Applied Ergonomics 53 (2016) 152–160

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Wrist rotations about one or two axes affect maximum wrist strength

Katherine Plewa [a], Jim R. Potvin [b], James P. Dickey [a, *]

[a] Joint Biomechanics Laboratory, School of Kinesiology, Western University, London, Ontario, N6A 3K7, Canada
[b] Department of Kinesiology, McMaster University, Hamilton, Ontario, L8S 4K1, Canada

ARTICLE INFO

Article history:
Received 26 May 2011
Received in revised form
8 September 2015
Accepted 17 September 2015

Keywords:
Wrist strength
Wrist torque
Wrist motion

ABSTRACT

Most wrist strength studies evaluate strength about one axis, and postural deviations about that same axis. The purpose of this study was to determine if wrist posture deviations about one axis (e.g. flexion/extension), or two axes (e.g. flexion/extension and pronation/supination), affect the strength about another axis (e.g. ulnar deviation). A custom-built instrumented handle was used to measure maximum static isometric torque exertions at 18 wrist postures (combinations of flexion/extension, radial/ulnar deviation, and pronation/supination). Ulnar deviation torques were highest when the wrist was in neutral. This pattern was not maintained for the other torque directions; the generated torque tended to be highest when the wrist posture was not neutral. The effects were similar for male and female subjects, although male subjects exerted significantly larger torques in all directions. This study illustrates that there is a complex relationship between wrist posture and maximal wrist torques.

1. Introduction

Strength limits of the upper extremities are of interest to ergonomists in light of the high prevalence of injuries in the workplace. The National Institute of Safety and Health reviewed epidemiological studies and observed strong evidence showing a positive association between work that requires extreme postures and the prevalence of hand/wrist tendinitis (Bernard, 1997). Risk factors and disorders associated with hand and arm injuries reveal that awkward postures of the wrist, along with repetitive tasks, high wrist velocities and high-force exertions, are related to an increased risk of injury (Muggleton et al., 1999; Nordander et al., 2013).

Ergonomists use different tools, including computer programs, when assessing and designing workplaces (Roman-Liu, 2014). HandPak (Work in Progress Ergonomics, Hamilton, Ontario, Canada) and 3DSSPP (The University of Michigan, Ann Arbor, MI) are two examples of software packages that are designed to determine recommended acceptable force and torque values for a wide variety of tasks commonly found in the workplace. These guidelines are valuable for determining the injury risk associated with tasks that have different grips, postures, frequencies, durations and effort requirements. These programs have a number of modules for specific task demands, one of which is torque. This module applies to tasks that require the application of a torque or moment to some object that has been grasped with the hand. Acceptable limits have been separately determined for pronation, supination, flexion, extension, radial deviation and ulnar deviation exertions.

These ergonomic software packages have been developed by integrating a large body of scientific research from published literature. However, the limitation with most wrist strength studies, and thus most strength predicting software, is that maximum torques about a particular axis were only measured with respect to postural deviations about that same axis (eg. the effect of wrist flexion/extension angle on wrist flexion strength; Greig and Wells, 2004; Hallbeck, 1994; Jung and Hallbeck, 2002; Marley and Thomson, 2000; Snook et al., 1999, 1995, 1997). These previous studies have not investigated the potential effects of a rotation, or rotations, about axes other than that which is being tested for strength. For example, we are not aware of published studies that have evaluated the effect of radial, ulnar, pronation or supination deviations on wrist flexion or extension strength.

Wrist joint motion in one direction affects the magnitude of the range of motion (ROM) in the other directions (Li, 2002; Li et al., 2005; Marshall et al., 1999). For example, there is coupling between flexion/extension and radial deviation/ulnar deviation directions in the wrist; the ROM in one direction (flexion or extension) decreases as the wrist moves away from neutral in the

* Corresponding author. Joint Biomechanics Laboratory, TH 3156, School of Kinesiology, Western University, 1151 Richmond Street, London, Ontario, N6A 3K7, Canada.
E-mail address: jdickey@uwo.ca (J.P. Dickey).

http://dx.doi.org/10.1016/j.apergo.2015.09.005

other direction (radial or ulnar deviation; Li et al., 2005; Marshall et al., 1999). Different anthropometrics (Kivell et al., 2013) result in females having greater wrist ROM than males (Marshall et al., 1999), and may result in females adopting more extreme postures in the workplace (Chen et al., 2010; Won et al., 2009).

Both grip strength and wrist torque decrease as the wrist deviates away from neutral (Dempsey and Ayoub, 1996; Jung and Hallbeck, 2002). It has been suggested that naturally coupled wrist motion affects wrist strength, and thus should be accounted for in workstation design and rehabilitation practices (Li et al., 2005). On average, the physiologic cross-sectional area of muscles is smaller in females than males; therefore, on average, they do not generate as much force as males in pinch and grips, and wrist flexion and extension (Abernethy et al., 2005; An et al., 1986; Dempsey and Ayoub, 1996; Hallbeck, 1994; Hallbeck and McMullin, 1993; Harkonen et al., 1993; Mathiowetz et al., 1985; Maughan et al., 1983; Morse et al., 2006). However, data do not currently exist related to how torque production trends vary between male and female subjects when wrist posture deviations are combined (e.g. flexed and ulnar deviated).

The purpose of this study was to investigate the effects of wrist postures on wrist flexion, extension, radial deviation, and ulnar deviation torque strengths (e.g. flexion strength when the wrist is in a combined posture of pronation and ulnar deviation). We hypothesized that wrist strength about one axis will be affected by deviations about one or both of the other two axes. This is currently not being considered in most ergonomic assessments of tasks that place torque demands on the wrist and/or forearm. Furthermore, we hypothesized that male subjects will generate higher maximum wrist torques than female subjects in all directions of exertion, and that there will be similar effects of posture on maximum wrist torques for male and female subjects.

2. Methods

2.1. Subjects

A total of 28 young, healthy university-aged subjects (14M, 24.3 ± 2.6 years old, 81.6 ± 12.9 kg; 14F, 24.6 ± 2.4 years old, 67.6 ± 7.4 kg) participated in this study. All subjects reported no current or previous history of hand and upper extremity pain, disorders, or carpal tunnel syndrome. All subjects were right-hand dominant, and applied torques with their right hands.

2.2. Pilot testing

Ten subjects (5M, 5F) participated in pilot testing to determine maximum ROM of the wrist in flexion/extension and radial deviation/ulnar deviation directions. The maximum ROM of the right wrist was measured using an electrogoniometer (SG150, Biometrics Ltd., Ladysmith, VA, USA). Subjects stood with the shoulder slightly flexed, but with no internal/external rotation, the elbow flexed at 90°, with the forearm resting on an armrest in neutral (halfway between full pronation and full supination, thumb facing up) and the wrist in neutral flexion/extension (neither flexed nor extended), and the digits slightly extended. From this position, the electrogoniometer was placed on the posterior aspect of the hand and forearm, crossing the wrist joint in line with the 3rd digit of the hand. The voltage from the electrogoniometer in this neutral wrist posture was defined as zero. Studies have shown that flexible biaxial electrogoniometers have crosstalk errors that are related to rotations (Hansson et al., 1996, 2004); these errors are only a few degrees and are considered small in both epidemiological and physiological contexts (Hansson et al., 2004). Although some previous studies have presented correction algorithms (Hansson et al., 2004; Sato et al., 2010), we used uncorrected goniometer outputs due to the relatively small errors, similarly to other previous studies (Finneran and O'Sullivan, 2013). Subjects moved through the full range of wrist motion in flexion (FLX), extension (EXT), radial deviation (RD) and ulnar deviation (UD) – and returned to neutral between each movement. Each trial was repeated twice to ensure consistency. Data were collected using a custom-made LabVIEW program v8.6 (National Instruments, Austin, TX, USA).

Maximum values for flexion, extension, radial deviation, and ulnar deviation were measured for each subject (Table 1). Using z-scores, wrist angles were calculated that would allow 99% (i.e. z-score of −2) of the sample population to comfortably achieve the four wrist angles (50° FLX, 35° EXT, 15° RD, and 20° UD). These four angles, and 45° for pronation (PRO) and supination (SUP) respectively (Matsuoka et al., 2006; O Sullivan and Gallwey, 2005), were used to define the posture matrix to establish the combinations of wrist postures for testing (Table 2). Some combinations of wrist posture were not used for testing because it was not physically possible to achieve the posture. For example, pilot subjects complained of pain while attempting to combine flexion and radial deviation. Although there were some differences in average ROM between male and female subjects, these differences were small (about 2–10°) for all directions (Table 1). By using a z-score of −2, we calculated angles that were comfortable for both male and female subjects and did not require any extreme ROM; therefore, we did not test different positions for male and female subjects. Although extreme postures are important for studying injury risk, these postures are less common during daily work activities (Keir et al., 1998).

2.3. Apparatus

A custom-built device was used to measure wrist torque (Fig. 1a). This device consisted of a standard hand-tool handle (the handle from a 21–295 – Surform® Flat File – Regular Cut Blade, Stanley Black and Decker LTD., New Britain, CT, USA). This handle had a smooth hard plastic finish and an oval cross-sectional area (12 cm circumference). The handle was attached to a force/torque transducer (Omega 160, ATI Industrial Automation, Apex, NC, USA) via a lockable ball-and-socket joint. This setup permitted easy positioning of the handle so that the desired wrist posture could be set. This apparatus was similar to other studies (Seo et al., 2008), though we did not use a wrist support and they did not measure off-axis torques.

Handle positions corresponding to the desired wrist positions were based on the average ROM angles determined in the pilot testing described in Section 2.2. One control subject was used to pre-set the desired 18 handle positions using the electrogoniometer and all of the test subjects used these handle positions. The location of the wrist joint center and the orientation of the handle were digitized using a 3D digitizer (MicroScribe G2,

Table 1
Average ROM (with standard deviations) for male and female subjects during the pilot testing. These data were used to define the combinations of wrist postures for the main experiment. The greatest amount of ROM was seen for female subjects in flexion and ulnar deviation.

	Male		Female	
	Average	SD	Average	SD
FLEX (°)	76.4	11.0	82.6	14.7
EXT (°)	58.2	7.8	60.6	13.2
RD (°)	27.1	4.1	25.5	5.3
UD (°)	34.6	8.4	43.7	7.4