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Dynamic and static shoulder strength relationship and predictive model

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ABSTRACT

Static strength is typically used to standardize occupational tasks in an effort to limit over-exertion injuries; however, workplace tasks are commonly dynamic in nature. The purpose of this investigation was to assess factors influencing isokinetic shoulder strength and to develop predictive equations for isokinetic shoulder flexion and extension strength using isometric strength. Fifteen women performed a set of concentric isokinetic and isometric shoulder flexion and extension maximal exertions across a series of movement planes, angular velocities, and grip types. Data were used to generate two stepwise multiple regression models for predicting isokinetic shoulder flexion and exertion strength across the various exertion parameters. The final regression models explained a high degree of variance in predicting isokinetic shoulder flexion (R^2 = 0.59) and extension (R^2 = 0.67) with a subset of four and five inputs, respectively. The predictive equations can help establish acceptable force limits for workplace tasks requiring dynamic actions using more easily attainable static forces.

1. Introduction

The three-dimensional geometry of the shoulder complex allows the hand to exert force in any direction, however, the potential magnitudes of these forces are dependent upon several factors (Halder et al., 2000; Veeger and Van Der Helm, 2007). Shoulder muscle moment production capabilities depend on the force generating capacity of the contributing muscles, muscle orientations and lines of action, posture-specific muscle moment arms, and individual capabilities (Halder et al., 2000; Garg et al., 2005). Isometric maximal strength is defined as the maximum force that a person can produce with constant muscle lengths (Mital and Das, 1987). Various factors such as exertion direction (Warwick et al., 1980; Peebles and Beverley, 2003), posture (Warwick et al., 1980; Lannersten et al., 1993; Haslegrave et al., 1997; Coury et al., 1998; Roman-Liu and Tokarski, 2005), hand dominance (Warwick et al., 1980; Hughes et al., 1999; Westrick et al., 2013), age (Lannersten et al., 1993; Hughes et al., 1999; Peebles and Beverley, 2003; Roy et al., 2009; McKay et al., 2017), training/occupation (Meldrum et al., 2007; Douma et al., 2014), injury (Bjelle et al., 1981; MacDermid et al., 2004), anthropometry (Lannersten et al., 1993; Hughes et al., 1999; Gielo-Perczak et al., 2006; Meldrum et al., 2007; Gielo-Perczak, 2009), and gender (Lannersten et al., 1993; Roman-Liu and Tokarski, 2005, Hughes et al., 1999; Peebles and Beverley, 2003; Meldrum et al., 2007; Roy et al., 2009; McKay et al., 2017) influence isometric strength measures. Isokinetic maximal strength is defined as the maximum force produced while moving at a constant velocity in a concentric or eccentric direction (Mital and Das, 1987). The magnitude of the difference between isokinetic and isometric strength depends on the type of contraction (eccentric, concentric). Specifically, eccentric isokinetic shoulder strength is greater than isometric strength, and concentric isokinetic strength is less than isometric strength (Koski and McGill, 1994; Julienne et al., 2007; Harbo et al., 2012).

The numerous factors influencing joint strength capability suggest that measuring strength capabilities in a situation that mimics the application conditions is important for validity. Isokinetic strength measures may be more functionally relevant than isometric strength measures (Cerrah et al., 2012), as most workplace tasks are dynamic in nature. Similar to isometric strength, isokinetic strength and its measurement reliability is influenced by many factors including gender, posture, direction, velocity, injury, training, and anthropometry (David et al., 2000; Erol et al., 2008; Forthomme et al., 2011; Hadzic et al., 2012; Hill et al., 2005; Malerba et al., 1993; Plotnikoff and MacIntyre, 2002; Wong and Ng, 2008; Zanca et al., 2011a; Lin et al., 2015). While it is unlikely that any job is truly isokinetic, isokinetic testing allows determination of maximal dynamic strength at different velocities of movement, including zero velocity (isometric/static).

A well-known, influential factor in isokinetic strength is movement velocity. In control populations, exertion velocity has an inverse relationship with concentric strength (Kumar et al., 1988; Garg and Beller, 1990; Imrhan and Ramakrishnan, 1992; Mital et al., 1995; Shklar and Dvir, 1995; Whitcomb et al., 1995; Forthomme et al., 2011). However, changing test conditions can influence the relationship between velocity and strength. Garg and Beller (1990) found that for a 1% increase in velocity there was a 0.7% decrease in strength in concentric,

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towards body pulling, while Mital et al. (1995) found a more linear decline in vertical pulling force with increased velocity. Unlike concentric exertions, eccentric torque may increase with increasing exertion velocity (Shklar and Dvir, 1995; Andrade et al., 2010; Power et al., 2015). Eccentric strength tests at high velocities should be evaluated with caution to ensure participants reach the isokinetic phase of the movement (Zanca et al., 2011b).

Similar to isometric strength, body posture is an influential factor on isokinetic strength and on the strength ratios between opposing movements (Mital and Genaidy, 1989; Imrhan and Ramakrishnan, 1992; Radaelli et al., 2010). There are also some unique parameters to consider during isokinetic strength testing. During an isokinetic test, an individual's range of motion can influence the posture of peak force generation, but it occurs at approximately the same normalized relative angle between subjects (Radaelli et al., 2010). The starting posture in a dynamic strength test changes muscle activation and the muscles location on the force-length curve, which can significantly influence peak force and time to reach peak force (Imrhan and Ramakrishnan, 1992; Kumar et al., 1995). When allowed the same range of motion for the task, the posture of peak force is the same regardless of starting position, although the magnitude of force may change (Imrhan and Ayoub, 1990). Upper extremity posture can have a large influence on isokinetic shoulder strength. Similar to isometric strength for pulling exertions, increased reach distance increases isokinetic pulling strength (Mital and Faard, 1990; Grant and Habes 1997; Das and Wang, 2004). The hand height of an exertion can significantly influence maximum isokinetic pulling strength, with the weakest postures being above shoulder height and the strongest below shoulder height in a stooped posture (Garg and Beller, 1990; Imrhan and Ramakrishnan, 1992). The influence of velocity on strength may be mediated by posture as velocity tends to have a greater effect below shoulder height than above (Imrhan and Ramakrishnan, 1992). Different velocities and training can also affect the posture at which peak force is achieved (Kumar et al., 1988; Imrhan and Ayoub, 1990; Zanca et al., 2011a).

Isokinetic strength tests have been performed in a range of gross body postures, including standing, seated, and supine. As in the isometric strength literature, the effect of sitting versus standing on isokinetic strength is variable, ranging from no difference to 37% greater strength in standing compared to sitting (Mital and Faard, 1990; Mital et al., 1995). The differences in these results may be due to differences in test parameters, such as upper extremity posture and velocity. Test postures can change the plane that the movement is occurring in and consequently alter moment arms, the muscle location along the force-length curve and force production capabilities (de Toledo et al., 2008). The optimal plane for peak force production is dependent upon the exertion direction (Mital and Faard, 1990; Whitcomb et al., 1995; Hartsell and Forwell, 1997; Hill et al., 2005; de Toledo et al., 2008; Radaelli et al., 2010; Forthomme et al., 2011; de Castro et al., 2012).

The direction of force application has a significant influence on isokinetic strength. In men, the order of strength magnitudes in different concentric and eccentric directions was extension, adduction, flexion, abduction, internal rotation and external rotation, while in women, the order was similar but flexion strength was stronger than adduction (Shklar and Dvir, 1995). Other investigations have found similar relationships between opposing movements, with pulling strength being greater than pushing, extension strength being greater than flexion, adduction being greater than abduction, and internal rotation being greater than external rotation (Cook et al., 1987; Brown et al., 1988; Reid et al., 1989; Chandler et al., 1992; Malerba et al., 1993; Kumar 1995; Kumar et al., 1995; Ellenbecker and Mattalino, 1997; Alfredson et al., 1998; Mayer et al., 2001; Smith et al., 2001; Morris et al., 2004; Wilkin and Haddock, 2006; Julienne et al., 2007; van Cingel et al., 2007; Andrade et al., 2010; McKean and Burkett, 2010; Lategan, 2011).

All of these factors influencing strength create challenges to effectively and efficiently evaluate capabilities for workplace design applications. Although there is ample literature on factors affecting both dynamic and static strength there is very little on the predictive relationship between them. Equipment limitations make the measurement of dynamic strength challenging for ergonomics in the workplace and to date, there has only been one study that attempted to quantify the relationship between isometric and isokinetic strength. Although it shows promise for a predictive relationship between isometric and isokinetic strength, it is limited to flexion exertions in a single posture (Koski and McGill, 1994). The purpose of this investigation was to evaluate the effects of shoulder posture, velocity and exertion direction on strength and to determine a predictive relationship between shoulder isometric and isokinetic strength and to evaluate its efficacy. We hypothesized that a strong predictive relationship will exist between isometric and isokinetic shoulder strength.

2. Methods

2.1. Participants

Fifteen healthy, right-hand dominant females who were free from upper body injury within the last 2 years were recruited from the university population. The McMaster Research Ethics Board approved this study and all participants provided informed written consent prior to participation.

2.2. Apparatus

Participants performed all exertions while seated and secured into a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, NY, USA). Their feet were supported and their body secured using padded straps crossing their waist and torso (Fig. 1). The Biodex shoulder attachment was used, which allowed the handle to change length throughout each exertions range of motion. For each plane of action, the dynamometer position was adjusted such that the head of the humerus was aligned directly with the axis of rotation of the dynamometer. The alignment and shoulder posture was confirmed manually with a goniometer and palpation of anatomical landmarks (acromion, greater tuberosity of the humerus).

Fig. 1. Dynamometer setup for the isokinetic and isometric strength testing.