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Dynamic push–pull characteristics at three hand-reach envelopes: Applications for the workplace☆

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ABSTRACT

Pushing and pulling are common tasks in the workplace. Overexertion injuries related to manual pushing and pulling are often observed, and therefore the understanding of work capacity is important for efficient and safe workstation design. The purpose of the present study was to describe workloads obtained during different reach envelopes during a seated push–pull task. Forty-five women performed an isokinetic push–pull sequence at two velocities. Strength, work and agonist/antagonist muscle ratio were calculated for the full range of motion (ROM). We then divided the ROM into three reach envelopes – neutral, medium, and maximum reach. The work capacity for each direction was determined and the reach envelope work data were compared. Push capability was best at medium reach envelope and pulling was best at maximum reach envelope. Push/pull strength ratio was approximately 1. A recommendation was made to avoid strenuous push–pull tasks at neutral reach envelopes.

1. Introduction

The acts of pushing and pulling are often utilized in the workplace. Sliding objects such as cartons on flat surfaces or conveyer belts, opening and closing doors, and pushing manual carts are a few typical examples. It has been estimated that pushing and pulling constitutes around 50%–75% of all manual material handling across selected industries (Baril-Gingras and Lortie, 1995; McDonald et al., 2012). As much as 20% of all overexertion injuries were ascribed to push–pull activities by the National Institute for Occupational Safety and Health (NIOSH) (Kumar, 1995a).

An important parameter for the design of a workstation setup is reach capability, referred to as reach envelope. In defining the area of the workplace, three upper body reach envelopes have been classified. Normal or neutral reach envelope is the workspace closest to the body, where the forearm can pivot about around a relaxed vertical arm (Das and Sengupta, 1995; Sengupta and Das, 1999). Medium to maximum reach envelope is described as movement towards a fully extended arm around the shoulder. Extreme reach workspace is described as when movement of the trunk extends the reach of the fully extended arm.

Little is known about the exact distribution of dynamic muscle work or about the optimal agonist/antagonist ratio through the different reach envelopes during a push–pull activity. Dynamic data regarding workplace efforts are lacking, but are vital in order to assure safe and efficient working environments in industrial settings. Isometric push–pull strength profiles in the workspace were reported by a number of investigators (e.g., Chaffin et al., 1983; Davis and Stubbs, 1977; Kroemer and Robinson, 1974; Kumar, 1995b; Tiwari et al., 2010), with comparisons made of positions and reach envelopes between genders. Reach level was found to have a significant effect on women's static pull strength in the seated position (Das and Wang, 2004a, 2004b). Highest values were recorded for the extreme reach envelope, which was defined as a large area extending beyond the maximal reach available with a fully extended elbow. Push strength was found to be less affected by the reach level in the Das and Wang studies but followed a similar trend of force values recorded of extreme > maximal > normal reach envelope. These works focused on static positions under various combinations of reach distance and height. Dynamic strength profiles of a push–pull motion were reported for various athletic activities through the use of common field tests, such as push-up and pull-up exercises. Antagonist ratios

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of 97% were reported by Baker and Newton (2004). Negrete et al. (2013) reported markedly different values of pulling strength, measuring 37% of pushing muscles strength as evaluated by a modified push-up versus a modified pull-up exercise. Negrete et al. (2013) related the marked differences in these strength levels identified in their study to the experimental set-up, which resulted in a longer level arm utilized during pulling, and contributed to the skewed results.

Isokinetic devices have been considered the gold standard for evaluating dynamic muscle work for many years (Dvir, 2004). Linear motion patterns, such as push–pull, typically involve the simultaneous contraction of a number of muscles using several joints, for the purpose of executing a given task. The resulting motion of the end segment pattern is a linear displacement. A significant relationship has been demonstrated between muscular output during linear isokinetic testing and various functional tests, primarily for the lower extremities (Manske et al., 2003).

The use of linear motion patterns has been reported for upper extremity shoulder protraction-retraction (see Cools et al., 2004; Kovaleski et al., 1999). The current protocol was expanded beyond previously reported scapular motion (Cools et al., 2004) to simulate functional push–pull sequences commonly used in the workplace. Seated push–pull tasks seen in the work place include vertical lever operation, such as a floor shift on heavy equipment, or moving objects on or off conveyors. The purpose of the present study was to describe normal strength characteristics of a push–pull functional sequence motion conducted in a seated posture, and to describe workloads obtained during different reach envelopes of the workspace.

2. Materials and methods

2.1. Participants

Forty-five healthy women, without a history of or current upper extremity or neck pathologies were randomly recruited in a university setting to participate in the study (age: 28 ± 12.2 years, height (cm): 166 ± 1.0, mass (kg): 58 ± 6.4 and bmi: (kg/m2): 21.3 ± 4.2). Participants did not have prior isokinetic training experience and were not involved in any form of competitive sports during the time of the experiment.

Prior to enrollment, each subject completed a qualification interview, received an explanation regarding the aims of the study, and signed an informed consent form complying with the regulations of the Institutional Review Board of the University of Haifa. This was done in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki). Each subject was required to present a medical clearance for fitness training, signed by a licensed physician, in accordance with the governmental sports medicine law. Criteria for exclusion beyond those mentioned above included restricted range of motion (ROM) of the shoulder or elbow, any history of surgery or functional limitation of the upper extremities, or the presence of pain or other symptoms in the upper extremity and neck region, for a period of six months prior to the study.

2.2. Instrumentation and procedure

We conducted testing with the isokinetic Biodex System 3 (Biodex Medical Systems, NY, http://www.biodex.com and the computer software program version 3.29 and 3.30), utilizing the upper extremity closed kinetic chain (CKC) attachment (Fig. 1a and b). The apparatus was calibrated according to the manufacturer's instructions. The linear ROM was established in the following manner: For the push phase, also termed the “Away” motion, the subject was seated in the starting position with her arm held parallel to the body and the elbow flexed (Fig. 1a). This phase consisted of scapular protraction, gleno-humeral flexion, and elbow extension to a position of 0° extension. From that point (Fig. 1b) the pull phase consisted of elbow flexion, shoulder extension, and scapular retraction back to the starting position. This phase was termed the “Towards” motion. The wrist joint perpendicular handle was not fixed, allowing for some adjustments away from neutral grip position. Work done by Seo et al. (2010), suggested that greater pull/push forces may be exerted at right angles to the handle than parallel to it. The procedure was repeated on both sides, with randomization of testing order.

Performance of a pull task alongside the body was shown to be conducive to better force production, particularly when handle height increased (Lin et al., 2013). In order to learn about workloads endured at different reach envelopes, the linear ROM was divided into three reach envelopes typical of a workspace. This is discussed in detail in the data collection section.

We utilized a full ROM for all testing procedures. We defined the full ROM (R) as the distance covered by pushing the handle from a neutral arm position to a fully extended elbow position, while preventing trunk participation by stabilizing straps applied across the trunk. Linear displacement values of the hand-held handle ranged from 31.3 to 37.1 cm, with an average value of 34.8 cm. Two velocities were employed for testing in order to best simulate tasks which require considerable force exertion (slow velocity, resulting in an approximate effort of 3 s in each direction), as well as tasks that are more fluid in nature (high velocity, resulting in a 1 s effort in each direction). Prior to testing each subject was asked to answer the question “Which side is your favorite side?”, or if there was no conclusive preference, “Which hand do you use for throwing a ball?” This was done during the initial screening and while obtaining informed consent.

2.2.1. Reliability

Prior to data collection, calibration of the isokinetic device was performed according to the manufacturer's recommended procedure. In order to establish reliability for this novel movement pattern, a reliability study was conducted prior to the beginning of the main study. Data were collected from 15 women volunteers who performed two sets of 5 repetitions of the pull–push motion at two velocities – 12.22 cm/s and 36.67 cm/s. Two testing sessions were conducted one week apart. Peak force and work data were collected and analyzed for all repetitions, at both testing velocities on both days. In order to test for the degree of agreement between repeated measurements, an interclass correlation coefficient was calculated. With values ranging between 0.784 and 0.981, excellent reliability was achieved.

2.2.2. Warm-up and familiarization

A familiarization/warm-up procedure consisting of an inverse velocity pyramid was performed: Each subject performed three comfortable repetitions (defined as an effort of 50% of their own perceived maximal effort) at each of the following velocities: 36.67 cm/s, 24.24 cm/s, and 12.22 cm/s, in that order. This sequence was chosen as the most comfortable by participants in the preliminary trials. Satisfactory scores achieved by the “naive” participants of the reliability study assured an adequate level of learning through this procedure. Following this, participants rested for 10 min, after which final adjustments were made and testing commenced with a warm-up of six graded sub-maximal repetitions followed by a 1-min rest.