posture to avoid participant fatigue. This load was applied as a set weight to a pulley system that allowed resistance for each task to be explicitly controlled. This load did not change between task targets or task type (unimanual or bimanual pushing and pulling) in the testing protocol.

A series of unimanual and bimanual push and pull tasks were performed by subjects. Tasks were performed to a combination of 3 thoracohumeral elevation angles (20°, 90°,170°) and 4 planes of elevation (0°/abduction, 45°, 90°/flexion, and 135°) as defined by the International Society of Biomechanics (Wu et al., 2005) for a total of 12 task targets (Fig. 1). These task targets represent the angle of the dominant arm at the end of the push task and start of the pull task. Subjects performed both unimanual and bimanual pushes and pulls at each task target for a total for 48 unique tasks. Three repetitions of each unique task were performed for a total of 144 exertions per subject. To prevent fatigue, participants were provided with a rest period of 1 min between each task. For each task, all three repetitions were performed consecutively without a rest period. The order of tasks was randomized to avoid any ordering effects.

Participants performed tasks in a seated position (chair height: 0.53 m) with their torso restrained by straps to standardize incline across participants. Tasks were performed on a custom pulley resistance system (Fig. 2) to reduce variability in the direction of applied force between participants and trials. The custom device has a resistance pulley system employing a linear track that allows for height adjustments and locks at 3 angles to achieve the thoracohumeral elevation angle targets (Powertec Strength, Powertec Fitness, Long Beach, CA). Plane of elevation angle selection was achieved by rotating the seat. For pulling, participants held a fixed-length handle in the dominant hand (unimanual tasks) or both hands (bimanual tasks). The handle was mounted on a carriage that slides along a linear track. Handle orientation was perpendicular to the linear track. Hand trajectory was controlled by the linear tack, but other joint angles were not controlled

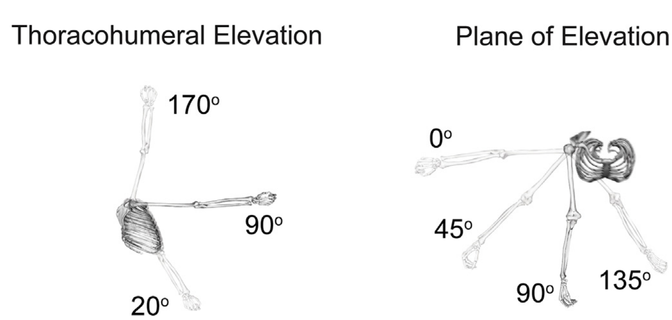

Fig. 1. Task targets. Subjects reached to a combination of 3 thoracohumeral elevations (20°, 90°, and 170°) and 4 planes of elevation (0°, 45°, 90°, and 135°) for a total of 12 distinct task targets.