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Clinical Biomechanics 19 (2004) 671–677
CLINICAL BIOMECHANICS
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Measurement of angular wrist neutral zone and forearm muscle activity

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Received 13 November 2003; accepted 10 May 2004

Abstract

Objectives. To determine the forearm muscles activity in different wrist deviated positions and wrist neutral zone, and to assess the self-selected resting position without visual feedback.

Background. Wrist deviation occurs in almost all industrial and office jobs. This has been deemed hazardous for carpal tunnel syndrome. Proper resting wrist position is likely to decrease the hazard for carpal tunnel pressure.

Methods. Twenty blindfolded subjects without history of hand/forearm musculoskeletal disorders participated in the study. The EMG of the forearm muscles (flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis and, extensor carpi ulnaris) in deviated and neutral wrist postures was recorded at a sampling rate of 1 kHz. Also, wrist neutral zone at rest was measured using a custom-made calibrated uniaxial electrogoniometer. One-way ANOVA with repeated measures was used in order to find the impact of wrist deviation on muscles activity.

Results. The participants positioned their wrist in rest at 7°–9° extension and 5°–7° ulnar deviation. Significantly higher EMG activity was recorded for each muscle in the wrist deviated postures when compared to neutral position ($P < 0.001$).

Conclusions. Self selected wrist neutral posture decreased the muscle activity significantly. Placement of wrists in neutral zone is expected to reduce risk of injuries.

Relevance

A knowledge of wrist neutral zone and associated muscle activity is likely to be of assistance in treating patients that require wrist reconstruction. Also, these results would assist job and workstation design/redesign for control and prevention of carpal tunnel problems

Keywords: Wrist neutral zone; Wrist deviation; Forearm muscles EMG

1. Introduction

In the last decade, cumulative trauma disorders (CTD) were the fastest growing occupational health problem. According to the Bureau of Labor Statistics (1994), in 1992, almost two third of all work related illnesses reported in the United States were CTD. In 1981 only 24% of all occupational musculoskeletal disorders were CTD. Changes have occurred in many jobs during recent years (characterized by less force demands and increased mental load, higher social load leading to a sustained increase in muscle load) (Viikari-Juntura and Riihimaki, 1999). This trend is expected to continue. The treatment costs and human suffering continue to increase in addition to productivity losses due to the growth of work-related hand and forearm injuries. Hence, ergonomic intervention becomes very important.

The neutral zone is defined as "the part of the range of physiological motion, measured from the neutral position, within which the motion is produced with a minimal internal resistance" (Kumar and Panjabi, 1995).

Highly repetitive movements of the wrist, hand and forearm in office and industry jobs play an important

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0268-0033/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2004.05.004

role in the development of CTD (Kuorinka and Forcier, 1995). In order to mitigate the risk of carpal tunnel syndrome (CTS), one should avoid the postures that force wrist deviation close to the limit of its range of motion (RoM) (Bernard, 1997). Rempel and Horie (1994) and Werner et al. (1997) demonstrated that the carpal tunnel pressure increases proportionally with the increase in wrist deviation. The risk level increases even more when repetition and/or high-force exertion occur (Keyserling et al., 1982).

Because the wrist, with deviation, permits the hand to adopt an optimal posture in order to perform the required tasks (Kapandji, 1982), the forearm muscles tendons become stressed. Deviated wrist postures have been demonstrated to decrease hand force (grip and pinch strength) (Fernandez et al., 1991; Marley, 1990; Lamoreaux and Hoffer, 1995; Dempsey and Ayoub, 1994; Terrell and Purswell, 1976), forcing the worker to exert greater effort while maintaining the wrist in unsafe postures in order to do his job. Also, hand performance is highly affected by forearm position (degree of supination or pronation). Grip and pinch strengths are increased or not changed by supination (Agresti and Finlay, 1986) and decreased by forearm pronation (Marley and Wehrman, 1992). Richards et al. (1996) assessed grip force exertion in pronation as being the weakest followed by neutral position and forearm supination. Muscle overexertion follows (Kumar, 2001). The decrease in hand strength may be due to the change in the angle between tendons and the finger bones (Hazelton et al., 1975), compression of the finger flexor tendons against the intratunnel structures (Tichauer, 1966; Armstrong and Chaffin, 1979) or changes in the musculotendinous units' length and orientation (Pryce, 1980). Also, during office work the wrist is maintained in extreme flexion or extension (Szabo and Chidgey, 1989) and radial or ulnar deviation (Smith et al., 1998), leading to increased carpal tunnel pressure resulting in stress on the median nerve, blood vessels and forearm muscles tendons.

All these awkward postures result in an increased load level on the hand/wrist/forearm musculoskeletal structures. Information on wrist neutral zone, and muscle activity needed to deviate or maintain deviated the wrist, could be used to design products (e.g. manual wheelchairs, keyboards) that may minimize risk of wrist/hand injuries. Also, wrist surgical correction may need such biomechanical information.

Consequently, an experiment was designed where blindfolded subjects were asked to position their wrist in the neutral posture starting from a randomly chosen wrist deviated postures (45° for flexion and extension, 30° for ulnar deviation, and end of range of motion for radial deviation). An additional aim of the study was to measure the forearm muscle activity in both deviated and neutral wrist positions.

2. Methods

2.1. Sample

The experimental population consisted of 10 normal young adult males (age 27.5 (4.7) years, height 177.5 (7.2) cm, and weight 74.8 (12.6) kg) and ten normal young adult females (age 29.4 (9.8) years, height 165.7 (8.5) cm, and weight 62.1 (5.0) kg. All subjects were in good health, free of wrist/forearm pain and without history of upper extremity musculoskeletal disorders. Nineteen subjects were right-handed. Ethics approval was granted by the Human Research Ethics Board.

2.2. Tasks and measurements

2.2.1. Apparatus

Wrist motion angles were measured using a custom-made calibrated electrogoniometer. It consisted of two mobile plastic arms attached to a central potentiometer. The uniaxial electrogoniometer was calibrated before each experiment (Fig. 1).

The EMG forearm muscle activity was measured using DelSys Bagnoli™ (Boston, USA) EMG system (active surface electrodes, electrode cables, preamplifiers and amplifiers). The DE-2.1 single differential electrodes had 99.9% pure silver contacts 10 mm apart for ion flow maximization. Preamplification of the EMG at the source and low impedance active output reduced signal noise. The system had low noise (less than 5 μV) and exceptionally low leakage currents (less than 10 μA).

2.2.2. Experimental procedure

An informed consent was obtained from each volunteer. Age, gender, weight, height and hand dominance were recorded for the subjects. They were seated upright into a straight-back chair with feet flat on the floor and

Fig. 1. Experimental set-up.

looking straight ahead. The forearm was rested on the table, being fully pronated (the forearm volar side was parallel to the table) when wrist deviation in the ulnar–radial deviation plane was measured and semipronated (the forearm lateral side was parallel to the table) for the flexion–extension plane (Fig. 1).

The electrogoniometer was adjusted across the wrist with goniometer's arms aligned to the long axes of the hand and the lower arm. For radial and ulnar deviation assessment, the electrogoniometer's fulcrum was centred over the middle of the dorsal aspect of the wrist over the capitate. The proximal arm was aligned with the dorsal midline of the forearm, using the lateral epicondyle of the humerus for reference and the distal arm was aligned with the dorsal midline of the third metacarpal bone. For flexion and extension measurement, the fulcrum of the electrogoniometer was centred over the radial aspect of the wrist (trapezium level) with the proximal arm aligned with the medial side of the radius and the distal arm aligned with the midline of the second metacarpal bone. The device was adhered using Velcro closures. For EMG recording, the subject's forearm was shaved, where needed, and the skin was cleaned with alcohol. Four bipolar silver–silver chloride active surface electrodes with knife edge configuration 10 mm apart were applied bilaterally. The electrodes were applied 5–7 cm distal to the line connecting the medial epicondyle and biceps tendon for flexor carpi radialis (FCR), above the shaft of ulna in the middle of forearm for extensor carpi ulnaris (ECU), at 2–3 cm volar to ulna at the junction of the upper and middle thirds of the forearm for flexor carpi ulnaris (FCU), and at 3 cm medio-distal to lateral epicondyle for extensor carpi radialis (ECR).

Subjects were blindfolded. For each muscle a 5 s maximum isometric contraction against a fixed resistance was performed. The muscle testing order was computer randomized. Participants received training on how to perform the maximal voluntary contractions (MVC) for each muscle. Starting from the wrist neutral position, volunteers were asked to push against the fixed obstacle as hard as they can, while trying to extend and adduct the wrist for ECU, extend and abduct for ECR, flex and adduct for FCU and flex and abduct for FCR. The highest activity level was used to normalize the data for each subject. After completing the isometric contractions (MVCs), volunteers were asked to bring the passively deviated wrist (45° flexion, 45° extension, 30° ulnar deviation, and at the end of range of motion for radial deviation) in the subjective neutral position. The sequence was randomized in order to avoid the carry-over effect. Each condition was repeated once (two trials). Between conditions a 2 min resting period was given. Thus, the experiment had a double randomized block design. The forearm muscles' EMG activity was measured in both deviated and neutral wrist positions.

2.2.3. Data acquisition

The EMG and electrogoniometer output were sampled at 1 kHz using a DAQ 700 National Instrument data acquisition card. The signals were collected at a sampling frequency of 1 kHz. The data were collected by a specially written software, which stored them on a Toshiba laptop.

2.2.4. Data analysis

The peak EMG amplitudes of FCR, ECU, FCU, and ECU (left and right) in isometric MVC for activities in which muscles were primary effectors were measured and considered as 100%. The EMG amplitudes measured with both deviated and neutral wrist positions were normalized against peak MVC. When analyzing the effect of wrist deviation on muscle activity, angle of deviation was the independent variable and the EMG values were the dependant variables. Wrist deviation acted as dependant variable when the effect of lack of feedback on wrist resting position was studied. The normalized data were analyzed using SPSS 11.0 (SPSS Inc., Chicago, USA) statistics software. The group data were subjected to one-way ANOVA with repeated measures in order to find the effect of wrist deviation on forearm muscles activity. Also, differences between genders/sides in terms of wrist neutral zone were analyzed. For significance, an alpha level of $P < 0.05$ was chosen.

3. Results

Since there was no significant difference between the two trials, data were pooled and analyzed together.

3.1. EMG in wrist deviation

Figs. 2 and 3 present the normalized average EMG (% isometric maximal voluntary contraction (MVC)) for each recorded forearm muscle in each wrist deviation (ulnar and radial deviation, flexion and extension). FCU required significantly higher activity in females when compared with males ($P = 0.03$). For the other muscles, although females had somewhat higher percent MVC in all wrist deviated postures, gender did not have a statistically significant effect on normalized muscle activity ($P > 0.05$). Also, no differences were found between sides for all muscles and wrist deviations ($P > 0.05$).

For ulnar deviation, the maximum activity was observed for ECU (26.9–35.7% of MVC) and FCU (16.5–29.1% of MVC). Along with FCR (19.9–26.8% of MVC), FCU (18.3–23.6% of MVC) was among the most active muscle while the wrist was maintained in flexion. ECR presented the maximum activity in both wrist radial deviation (25.5–36.8% of MVC) and extension (29.4–38.3% of MVC). It was followed by FCR in radial

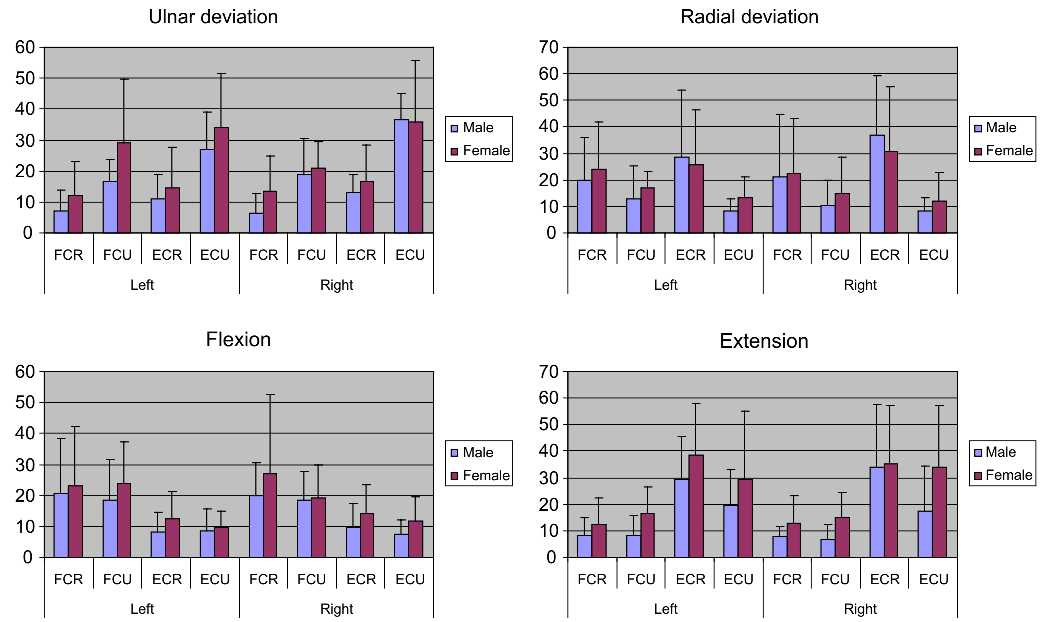

Fig. 2. The forearm muscles normalized average EMG (% isometric MVC) in wrist deviation postures: (FCU) flexor carpi ulnaris; (FCR) flexor carpi radialis; (ECR) extensor carpi radialis; and (ECU) extensor carpi ulnaris).

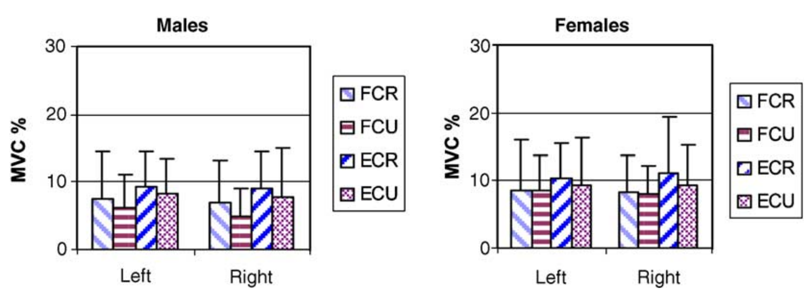

Fig. 3. The forearm muscles normalized average EMG (% isometric MVC) for both genders in the self-selected neutral position: (FCU) flexor carpi ulnaris; (FCR) flexor carpi radialis; (ECR) extensor carpi radialis and (ECU) extensor carpi ulnaris).

deviation (19.8–24.2% of MVC) and ECU in extension (17.3–34.1% of MVC).

3.2. EMG in wrist neutral zone

In the neutral zone muscle activity was significantly lower than that of the deviated postures ($P < 0.05$). Table 1 presents significance levels for differences between each muscle activity in the neutral position and deviated postures where it is the primary muscle. For both genders, all four forearm muscles demonstrated a similar pattern with ECR being the most active (9.2–11.1% of MVC), followed by ECU, FCR, and FCU with normalized average EMG values varying between 7.7–9.3%, 6.9–8.4% and 4.8–8.5% of MVC, respectively (Fig. 4). These represent a drop of up to 75% in the muscle activity in the neutral zone when compared to normalized average EMG values in wrist deviated postures (16.5–38.3% of MVC). Although %MVC values for all muscles were higher in females, no significant differences were found between genders. Also, side did not have a significant effect on muscle activity in neutral zone.

3.3. Self-selected wrist neutral position

All subjects consistently positioned their wrist in 5°–7° ulnar deviation and 7°–9° extension. Males tend to adopt more deviated postures (8°–9° extension and 7° ulnar deviation compared to 7°–8° extension and 6° ulnar deviation for females) while keeping the wrist in the neutral posture. The differences between genders were not statistically significant. Also, no significant differences in terms of wrist position in the neutral

Table 1
Significance level of the differences between each muscle activity in the neutral zone and its activity in wrist deviations in which it acts as a primary muscle

Muscle	Male		Female	
	Right	Left	Right	Left
FCR	□ 0.013 ★ 0.028	□ 0.038 ★ 0.024	★ 0.023	□ 0.020
FCU	▲ < 0.001 ★ < 0.001	▲ 0.028 ★ 0.006	▲ 0.001 ★ 0.006	▲ < 0.001 ★ 0.005
ECR	□ < 0.001 • < 0.001	□ 0.002 • 0.001	□ 0.004 • < 0.001	□ 0.01 • < 0.001
ECU	▲ < 0.001	▲ < 0.001 • 0.005	▲ < 0.001 • < 0.001	▲ < 0.001 • < 0.001

□ = radial deviation; ▲ = ulnar deviation; • = extension; ★ = flexion; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECR = extensor carpi radialis and ECU = extensor carpi ulnaris.

posture were found between the left and right sides for both genders.

4. Discussion

This study reports the relationship between wrist deviation and forearm muscle activity. Significant lower muscle activity was found in the neutral position compared to muscle activity in all four deviated postures. Each movement direction caused wrist muscle co-activations in different pairs and proportions (ECU and FCU for ulnar deviation, ECR and FCR for radial deviation, FCR and FCU for flexion, and ECR and ECU for extension). The 20–35% of MVC recorded for forearm muscles during wrist deviations, demonstrate a significant muscle load. Our results are supported by Hoffman and Strick (1999), who noted that there was co-activation of wrist muscles. This co-activation included both synergists and antagonist muscles. Because wrist flexors have larger moment arms compared to extensors, larger forces will be required by extensors to maintain the wrist posture (Keir et al., 1996) leading to possible increased risk of injury for this muscle group while working with flexed wrist position. Passive muscle forces in antagonist muscles may further increase the risk. The deviated joints cause muscle overstretch, thus pose a greater risk for musculoskeletal injury.

The secondary effectors (FCR in extension and ulnar deviation, FCU in extension and radial deviation, ECR in flexion and ulnar deviation, and ECU in flexion and radial deviation) presented activity between 8% and 17% of MVC. These levels demonstrate their concomitant dual role in wrist stabilization and force exertion. Muscle's prolonged loading results in fatigue. Therefore, due to lack of rest, the risk of musculoskeletal injury is increased (Kumar, 2001). The effect of wrist deviation on muscle EMG activity was also noted by Drury et al. (1985) in manual materials handling tasks. Authors noted an important increase in EMG at extreme wrist deviations, whereas the muscle activity for wrist angles between 5° radial deviation and 10° ulnar deviation was low and almost constant.

ECR was the most active muscle in both radial deviation (25.5–36.8%) and extension (29.4–38.3%) making it vulnerable in activities that require this combination of wrist deviations (e.g. manual wheelchair propulsion). In addition to being the primary muscle in wrist extension and radial deviation, ECR also acts as a wrist stabilizer. Therefore it is exposed more to static load than flexor muscles. This may explain a higher prevalence of epicondilitis on the extensor side. A 20–25% activity of FCR during flexion and radial deviation suggests it to be an important risk factor in tasks such as grasping and packing of products. One should bear in mind that these force magnitudes were obtained in passively deviated wrist postures and any active contractions would require significantly greater muscle activity.

All subjects positioned their wrists in extension and ulnar deviation while in the neutral posture. The recorded postures (5–7° ulnar deviation and 7–9° extension) had a significant effect on all four forearm muscles, causing a 66–75% decrease in muscle activity. This demonstrates that with additional training and design modifications, workers would be able to carry out tasks more safely. The results may assist physical therapists, surgeons, and ergonomists in their evaluations of office and industrial workstations and in making recommendations for interventions (e.g. job/device design/redesign, final wrist joint position following reconstructive interventions).

In addition to the effect on forearm muscle activation, sustained extreme wrist position poses significant risk for CTS development. Extreme wrist extension causes the finger flexors' tendons to slide in the area between volar carpal ligament and the carpal bones increasing tissue crowding. Wrist flexion causes the tunnel elements to be close together on the volar side of the wrist and spread apart on the dorsal side. Also, the flexor retinaculum presses the flexor tendons and bursae against the head of the radius. Although the carpal tunnel cross section decreases in ulnar and radial deviations, it is not so pronounced, due to constrained range of motion, to cause significant problem.

Our results are supported by Hedge and Powers (1995) who demonstrated that the lowest carpal tunnel pressure (CTP) is recorded when the hand is 5° ulnar deviation. Also, O'Driscoll et al. (1992) reported the same self-selected wrist posture with extension and ulnar deviation. It is suggested that completing tasks with a wrist position within neutral zone would lessen carpal tunnel pressure, helping those with a diagnosis of carpal tunnel syndrome or exposed to increased risk.

The results show that the EMG or the wrist neutral zone were not significantly different on two sides. Contrary to our findings, Drury et al. (1985) noted that EMG for the left hand was consistently higher (by 27%) than the right hand. Also, the wrist angle deviation determined a more pronounced variation in the right hand. This may be due to the training effect of daily work in which most of the tasks determine an overload of the right upper extremity muscles.

Studies that will measure simultaneously forearm muscle activity and carpal tunnel pressure should be performed in order to find the selected wrist posture with the lowest values for both EMG and carpal tunnel pressure. One should consider that although during rest, wrist posture would present minimal muscle activity and carpal tunnel pressure, yet in some stages of industrial work, due to force requirement and awkward postures, the forearm muscle activity may be significantly increased.

5. Conclusions

The aim of this paper was to record the self-selected wrist neutral position for both flexion–extension and radial–ulnar deviation planes and the forearm muscle activity. The neutral zone varied between 7° and 9° extension and between 5° and 7° ulnar deviation. Significantly lower EMG muscle activity was recorded while the wrist was positioned within neutral zone as compared to deviated postures. Also, the effect of adaptation following daily activities that require extensive wrist ulnar deviation and extension (office work, industrial pinch and grip exertions), on wrist resting posture, should also be determined. Encouraging workers to perform with wrist positions within neutral zone is desirable as it could reduce job-associated musculoskeletal disorders risks. The measurement of wrist deviation and forearm muscle activity during force applications also requires exploration. A balance between performance, safe postures, and load should be considered for design solutions.

Acknowledgements

This study was supported in part by The Worker's Compensation Board (WCB) and Alberta Heritage Foundation for Medical Research (AHFMR).

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