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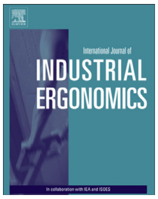

The effects of shoulder abduction angle and wrist angle on upper extremity muscle activity in unilateral right handed push/pull tasks

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ABSTRACT

Workstation design often considers wrist posture or humeral angle in efforts to minimize worker injury risk. However, little research exists on examining co-dependencies between upper extremity joint angles for horizontal pushes and pulls. This study examined interactions of wrist posture and humeral abduction angle on upper extremity muscular activity in pushes and pulls. Twenty female participants exerted 30N while seated in neutral, flexed and extended wrist postures and humeral abduction angles of 0°, 45°, 90°, and 120°. Influences of wrist posture and humeral abduction angle existed for almost all muscles in both force directions, with interactions appearing in some muscles ($p = .0001–.0436$). A main effect of humeral abduction angle occurred for 8 of the 14 muscles tested in pushes ($p = .0001–.045$), and 12 of 14 muscles in pulls ($p = .0001–.0488$). The greatest increase in activation was in lower trapezius, experiencing a 25 %MVE activation when moving from low humeral angles to high angles. A bimodal distribution in activation by humeral angle appeared in many muscles, with 0° and 45° abduction generally eliciting lower activation levels than 90° and 120° exertions. Wrist posture affected over two thirds of muscle activation levels ($p = .0001–.0436$) with non-neutral wrist postures eliciting up to 13 % MVE increases over neutral wrist exertions. These novel findings indicate that these upper extremity joints should not be investigated in isolation, as effects at the distal joint affect muscles at the proximal one, and vice versa. Ergonomists and work task designers should focus on considering interactions of joints in the upper extremity, and use these insights to help devise future workstation designs.

1. Introduction

Holistic workspace design continues to be a primary challenge in ergonomics. An essential element of workstation design is minimization of harmful or awkward postures for the worker (Das and Sengupta, 1996). Sub-optimal workspace design creates postural and performance constraints on the worker, decreasing productivity and increasing musculoskeletal injury risk. Working in awkward postures and performing repeated exertions are associated with cumulative trauma musculoskeletal disorders of the upper extremity (Armstrong et al., 1986). The upper extremity is sensitive to small changes in work location relative to the individual. Previous research reported that musculature of the upper extremity and shoulder complex is influenced by hand location and force direction (McDonald et al., 2014; McDonald et al., 2012; Nadon et al., 2016). This research examined muscle activity in 70 different work positions at the same submaximal push and pull exertion level. Modulating total muscle activity depended on both the three-dimensional hand location and the force direction of exertion, however, pulling exertions were more sensitive to hand location than push exertions (McDonald et al., 2012). This work provided new insights into upper extremity muscle activity changes with changes in work location relative to the participant, but did not control individual joint angles, making inferences regarding upper extremity position difficult. While the location of the work relative to the participant strongly influences the muscular response, efforts to refine these assessments to determine the contributions of upper limb and wrist postures on these outputs is necessary.

Little research examines co-dependencies between joint postures and their effects on muscular activity. Describing interactions amongst upper extremity joints during a task will allow better

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identification of when a particular joint limits performance or raises musculoskeletal exposures. Effects of shoulder postures on push and pull exertions have been examined (Brookham et al., 2010; Chow and Dickerson, 2009; Garg and Beller, 1990; McDonald et al., 2012), but this research either involved maximal capacities or focused primarily on shoulder posture. Conversely, the current body of knowledge surrounding effects of wrist posture on force capability has generally focused on just the wrist joint with little consideration of other upper extremity contributors. Hand and forearm exertions often focus on the effects of wrist posture on grip forces or wrist moments (Delp et al., 1996; Mogk and Keir, 2003). Relationships between elbow strength and shoulder strength are also known (Schanne, 1972). Further investigations have linked biomechanical constraints and predicted strength capabilities based on body postures and direction of force application (Fischer et al., 2014) but these correlations were designed for maximal exertions at optimal joint postures, and did not include information on wrist capabilities. Most upper extremity strength prediction algorithms are based on the maximum strength generating capacity at the shoulder (LaDelfa et al., 2014), however, there is a paucity of evidence for the effects of wrist posture on other joints of the upper extremity or whether these relationships exist for submaximal tasks.

Therefore, this study aimed to quantify forearm and upper extremity muscle activity for multiple humeral abduction and wrist postures in push and pull exertions. More specifically, this study determined co-dependencies between shoulder posture and forearm muscle activity and distal upper extremity postures on shoulder muscle activity. Quantifying the nature of these co-dependencies can assist in the identification and potential mitigation of excessively demanding scenarios and thus could yield more holistic work designs.

2. Methods

2.1. Participants

Twenty right-handed female participants were recruited from a convenience sample [21.6 ± 1.5 years, height 1.68 ± 0.12 m, weight 72.5 ± 16.5 kg]. Exclusion criteria included self-reported forearm, upper arm, shoulder or back disorders or pain within the past 6 months. This study was approved through the institutional Office of Research Ethics, and all participants provided informed consent prior to participation.

2.2. Instrumentation

Surface electromyography, motion capture and hand force data were collected for all experimental trials. Sixteen electrode sites overlying muscles on the right side of the body were monitored using surface electromyography (sEMG), which included the anterior, middle and posterior deltoid, biceps brachii, triceps brachii, infraspinatus, the clavicular head of pectoralis major, latissimus dorsi, upper and lower trapezius, extensor carpi radialis, extensor carpi ulnaris, extensor digitorum communis, flexor carpi radialis, flexor carpi ulnaris, and flexor digitorum superficialis. Bipolar Ag-AgCl surface electrodes with fixed 20 mm inter-electrode spacing (Noraxon, Arizona, USA) were placed over each muscle belly in accordance with placements published by Cram & Kasman (1998). Prior to electrode placement, the skin was shaved and cleansed with an alcohol solution in an effort to minimize skin impedance. EMG signals were collected using the Noraxon Telemyo 2400 T G2 telemetered EMG system (Noraxon, Arizona, USA) and A/D converted at 1500 Hz using a 16-bit A/D card with a maximum range of ±10 V (VICON, Oxford, UK). This system included band pass filtering (10–500 Hz) and differential amplification (common-mode rejection ratio > 100 dB at 60 Hz, input impedance 100 MΩ) of the signals.

Three-dimensional motion was tracked using an 8-camera Vicon MX20 system (VICON, Oxford, UK). Thirteen individual markers were placed over anatomical landmarks including the C7 and L5 vertebrae, the left and right posterior superior iliac spines, the suprasternal notch, xiphoid process, the 2nd and 5th metacarpals, radial and ulnar styloids, medial and lateral epicondyles, and the acromion. Additional marker clusters secured on rigid plates were positioned on the forearm and upper arm (Fig. 1). The marker clusters were used to track segmental movements during the experimental testing. A static calibration frame established the relationship between the clusters and the calibration markers over the anatomical landmarks, and subsequently joint centers and segment coordinate systems were described (Kingma and de Looze, 1996). Kinematics were sampled at 50 Hz using VICON Nexus 1.7.1 software (Oxford, UK). Force outputs were measured using an AMTI 6 degree-of-freedom force transducer (MC3A, AMTI MA, USA), which was rigidly fixed between a D-shaped cylindrical handle and a steel attachment to a MOTOMAN HP-50 robotic arm (Motoman Robotics Division, Yaskawa America, USA), allowing movement of the transducer in relation to the participant. Force was sampled synchronously with sEMG at 1500 Hz using VICON Nexus 1.7.1 software.

2.3. Experimental design

Three parameters were manipulated: wrist posture, humeral abduction angle and hand force direction. Wrist postures were: 1) neutral, 2) self-selected maximum flexion and 3) self-selected maximum extension. For all non-neutral wrist postures, participants were asked to reach their comfortable end range of motion. Humeral abduction angles were defined as the angle between the acromion and the elbow from vertical. Four humeral abduction angles were considered: 0, 45, 90 and 120°, producing 12 (3×4) hand locations. All locations were adjusted to each participant's stature and limb lengths, such that the upper extremity postures were identical between participants. At each hand location, participants exerted a 30N hand force in two globally defined force directions, either pushing forward or pulling backward with respect to the anterior torso in the frontal plane.

2.4. Protocol

The protocol involved the application of surface EMG,

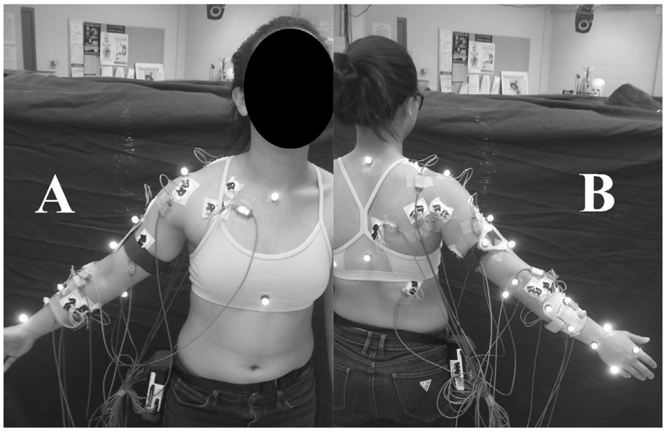

Fig. 1. EMG and motion capture setup, from anterior (A) and posterior (B).