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The Effects of Co-ordinating Postures With Shoulder and Elbow Flexion Angles on Maximum Grip Strength and Upper-Limb Muscle Activity in Standing and Sitting Postures

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Eighteen co-ordination postures with shoulder flexion angles (0°, 45° and 90°) and elbow flexion angles (0°, 45° and 90°) in standing and sitting positions were evaluated to identify the effects of co-ordination postures on maximum grip strength and muscle activities of the upper limb in this study. Thirty-nine subjects were recruited and their maximum grip strengths were measured. According to the analysis of grip strength, grip strength was shown to be stronger in a standing posture (297.4 N) than in a sitting posture (274.6 N). In addition, grip strength (293.8 N) at 90° shoulder flexion angle was significantly higher than that at 0° and 45° shoulder angles. There was no statistically significant difference in grip strength from the effects of elbow angles in this study. The results of muscle activities for all muscle groups showed a similar trend with the results of grip strength associated with shoulder angles.

co-ordination posture   shoulder and elbow angles   grip strength   EMG

1. INTRODUCTION

Understanding grip strength is important in the examination of hand functions and in the design of ergonomic handles. It would be also an important part of hand rehabilitation where grip strength is a measure of therapeutic effectiveness [1]. Grip strength is usually influenced by many factors such as age, gender, hand anthropometrics, etc. [2, 3, 4, 5]. Body postures that are determined by shoulder flexion angles and elbow flexion angles, and standing amd sitting body postures would also be important factors in grip strength.

The American Society of Hand Therapists (ASHT) recommended that grip strength would be measured in a sitting posture with 0° shoulder angle, 90° elbow angle and neutral wrist angle [6]. Although some researchers supported the ASHT recommendations following their own research [7, 8, 9, 10], others reported different findings about the maximum grip performance associated with shoulder, elbow and body postures [11, 12, 13, 14, 15, 16].

Many studies have been conducted to understand the effects of shoulder, elbow and body postures on the maximum grip performance by using a grip dynamometer. Some studies have found that the highest grip strength is obtained at 180° shoulder flexion angle [17, 13, 18, 19], whereas the lowest grip strength at 0° shoulder flexion angle [17, 13, 18] or at 90° shoulder flexion angle [19].

The effect of elbow flexion angle on the maximum grip performance was more controversial than that of shoulder flexion angle in previous studies. The findings showed discrepancies. Many researchers reported that generally subjects

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exerted their highest grip strengths at 0° elbow flexion angle, which is the fully extended posture [11, 13, 15, 20], whereas some other researchers found that subjects exerted their highest grip strengths at 90° elbow flexion angle [6, 7, 8, 9, 10]. Kattel, Fredericks, Fernandez, et al. reported the highest grip strength at 45° elbow angle (at 0° shoulder angle) [14].

Among the comparative studies on standing and sitting postures, the study of Balogun, Akomolafe and Amusa attempted to compare the levels of grip strengths between standing and sitting body postures and revealed that a standing posture led to higher levels of grip strengths than a sitting posture [11]. Teraoka [21] and Kang, Kim, Park, et al. [22] also revealed that a standing posture led to a higher level of grip strength than a sitting posture at shoulder angle of 0° and elbow angle of 0°.

Grip strength is mostly exerted by the flexors of the hand and forearm, while the extensors of the forearm stabilize the wrist [23]. Roman-Liu and Tokarski reported that forearm muscles, such as flexor carpi ulnaris (FCU) and extensor carpi radialis (ECR), were strongly involved in hand-grip force exertion [10]. As one of the primary muscle groups crossing the elbow and shoulder, biceps brachii (BB) plays a role in elbow flexion movements as well as shoulder elevation [24]. Regarding muscle activities associated with the shoulder movements, Kronberg, Nemeth and Broström showed that the highest muscle activities took place in anterior and middle parts of the deltoid and infraspinatus in carrying out shoulder flexion movements [25], and Kronberg et al. [25] and Sporrong, Palmerud and Herberts [26] also found that muscle activities of the posterior deltoid and trapezius increased with the extension of the shoulder joint.

Generally, most previous researchers, as mentioned here, have mainly focused on the effects of either only the shoulder flexion angle or only the elbow flexion angle on maximum grip strength, and not the effects of the co-ordinated postures of both shoulder and elbow flexion angles on maximum grip strength in standing and sitting body postures. Although a few research groups tested the effects of co-ordinated postures of shoulder and elbow angles on the maximum grip performance, their findings were different. In addition, there has been little study on the relationship between grip strength and muscle activities of the upper limbs for various co-ordinated postures of shoulder and elbow flexion angles.

Therefore, the objective of this study was to investigate the effects of co-ordinated postures of shoulder and elbow flexion angles on maximum grip strength as well as on the upper-limb muscle activities in standing and sitting postures

2. METHOD

2.1. Subjects

A total of 39 males who had no symptoms of work-related musculoskeletal disorders in the upper-body parts participated in this laboratory study. The means (*SD*) of the subjects' age, height, and weight were 25.1 (2.14) years, 174.1 (6.12) cm, and 70.9 (8.72) kg, respectively.

2.2. Equipment

In this experiment, custom-designed equipment made of steel and aluminium which can adjust the angles of two joint parts freely was used to evaluate the maximum grasp performance as well as the upper-limb muscle activities associated with shoulder and elbow flexion angles in standing and sitting postures (Figure 1).

Grip strength and muscle activities were simultaneously measured with a precision dynamometer G200 from Biometrics, UK (Precision ±1%, 0–90 kg or 0–200 lbs) and, also from from Biometrics, UK, SX230 electromyography (EMG, with 1024 Hz sampling rate) sensors. The surface electrodes were Ag/AgCl circular bipolar electrodes with a diameter of 10 mm and interelectrode distance of 20 mm. The amplifier's input impedance of >10 000 000 mΩ. The signals were filtered with a bandwidth of 10 and 500 Hz and sampled at 1000 Hz. The data were collected through the data acquisition system of DataLINK (Biometrics, UK) and used in the Biometrics analysis software to analyse grip strength and muscle activities in this study.

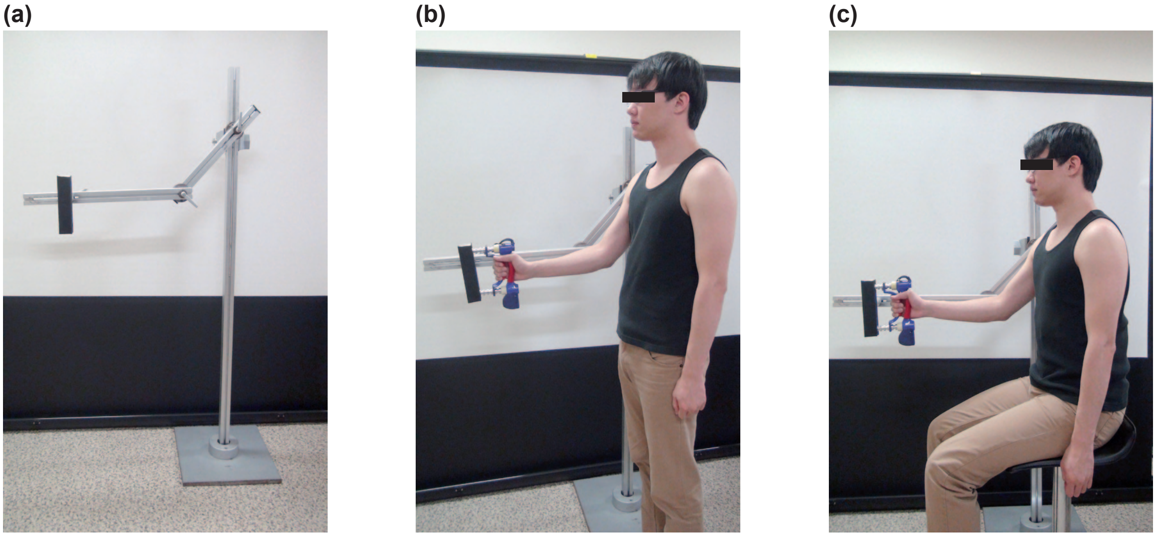

Figure 1. (a) Custom-made equipment, (b) 45º shoulder and 45º elbow angle in a standing posture and (c) 45º shoulder and 45º elbow angle in a sitting posture.

2.3. Procedures

All subjects were informed about the objectives and procedures of the experiment and their age, body weight and height were measured in advance of taking part in the experiment. Each subject was instructed to exert their maximum grip strength in a random posture for 5 s to obtain the maximum isometric grip performance as well as muscle activities from six muscle groups, simultaneously.

The muscles studied in the experiment were FCU, which flexes and adducts the hand at the wrist joint; ECR, which extends and abducts the hand at the wrist joint; BB, which flexes the forearm at the elbow joint; triceps brachii (TB), which extends the forearm at the elbow joint; anterior deltoid (AD), which flexes and medially rotates the arm; and upper trapezius (UT), which elevates, retracts and rotates the scapular. Figure 2 illustrates the locations of the EMG electrodes on the muscle groups. To eliminate personal differences among subjects, each muscle activity (root mean square, RMS, value) in each task posture was normalized based on the resting RMS, task RMS and maximum RMS values with Equation 1:

$$\%MVC = \frac{(RMS_{\text{TASK}} - RMS_{\text{RESET}})}{(RMS_{\text{MAX}} - RMS_{\text{RESET}})} \times 100, \qquad (1)$$

where $\%MVC$ = percentage maximum voluntary contraction, RMS_{TASK} = task root mean square, RMS_{REST} = resting root mean square, RMS_{MAX} = maximum root mean square.

The maximum force exertion tests for each muscle were as follows [27]:

- FCU: the subject lay on his forearm on the table with full supination; the examiner applied pressure with two hands on distal phalanges of finger, in the direction of elbow extension;
- ECR: the subject lay on his forearm on the table with slightly less full pronation; the examiner applied pressure with two hands on the dorsum of the hand, in the direction of ulnar side flexion;
- BB: the subject lay on his elbow on the table; the examiner applied pressure with two hands on the palmar side of the hand, in the direction of elbow extension;
- TB: the subject sitting on the chair and bent his torso; the examiner applied pressure with each hand on the posterior of the shoulder and the ulnar side of the hand, in the direction of elbow flexion;
- AD: the subject sat on the chair with the upper arm flexed horizontal to the ground; the examiner applied pressure with one hand on the radius side of the hand, in the direction of shoulder extension;
- UT: the subject sat on the chair and shrug; the examiner applied pressure with each hand on the shoulder.

These maximum tests were performed with two repetitions in a random order. While the subject sat on the chair and relaxed his shoulder, elbow, and wrist with a neutral posture, the resting muscle activities were measured in this study.

A 3-min was afforded between each experiment to reduce the effect of muscle fatigue in each grip strength experiment.

2.4. Experimental Design

Analyses of variance (ANOVA) were conducted for maximum grip strength and muscle activities with SPSS 12.0 with a significance level of .05. There were one dependent variable of maximum grip strength and six dependent variables of percentage maximum voluntary contraction (%MVC) in each posture (normalized RMS values from FCU, ECR, BB, TB, AD, and UT). The independent variables were three levels of shoulder angles (0°, 45°, 90°) and three levels of elbow angles (0°, 45°, 90°), and two levels of postures (standing and sitting). Thus, a total of 18 different postures depending upon the co-ordination of shoulder angle, elbow angle and body posture were evaluated in this study. All significant effects were further investigated using Tukey post hoc tests for all the dependent variables.

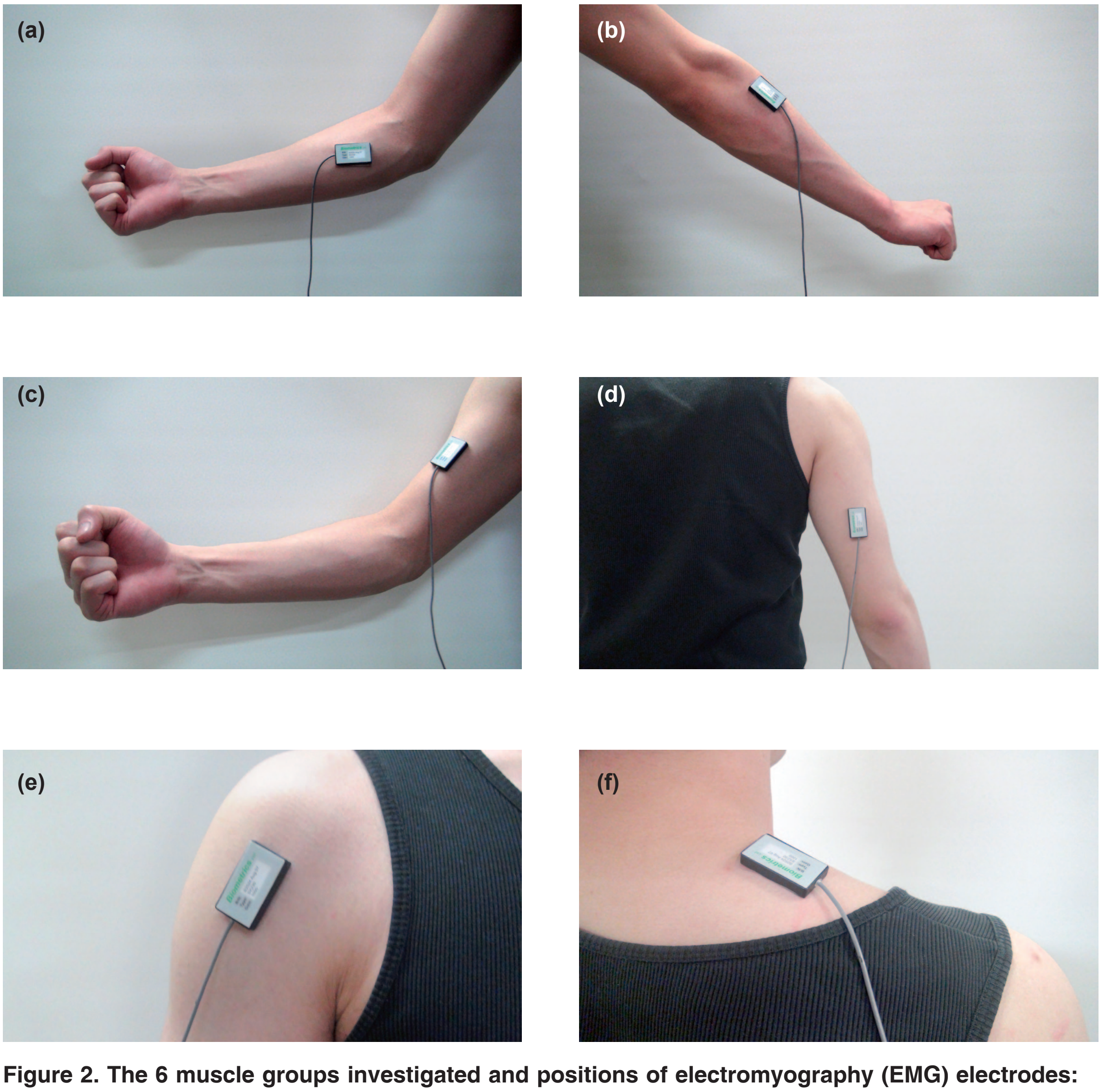

Figure 2. The 6 muscle groups investigated and positions of electromyography (EMG) electrodes: (a) flexor carpi ulnaris, (b) extensor carpi radialis, (c) biceps brachii, (d) triceps brachii, (e) anterior deltoid, (f) upper trapezius.

3. RESULTS

3.1. Grip Strength

The results of statistical analyses showed that the effects of shoulder angle (p = .004) and body posture (p < .001) on grip strength were statistically significant at α = .05.

Figure 3 shows that grip strength was statistically stronger in the standing posture (302.9 N) than in the sitting posture (274.7 N). The result on the effect of shoulder flexion angle on maximum grip strength also showed that the grip strength at 90° shoulder flexion angle (293.8 N) was significantly stronger than that at 0° and 45° shoulder angles. The grip strength (284.9 N) at 0° shoulder angle was not significantly different from that (287.6 N) at 45°. The effect of elbow flexion angle was not statistically significant (p = .092) in this study (286.1, 290.4 and 289.9 N for 0°, 45° and 90° of elbow angles, respectively).

The three-way interaction effect of shoulder angle, elbow angle and posture was statistically significant (p = .009). In the standing posture, grip strengths (302.0–305.4 N) at 0° and 45° elbow angles were relatively higher than those (294.1–302.2 N) at 90° elbow angle with 0° and 45° shoulder angles, whereas the grip strengths (306.5–314.4 N) at 45° and 90° elbow angles were relatively higher than that (294.7 N) at 0° elbow angle with 90° shoulder angle. Grip strengths in the sitting posture, however, showed a different pattern from that of the grip strengths in the standing posture: grip strengths (272.6–274.8 N) at 45° and 90° elbow angles were relatively higher than those (265.5–265.8 N) at 0° elbow angle with 0° and 45° of shoulder angles, whereas grip strengths (283.9 N) at 0° elbow angle were relatively higher than those (281.1–282.1 N) at 45° and 90° elbow angles with 90° shoulder angle. Table 1 shows the average grip strength for each posture.

3.2. Muscle Activities of Forearm Muscles

There were significant effects of the shoulder angle, elbow angle and the interaction of shoulder and elbow angles on FCU activities as well as on ECR activities in this study (p < .005).

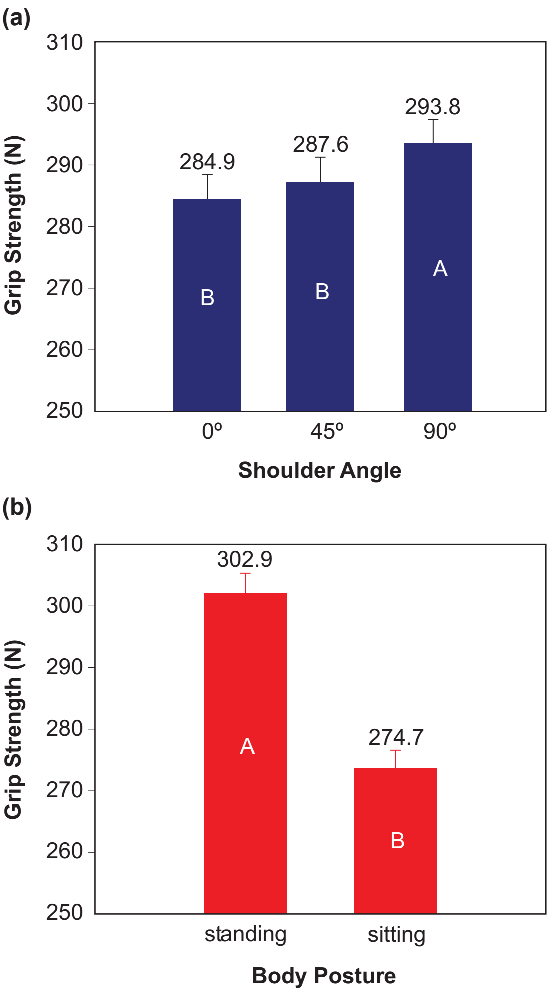

Figure 3. Grip strength according to (a) shoulder angle and (b) body posture. *Notes.* A, B indicate the significant statistical groupings; error bars represent *SD*.

TABLE 1. Mean (*SD*) Grip Strength (N) for Each Posture

Angle		Grip Strength (N), *M* (*SD*)	
Shoulder	Elbow	Standing Posture	Sitting Posture
0°	0°	302.0 (70.6)	265.5 (59.5)
	45°	302.2 (52.9)	272.6 (49.9)
	90°	294.1 (62.8)	273.4 (48.3)
45°	0°	304.5 (56.9)	265.8 (49.3)
	45°	305.4 (58.5)	274.8 (51.0)
	90°	302.2 (56.7)	272.9 (51.7)
90°	0°	294.7 (54.9)	283.9 (44.5)
	45°	306.5 (52.9)	281.1 (50.8)
	90°	314.4 (61.0)	282.1 (48.4)

With regard to shoulder angles, the %MVC (29.98%MVC) of FCU at 90° shoulder angle was statistically significantly higher than that (27.8%MVC) at 0° shoulder angle (Figure 4). Similarly, the %MVC (72.5%MVC) of ECR at 90° shoulder angle was significantly higher than those (64.7% and 66.4%MVC) for 0° and 45° shoulder angles, respectively (Figure 5).

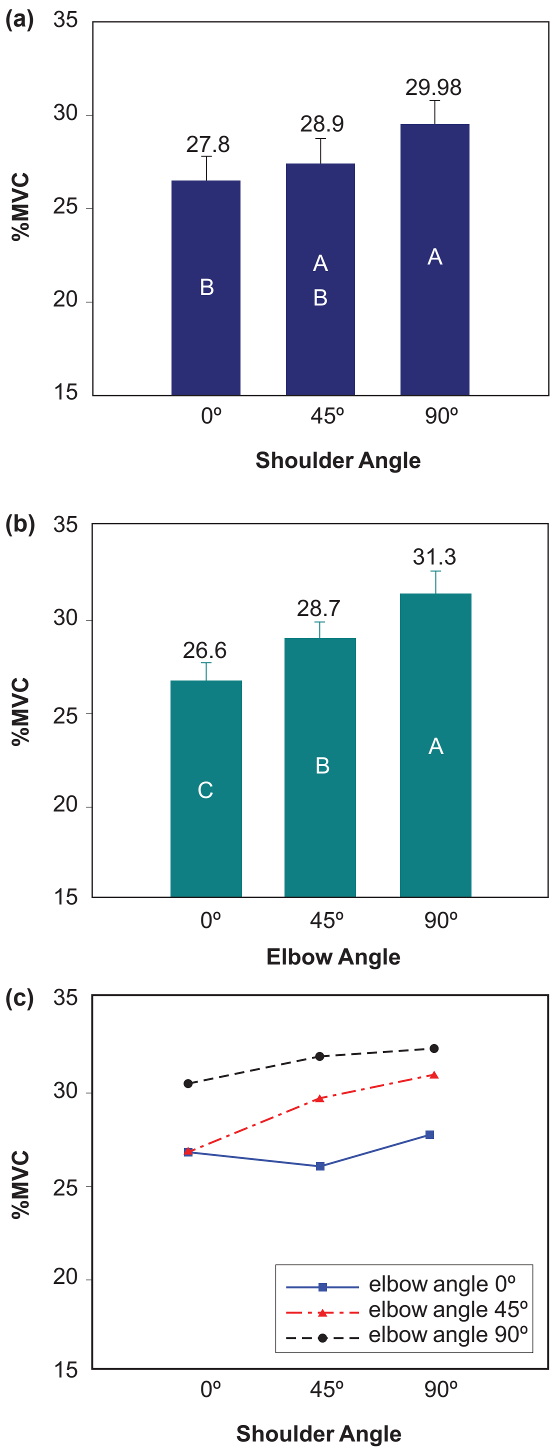

Figure 4. Percentage maximum voluntary contraction (%MVC) of flexor carpi ulnaris according to (a) shoulder angle, (b) elbow angle and (c) shoulder × elbow angles. *Notes.* A, B and C indicate the significant statistical groupings; error bars represent *SD*.

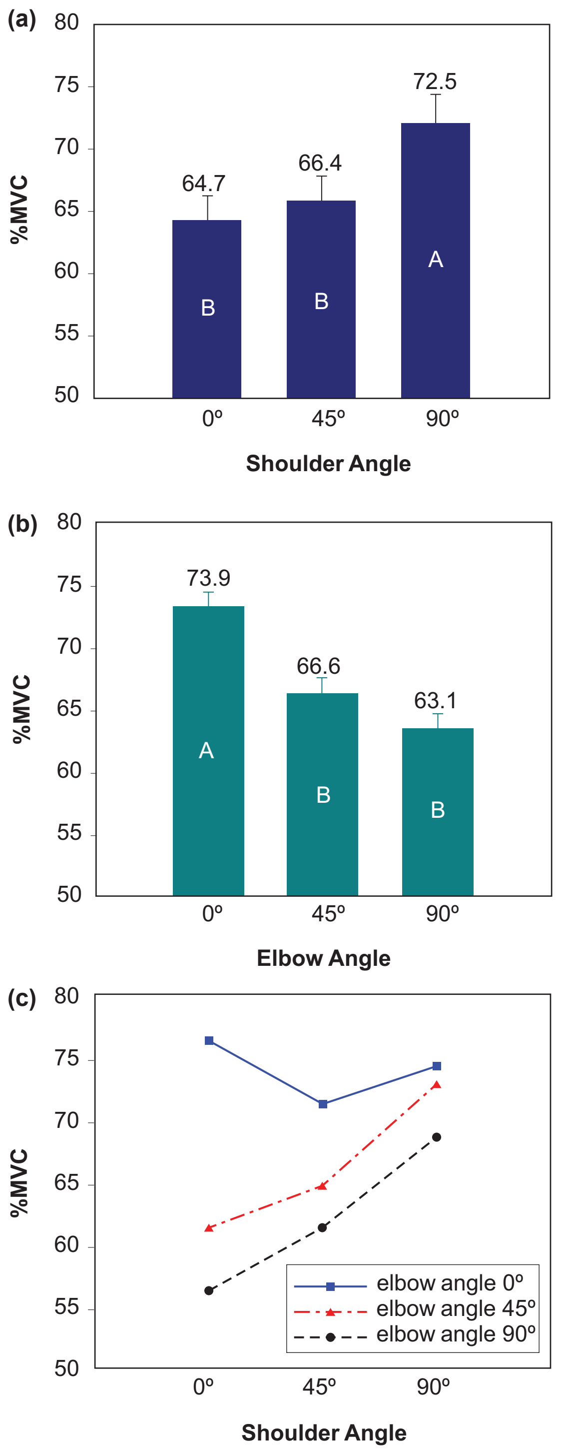

Figure 5. Percentage maximum voluntary contraction (%MVC) of extensor carpi radialis according (a) shoulder angle, (b) elbow angle and (c) shoulder × elbow angles. *Notes.* A, B and C indicate the significant statistical groupings; error bars represent *SD*.

With regard to elbow angles, muscle activities between the two were different. Figures 4–5 show that the %MVC of FCU tended to increase as the elbow angle increased (26.6%, 28.7% and 31.3%MVC for 0°, 45° and 90°, respectively), but that of ECR tended to decrease as the elbow angle increased (73.9%, 66.6% and 63.1%MVC for 0°, 45° and 90°, respectively).

With regard to the interaction analysis, generally muscle activities of FCU increased when shoulder and elbow angles increased from 0° to 90°, whereas muscle activities of ECR increased when the shoulder angle increased from 0° to 90° and the elbow angle decreased from 90° to 0°. In both cases, the increasing slopes were more distinct at 45° and 90° elbow angles than at 0° elbow angle when the shoulder angle increased (Figures 4–5).

3.3. Muscle Activities of Upper Arm Muscles

The statistical analysis of the %MVC of the muscle groups at each shoulder angle, elbow angle and body posture revealed a statistically significant difference of muscle activities in BB ($p < .05$) (Figure 6). Muscle activities of BB tended to increase as the shoulder flexion angle increased from 0° to 90° (21.5, 24.7 and 26.3%MVC for 0°, 45° and 90° shoulder angles, respectively); muscle activities (27.9 and 24.7%MVC) of BB at 45° and 90° elbow flexion angles were higher than that (19.8%MVC) at 0° elbow flexion angle; and the muscle activity (27.1%) of BB in the sitting posture was statistically significantly higher than that (21.2%) in the standing posture in this study.

Figure 7 shows that the %MVC of TB were statistically affected by the elbow angle ($p < .001$) and the interaction effects of shoulder and elbow angles ($p = .038$). According to the results, unlike BB, the highest muscle activity (15.8%MVC) of TB was obtained at 0° elbow angle, which was significantly higher than those (12.0 and 13.2%MVC) at 45° and 90° elbow angles. Interestingly, according to the results on the interaction effects, muscle activities of TB at 45° and 90° elbow angles decreased, whereas that of 0° elbow angle increased when shoulder angle increased.

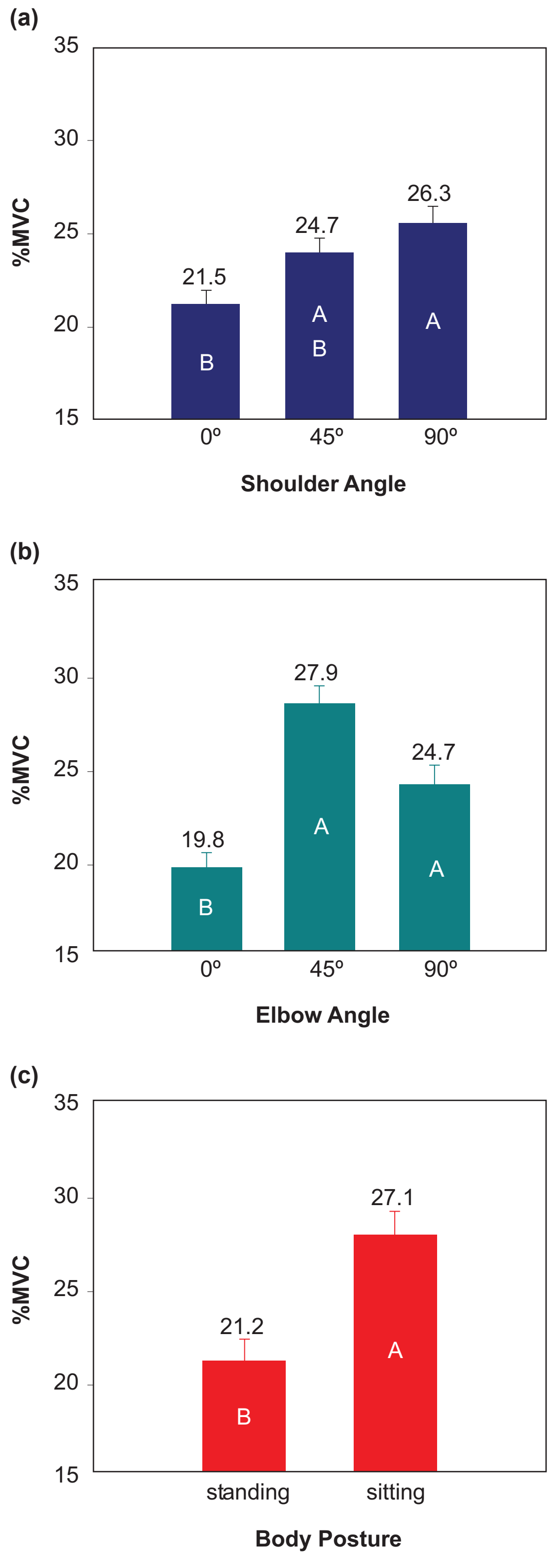

Figure 6. Percentage maximum voluntary contraction (%MVC) of biceps brachii according to (a) shoulder angle, (b) elbow angle and (c) body posture. *Notes.* A, B and C indicate the significant statistical groupings; error bars represent *SD*.

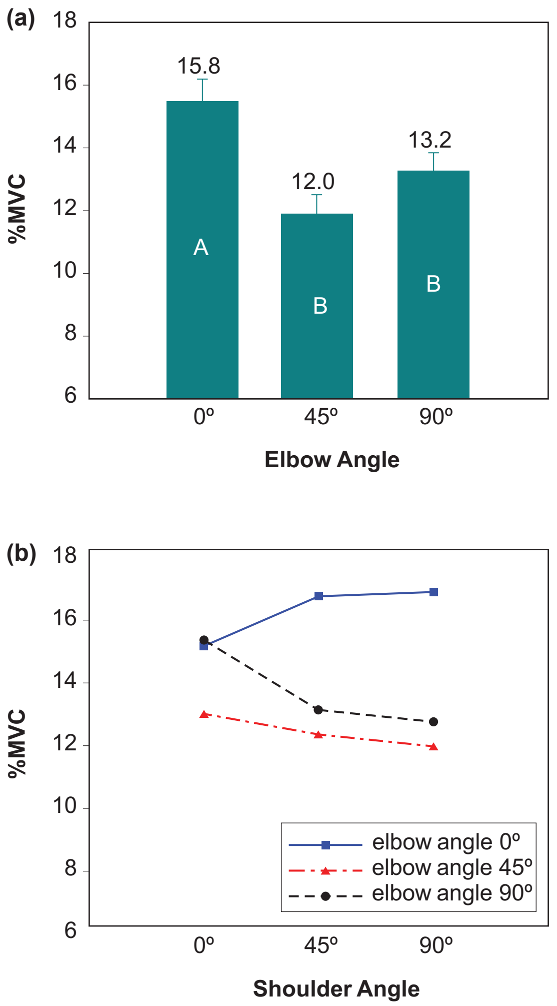

Figure 7. Percentage maximum voluntary contraction (%MVC) of triceps brachii according to (a) elbow angle and (a) shoulder × elbow angles. *Notes.* A, B and C indicate the significant statistical groupings; error bars represent *SD*.

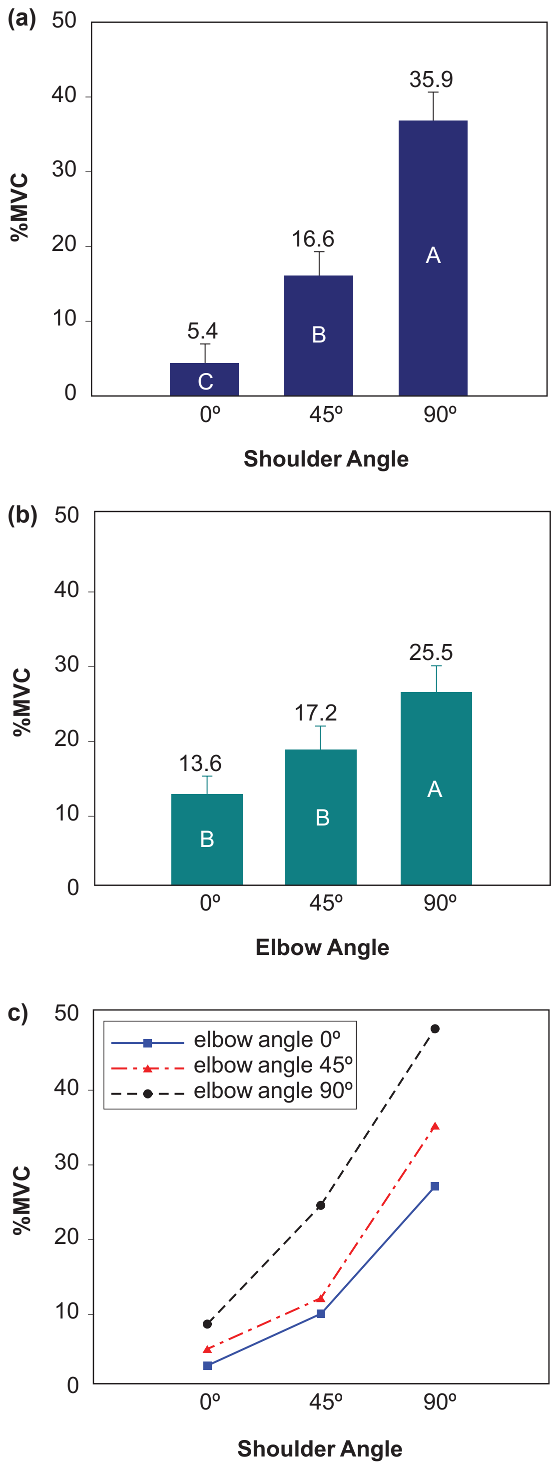

Figure 8. Percentage maximum voluntary contraction (%MVC) of anterior deltoid according to (a) shoulder angle, (b) elbow angle and (c) shoulder × elbow angles. *Notes.* A, B and C indicate the significant statistical groupings; error bars represent *SD*.

3.4. Muscle Activities of Shoulder Muscles

The effects of the shoulder angle, elbow angle and the interaction of shoulder and elbow angles on AD were statistically significant in this study ($p < .05$). With regard to the shoulder flexion angle, as expected, muscle activities of AD were dramatically increased from 5.4%MVC to 35.9%MVC as the shoulder angle increased from 0° to 90°. With regard to the elbow flexion angle, the %MVC of AD also tended to increase(13.6%MVC, 17.2%MVC and 25.5%MVC for 0°, 45° and 90° of shoulder angles, respectively) as the shoulder angle increased (Figure 8). With regard to the coordinated effects of shoulder and elbow angles, the lowest muscle activity of AD occurred at 0° elbow and 0° shoulder angles, whereas the highest occurred at 90° elbow and 90° shoulder angles. It is noted that the AD shoulder muscle was more active when both the elbow and shoulder were flexed than when either only elbow or only shoulder was flexed.

There were significant effects of the shoulder angle, posture and the interaction of shoulder and posture on UT in this study ($p < .05$). As expected, the activity of UT at 90° shoulder angle was significantly higher than that at 0° and 45° shoulder angles. There was no significant difference of muscle activities between 0° and 45° shoulder angles. The muscle activity of UT was also statistically significant affected by body posture: %MVC of UT was higher in the sitting posture than in the standing posture.

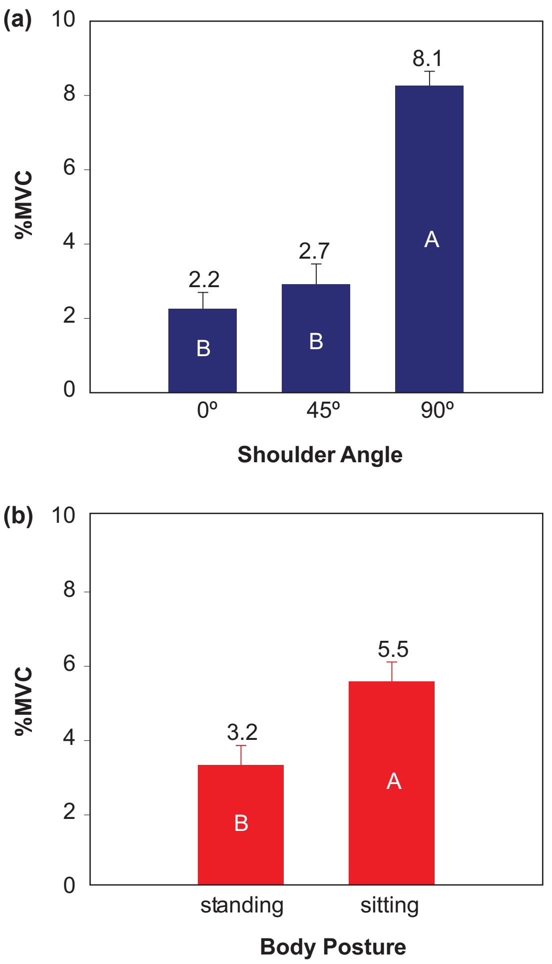

Figure 9. Percentage maximum voluntary contraction (%MVC) of upper trapezius according to (a) shoulder angle and (b) body posture. *Notes.* A and B indicate the significant statistical groupings.; error bars represent *SD*.

4. DISCUSSION

In the analysis for shoulder flexion angle, the results revealed that grip strength significantly increased when shoulder angle increased from 0° to 90°. This finding is in agreement with the results of previous research [13, 17, 19], which reported higher grip strengths at higher shoulder flexion angles. This result can be explained by the analyses of upper-limb muscle activities, which were tested in this study. According to the results, overall muscle activities (%MVC) of the upper-limb muscle groups (FCU, ECU, BB, AD, UT), except TB, tended to increase as the shoulder flexion angle increased. Although the main functions of FCU and ECR are flexion of the hand at wrist radial deviation, and extension/radial deviation of the wrist, respectively, these muscle groups were also active when the shoulder was flexed in this study. Landin, Myers, Thompson, et al. [24] and Kronberg et al. [25] also reported that muscle activities of BB, which is a function of forearm flexion, and supination movements and AD, which is a function of arm flexion and rotation, increased as the shoulder flexion angle increased in their studies. As expected, UT, which is in charge of elevating the shoulder, showed the highest muscle activities at 90° shoulder flexion angle and the lowest muscle activities at 0° shoulder flexion. Especially AD and UT showed 3.7–6.7 times more muscle activities at 90° shoulder angle than at 0° shoulder angle. In addition, according to the results on the interaction effects of shoulder and elbow flexion angles (Figures 4, 5 and 8), muscle activities of FCU, ECR, and AD muscle groups increased as the shoulder flexion angle increased when the elbow was flexed at 45° and 90° rather than at 0°. Thus, higher grip strengths at higher shoulder flexion angles might be explained by the analyses of upper-limb muscle activities in this study. In addition, AD and UT muscle groups contributed more than the other muscle groups to higher grip strengths at higher shoulder flexion angles.

As mentioned, the effect of elbow flexion angle on total grip strength is controversial. Some research groups [11, 13, 20, 15] obtained highest grip strengths at the fully extended elbow posture (i.e., 0° of elbow flexion angle), whereas others [6, 7, 8, 9, 10] obtained highest grip strengths at the fully flexed elbow posture (i.e., 90° of elbow angle). Also, Kattel et al. [14] reported the highest grip strength in their study at 45° elbow flexion angle. In this study, the effect of elbow flexion angle on maximum grip strength was not statistically significant (286.1–290.4 N for 0°–90° of elbow angle), as it was in the studies of Desrosiers, Bravo, Hébert, et al. [8] and Kumar, Parmare, Ahmed, et al. [28]. Kumar et al. [28] tested 16 males and 29 females in a standing posture with 0° and 90° elbow angles and found no significant difference between grip strength (264.2 N) at 0° elbow angle and grip strength (262.8 N) at 90° elbow angle. These findings might be interpreted on the basis of the analyses of upper-limb muscle activities. According to the results of the effects of upper muscle groups for elbow angles on maximum grip force in this study, interestingly, muscle activities (%MVC) of FCU, BB, and AD tended to increase, whereas those of ECR and TB tended to decrease as the elbow angle increased in this study. FCU and BB acted as agonist muscles, while ECR and TB acted as antagonist muscles during grip exertions at flexed elbow postures. Although AD usually shows more activity with more shoulder flexion movements [25], this muscle group also showed higher muscle activities when the elbow was flexed at 90° than when it was flexed at 0°. The muscle activity of UT, which is usually in charge of shoulder elevation or flexion [26], was not significantly affected by elbow flexion angles in this study, most likely because this muscle group was too far from the elbow. Roman-Liu and Tokarski revealed that the farther the muscle from the forearm, the less impact it had on grip strength [10].

Although BB and UT had a significantly higher %MVC in the sitting posture than in the standing posture, mean grip strength (302.9 N) obtained in the standing posture was significantly greater than that (274.7 N) obtained in the sitting posture. Grip strength in the sitting posture was ~90.7% of that in the standing posture. This finding was also consistent with other research findings [11, 15, 20, 21].

Higher grip strength in the standing posture could be attributed to the synergistic effect of the muscles with the lower extremities, which may have enhanced maximum grip strength in the standing posture [29]. Generally, a sitting posture induces muscle relaxation, whereas a standing posture can increase cortical and peripheral arousal [11]. Ĺstrand and Rodahl also explained this finding with continuous interactions of central commands with sensory feedback from joints and muscles of the lower extremities in a standing posture [30]. They found that the sensory feedback from the joints and muscles was minimal in a sitting posture. The peripheral input from the joints and muscles of the lower extremities can control the number of motor units recruited and, ultimately, the force of contraction [31]. Teraoka also reported differences between the physiological conditions in a standing posture and those in a sitting posture (i.e., the mental or physical strain of subjects is more intense in a standing posture than in a sitting posture) [21].

5. CONCLUSIONS

Grip strengths obtained with 90° shoulder flexion angle were significantly greater than those obtained with 0° shoulder flexion angle. Unlike the results of shoulder flexion angles, the effect of elbow angles on total grip strength was not statistically significant. The standing body posture yielded significantly greater grip strength than the sitting body posture.

Thus, the shoulder flexion angle and body posture were critical factors on the total grip strength, whereas the elbow flexion angle may not be considered an influential factor on total grip strength.

The ASHT recommendations (0° of wrist angle, 90° of elbow angle, and 0° of shoulder angle with a sitting posture) for measuring maximum grip tasks might also be reconsidered. For measuring maximum grip strengths, 90° shoulder flexion angle with a standing body posture would be a better recommendation based on this study.

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