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The effect of wrist position, angular velocity, and exertion direction on simultaneous maximal grip force and wrist torque under the isokinetic conditions

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Abstract

The objective of the study was to identify the effects of wrist position, force exertion direction, and angular velocity on simultaneous grip force and wrist torque under the isokinetic condition. Twenty-five male students participated in the study and the isokinetic wrist dynamometer was utilized to measure both forces from 90° of flexion to 90° of extension in the slow velocities of 10°/s, 20°/s, and 30°/s. The results revealed that grip force and wrist torque were larger around neutral and there was a passive force in the extremely extended wrist position. Wrist torque only was higher in the flexion direction but grip force for both directions did not differ significantly. Both grip force and wrist torque decreased when angular velocities increased and velocities could be classified into three groups, such as isometric, 5–20°/s, over 25°/s, according to the magnitude of force reduction. Finally, it was described that wrist positions, where maximal grip force and wrist torque occurred, were inconsistent and significant ranges of the wrist position including maximal forces were broad under the isokinetic condition of even slow velocities. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Grip force; Wrist torque; Isokinetic condition; Wrist position; Force exertion direction; Angular velocity

1. Introduction

Many studies performed under isometric conditions have proposed that handgrip force and wrist torque may be affected by age, gender, wrist position, forearm position, hand tested, glove type, and so on (Fredericks et al., 1995; Hallbeck, 1994; Hallbeck and McMullin, 1993; Hallbeck et al., 1993; Miller and Wells, 1988; Ramakrishnan

et al., 1994; Wilhelm and Hallbeck, 1997). Especially, the effect of wrist position is that any deviation from neutral decreases grip force and wrist torque, with a larger decrement in flexion than extension. As shown in Table 1, the result that maximal grip force and wrist torque occurred at the neutral position of the wrist was quite consistent in the isometric condition and significant ranges of wrist positions including those maximal forces were narrow.

Under the isokinetic condition, however, both phenomena appear to be quite unclear even in slower angular velocities because the wrist position

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Table 1
Significant range of wrist positions for grip force and wrist torque in the isometric condition^a

Force	Reference	Wrist position (°)
Grip	Fredericks et al. (1995)	36F 18F (0)
	Hallbeck and McMullin (1993)	65F 45F (0) 45E 65E
	Miller and Wells (1988)	70F 30F (0 30E) 60E
	Ramakrishnan et al. (1994)	45F (0) 45E
	Wilhelm and Hallbeck (1997)	42F (30F 15F 0 15E) 30E 42E
Wrist	Wilhelm and Hallbeck (1997)	42F (30F 15F 0 15E 30E) 42E

^a Bold digits are designated as maximal forces and parentheses mean the significant ranges of wrist positions.

Table 2
Significant range of wrist positions for grip force and wrist torque in the isokinetic condition^a

Force	Reference	Velocity (°/s)	Wrist position (°)
Grip	Wilhelm (1997)	15	(42F 30F 15F 0 15E 30E) 42E
		30	(42F 30F 15F 0 15E) 30E 42E
		45	42F (30F 15F 0 15E) 30E 42E
		60	42F (30F 15F 0 15E) 30E 42E
		175	45F 30F 15F 0 15E 30E 45E
	Lehman et al. (1993) ^b	5	45F 30F 15F 0 15E 30E 45E
		25	45F 30F 15F 0 15E 30E 45E
		50	45F 30F 15F 0 15E 30E 45E
		90	45F 30F 15F 0 15E 30E 45E
		125	45F 30F 15F 0 15E 30E 45E
Wrist	Wilhelm (1997)	15	42F (30F 15F 0 15E 30E) 42E
		30	42F (30F 15F 0 15E) 30E 42E
		45	42F (30F 15F 0 15E 30E) 42E
		60	42F 30F 15F 0 15E) 30E 42E

^a Bold digits are designated as maximal forces and parentheses mean the significant ranges of wrist positions.

^b The study of Lehman et al. (1993) cited only the case of extension to flexion wrist motion and did not mention specific ranges of the wrist positions for each angular velocity.

where maximal grip and wrist forces were generated were irregular as shown in Table 2 and significant ranges of wrist positions were somewhat broad (Lehman et al., 1993; Wilhelm, 1997; Wilhelm and Hallbeck, 1997).

Force exertion direction also affects grip force and wrist torque under both isometric and isokinetic conditions and angular velocity is one of the important factors in the isokinetic condition because grip force and wrist torque are dramatically reduced even in slow velocities (Lehman et al., 1993; Hallbeck et al., 1993; Wilhelm and Hallbeck, 1997).

Therefore, this study identified the effects of wrist position, force exertion direction, and

angular velocities focusing on the slow speeds that seem to be similar to the isometric condition for simultaneous grip force and wrist torque under the isokinetic condition and verified the patterns of wrist position where maximal forces occurred and significant range of wrist positions including these forces in the isokinetic condition.

2. Method

2.1. Subjects

The study used 25 male students as subjects whose average age, height, and weight were

25.44 ± 4.97 yr, 176.36 ± 6.95 cm, 72.56 ± 13.09 kg, respectively. They used the dominant hand to apply grip force and wrist torque and only two subjects were left-handed.

2.2. Apparatus

The specially developed isokinetic wrist dynamometer by Wilhelm (1997) was used for measuring grip force and wrist torque. As shown in Fig. 1, the dynamometer consisted of a cylindrical handle of 4 cm diameter mounting two miniature load cells (Sensotec[®] Model 13/2244-06-10) for grip force, tension/compression load cell (Omega[®] Model LCB-200) for wrist torque, and DC servo motor (Electro-Craft Model Number 652-501-205) and control box to adjust angular velocities. The goniometer ranging from 90° of flexion to 90° of extension was mounted in the bottom of the handle. In this study, neutral of 0° was set as the parallel between the longitudinal axis of the ulna and the center of the handle that the hand gripped for a test.

All load cells were wired to an STA-1800U screw terminal accessory. This terminal was connected to a DAS-1701AO board, Keithley Instruments, Inc., installed in an IBM compatible Pentium PC. The data acquisition software, TestPoint, was used to display and save the data. All load cells were calibrated with known weights prior to the test. The data from load cells were saved at one sample per each 15° of angle.

2.3. Experimental design

To conduct the analysis of variance (ANOVA), grip force and wrist torque were dependent variables. The independent variables for the $13 \times 3 \times 2$ within-subject design were 13 levels of wrist positions (90° of flexion through 90° of extension in 15° increments), three levels of angular velocities ($10^\circ/\text{s}$, $20^\circ/\text{s}$, and $30^\circ/\text{s}$), and two levels of exertion directions (flexion and extension). Interactions for both the dependent variables were also analyzed and post hoc tests

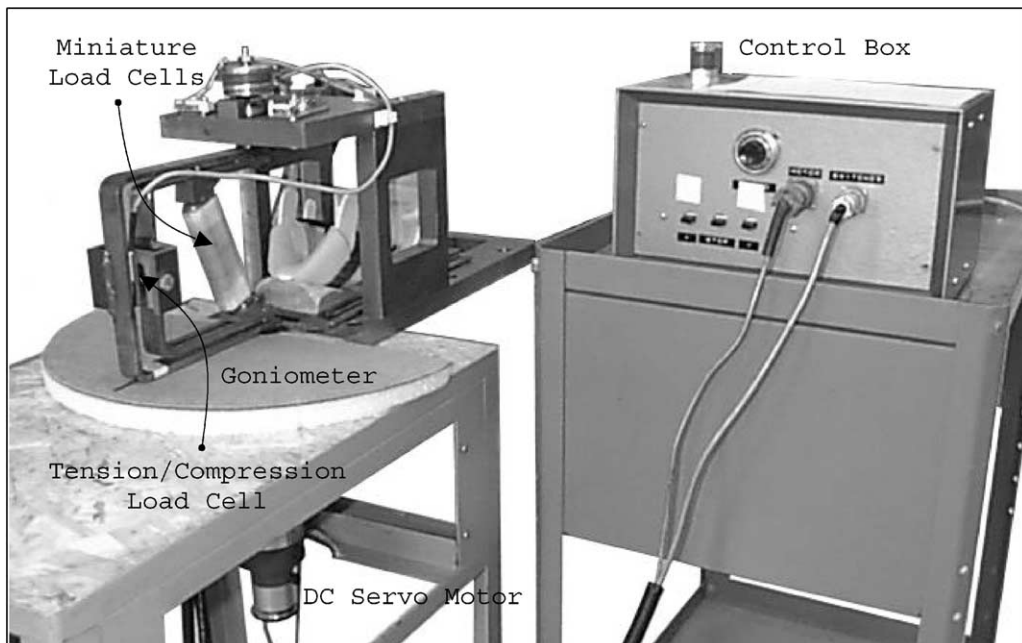


Fig. 1. Isokinetic wrist dynamometer.

were performed on all significant main and interaction effects.

2.4. Procedure

All subjects signed an informed consent from before beginning the test. Anthropometric dimensions were measured including wrist range of motion.

Each subject followed the American Society of Hand Therapists standard (Fess and Moran, 1981) and was strapped into the apparatus with restraints along the forearm and upper arm. In addition, the elbow was fixed so that leaning or pulling using the upper body would not affect the strength measured. And then, they were informed of test methods and tried each trial of two wrist motions once to become familiar with exerting grip force and wrist torque.

In order to minimize the potential effect of forearm fatigue, a total of 180° was divided into 3-s intervals and a separate trial was randomly performed for each interval. In other words, there were 6 intervals (90–60F, 60–30F, 30F–0, 0–30E, 30–60E, and 60–90E) for the $10^\circ/\text{s}$ 3 intervals (90–30F, 30F–30E, and 30–90E) for the $20^\circ/\text{s}$, and 2 intervals (90F–0 and 0–90E) for the $30^\circ/\text{s}$ velocity. Two-minute rest periods were allowed between trials.

3. Results

3.1. Grip force

The results of ANOVA performed for grip forces showed that there are significant differences in the variables of wrist position ($F(12, 288) = 28.96, p = 0.0001$) and angular velocity ($F(2, 48) = 12.44, p = 0.0001$) and interactions of wrist position and force exertion direction ($F(25, 599) = 20.77, p = 0.0001$), of wrist position and velocity ($F(38, 900) = 18.06, p = 0.0001$), and of wrist position, exertion direction, and velocity ($F(77, 1664) = 14.74, p = 0.0001$).

Post hoc tests were performed for significant main effects and interactions. Maximal grip force was 281.98 N at 0° and wrist positions of 45° of flexion through 15° of extension were grouped as shown in Fig. 2.

Although the mean difference of grip force between both directions of force exertion was not statistically significant, as shown in Fig. 3, extension direction (209.58 N) generated a little higher force than flexion (200.88 N). Grip forces were also greater at $10^\circ/\text{s}$ angular velocity (222.00 N) and decreased as velocities increased.

The mean grip forces at each wrist position were plotted separately for each exertion direction of flexion and extension in Fig. 4. The maximal force of 239.08 N at 0° and 30° of flexion through 0°

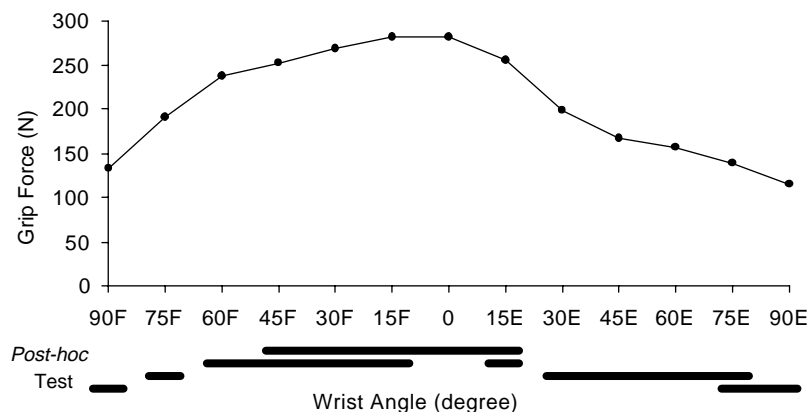


Fig. 2. Post hoc test for grip force by wrist position.

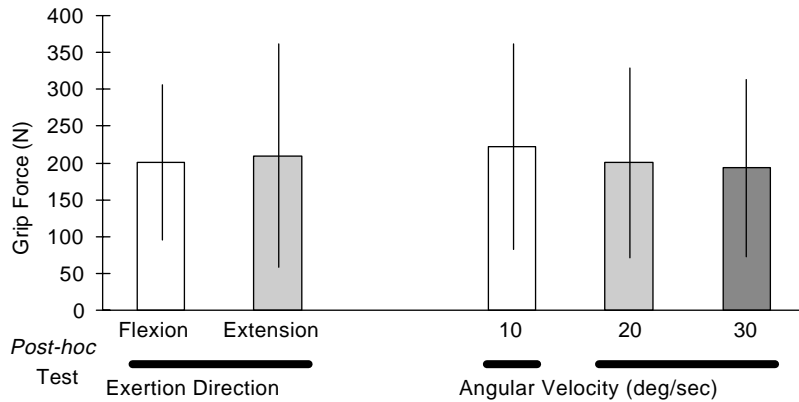


Fig. 3. Post hoc test for grip force by exertion direction and angular velocity.

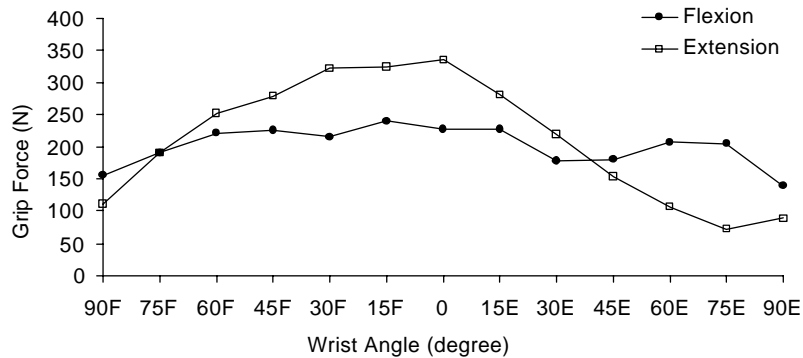


Fig. 4. Plot of flexion and extension grip force by wrist position.

were grouped by post hoc test as a significant range of wrist positions for extension. However, a wide range from 75° of flexion to 75° of extension was grouped for flexion direction and maximal force was at 15° of flexion.

Fig. 5 shows the results of interaction of wrist position and angular velocity. Maximal grip forces were 317.22 N at 0°, 282.73 N at 30° of flexion, and 280.77 N at 0°, respectively. Post-hoc test revealed that the significant range of wrist position for 10°/s of angular velocity was between 45° of flexion and 15° of extension in terms of grip force and it extended up to 60° of flexion for the other velocities.

As shown in Fig. 6, for the interaction of wrist position, force exertion direction, and angular velocity, most maximal forces were between 30° of

flexion and 15° of extension. Grip forces exerted in the condition of flexion direction were lower, between 60° of flexion and 30° of extension than in the extension direction, while this situation was reversed in extreme wrist positions.

3.2. Wrist torque

The results of ANOVA for wrist torque revealed that there were statistically significant differences for wrist position ($F(12, 288) = 17.30, p = 0.0001$), force exertion direction ($F(1, 24) = 92.37, p = 0.0001$), and angular velocity ($F(2, 48) = 6.45, p = 0.0033$) and interactions of wrist position and exertion direction ($F(25, 596) = 31.41, p = 0.0001$), of wrist position and angular velocity ($F(38, 895) = 10.09, p = 0.0001$) and of wrist

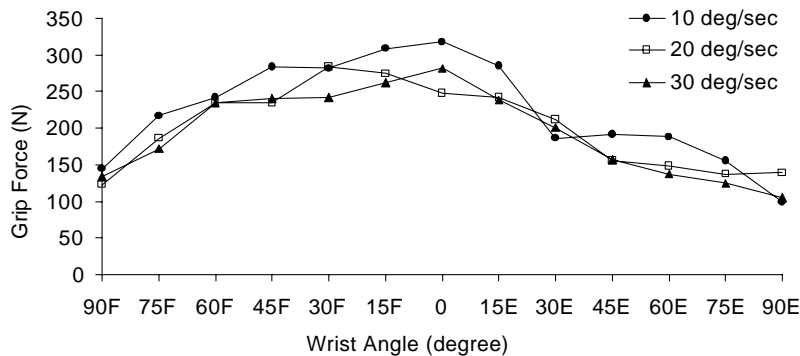


Fig. 5. Plot of grip force for each angular velocity by wrist position.

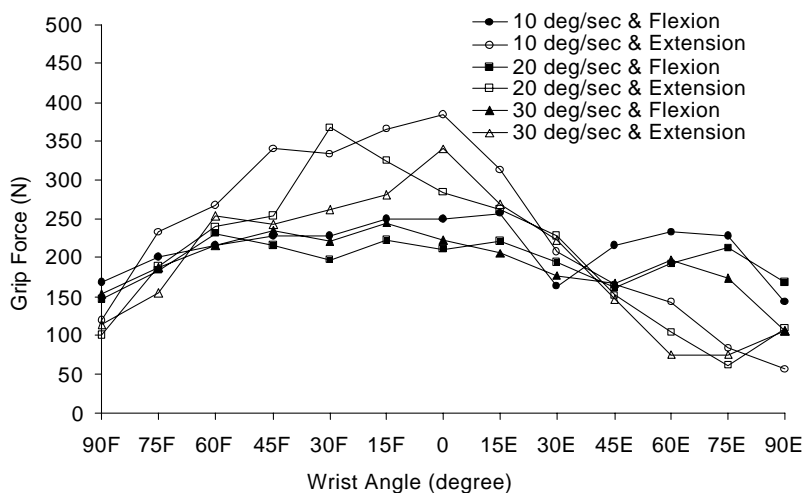


Fig. 6. Plot of grip force for each condition of angular velocity and exertion direction by wrist position.

position, exertion direction, and velocity ($F(77, 1657) = 20.08, p = 0.0001$).

The maximal wrist torque was 48.25 N at 45° of flexion and the significant range of wrist position was between 60° of flexion and 15° of extension as shown in Fig. 7. Unlike grip force, as shown in Fig. 8, wrist torque in the flexion direction (50.70 N) was much greater than in the extension direction (28.99 N) and both 10°/s (41.00 N) and 20°/s (41.33 N) velocities were grouped by post hoc tests.

Fig. 9 showed that wrist torque in the flexion direction was larger over all wrist positions than in

the extension direction. The maximal force was 63.59 N at 45° of flexion for the flexion direction and 45° of flexion, 15° of flexion, and neutral were grouped as a significant range. For the extension direction, maximal wrist torque was 37.13 N at neutral and 60° of flexion and 15° of flexion through 15° of extension were grouped by post hoc test.

Maximal wrist torque for both angular velocities of 10°/s (49.97 N) and 20°/s (50.14 N) were generated at neutral and ranges were similar between 45° of flexion and neutral except excluding 30° of flexion for 10°/s as shown in Fig. 10. In

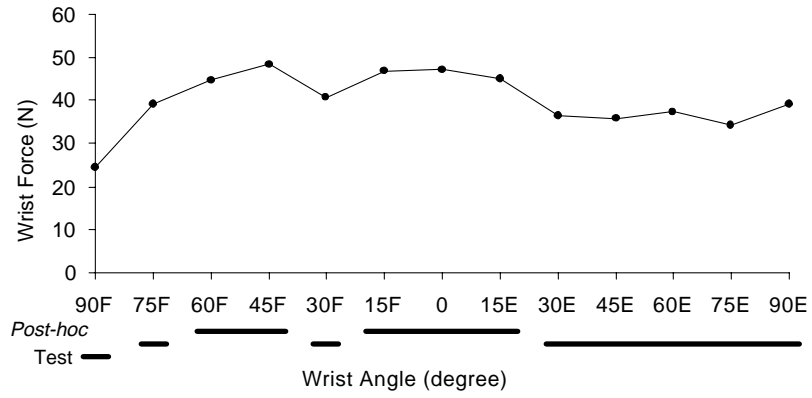


Fig. 7. Post hoc test for wrist torque by wrist position.

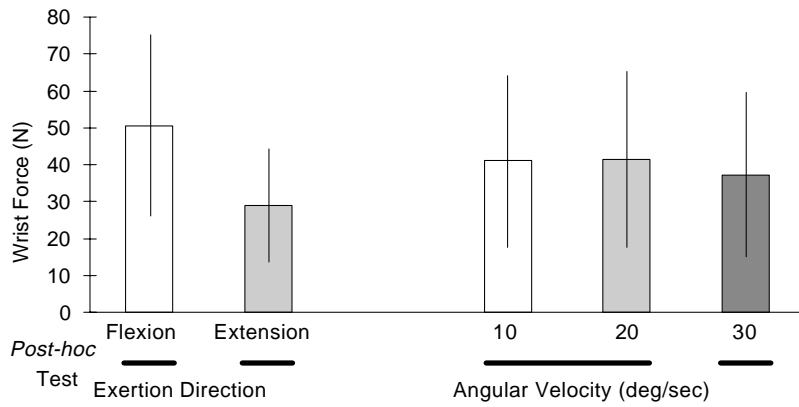


Fig. 8. Post hoc test for wrist torque by exertion direction and angular velocity.

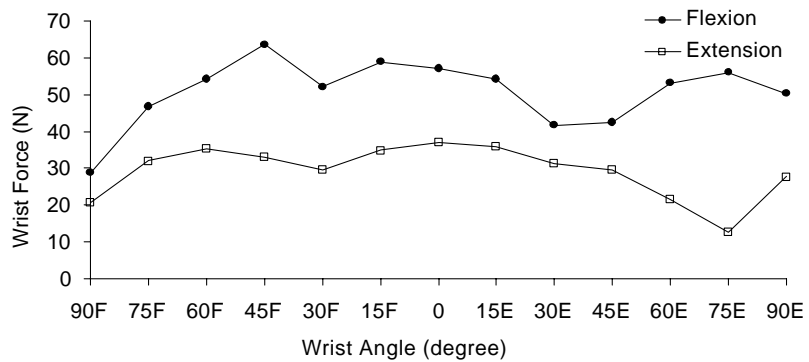


Fig. 9. Plot of flexion and extension wrist torque by wrist position.

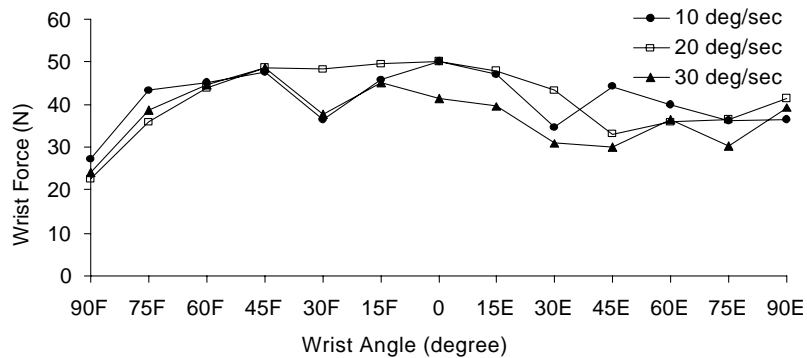


Fig. 10. Plot of wrist torque for each angular velocity by wrist position.

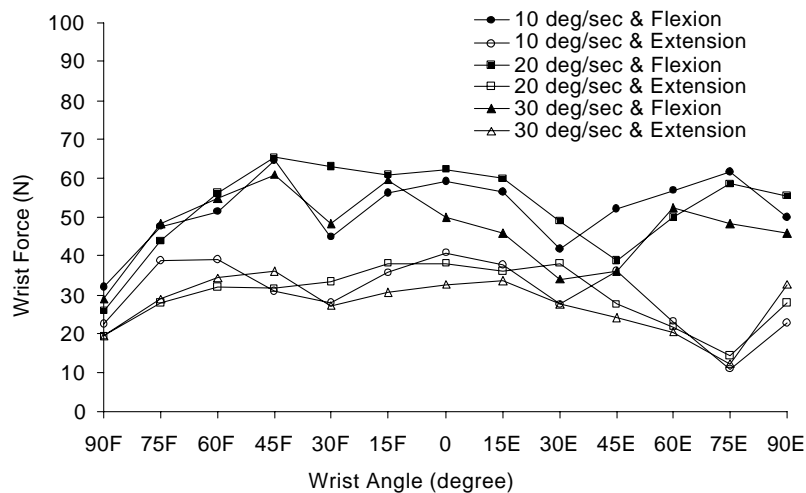


Fig. 11. Plot of wrist torque for each condition of angular velocity and exertion direction by wrist position.

the 30°/s velocity, maximal torque was 48.57 N at 45° of flexion and the significant range was 60° through 15° of flexion except 30° of flexion.

As shown in Fig. 11, wrist torque in the flexion direction for all velocities were much higher in almost all wrist positions. Locations where maximal torque occurred in the flexion direction tended to be inclined to the flexed wrist position, especially for 10°/s and 20°/s velocities.

4. Discussion

As expected, the ANOVA revealed that there were significant main effects of wrist position,

force exertion direction, and angular velocity on simultaneous grip force and wrist torque.

The curves of both grip and wrist forces over all wrist positions from 90° of flexion to 90° of extension were of inverted U shapes under the isokinetic condition as in the isometric condition. However, both forces increased again in extreme positions of the wrist, especially at more than 45° of extension. This effect can be explained by the relationship of muscle length and tension (Brand and Hollister, 1993). Out of the active range of motion of the wrist, active muscle force as well as passive force resulted from connective tissues surrounding the muscles which contributed to the entire hand forces. This situation was distinctly

observed in the exertion direction of flexion because both directions of flexor muscle force and passive force were same. In the direction of extension, however, active extensor muscle forces and passive connective tissue forces acted in opposite directions between 45° and 75° of extension so that the entire grip and wrist forces decreased. Since only passive force was working more than 75° of extension without extensor muscle force, additionally, total forces increased again. This wrist angle of 75° of extension corresponds to the result that active range of motion of the wrist extension found in some studies is around 70° (Brumfield et al., 1966; Norkin and Levangie, 1983).

Since cross-sectional area of wrist flexor muscles is larger than that of wrist extensor muscles, hand force in flexion direction can be expected to be greater than that in extension (Brand and Hollister, 1993). This study showed that mean wrist torque in extension direction is 57.2% of that in flexion and similar percentages were found in each angular velocity (Hallbeck, 1994; Wilhelm and Hallbeck, 1997). However, mean grip forces in both directions did not differ significantly. As shown in Figs. 3 and 5, grip forces were higher in the extension direction than in the flexion direction in the 60° flexed through 30° extended wrist positions, while it was the opposite in other wrist positions. This is a different result from the studies performed by Lehman et al. (1993) and Wilhelm and Hallbeck (1997).

The reason for this may be the different grip postures used in both directions. It was occasionally observed that subjects half pronated the hand in the extension direction to exert simultaneous grip and hand forces. Therefore, it should be necessary to inspect the subjects during the test.

In addition, one reason explained by Lehman et al. (1993) for a larger grip force decrement in flexion than extension was that finger and wrist extensor muscles were working in opposition to the finger flexor muscles in the extension direction. However, the characteristic of eccentric contraction of muscles may be considered in the isokinetic condition. As the velocity increases, the maximum force of muscles also increases in eccentric contractions (US Department of Health and

Human Services, 1992). Under the isokinetic condition, the force of eccentric contraction generated by large wrist flexors for a stabilization of the wrist may have a positive affect on the finger flexors in the extension direction, while high eccentric contraction force resulting from finger and wrist extensors may negatively act to the finger flexors in the flexion direction. Thus, further study of this phenomenon may be necessary.

The relationship of hand forces and angular velocity was reconfirmed by this study. Grip force and wrist torque reduced as the angular velocity of the wrist increased even in slower speeds. Based on post hoc test results of this study and Lehman et al. (1993), angular velocities may be classified into three groups, such as isometric, 5–20°/s, and over 25°/s, according to the decrement of hand forces.

Unlike isometric condition shown in Table 1, maximal grip forces were usually exerted between 30° of flexion and 15° of extension and maximal wrist torque was between 45° of flexion and neutral. Furthermore, significant, range of wrist positions included the position where the maximal forces generated were wider under the isokinetic condition even in slower speeds than that in the isometric condition. On average, this range for grip forces was from 45° of flexion to 15° of extension and widened a little at the velocities of 20°/s and 30°/s relative to 10°/s. The range for wrist torque was broader, from 60° of flexion to 15° of extension than that for grip forces. According to the results of force exertion direction, significant range of wrist positions for grip force was narrow in flexion but it was opposite for wrist torque.

When visually inspecting all figures in this study, it is easily recognized that all plotted curves for grip force and wrist torque are skewed a little to the flexed wrist positions. According to the method of measuring the angles of wrist flexion and extension suggested by Esch and Lepley (1974), they defined neutral or 0° as the parallel between the longitudinal axes of the ulna and the fifth metacarpal of the hand. Since 0° of the goniometer in this study was set as the parallel between the center of the handle the hand gripped and the longitudinal axis of the ulna, the wrist position defined as 15° of flexion in this study

Table 3

Modified significant ranges of wrist positions for grip force and wrist torque found in this study^a

Force	Condition	Level	Wrist position (°)
Grip	Overall		30F– 15E –30E
	Exertion direction	Flexion	60F– 0 –90E
		Extension	15F– 15E
	Velocity	10°/s	30F– 15E –30E
		20°/s	45F– 15F –30E
		30°/s	45F– 15E –30E
Wrist	Overall		45F– 30F –30E
	Exertion direction	Flexion	30F –30E
		Extension	45F– 15E –30E
	Velocity	10°/s	30F– 15E
		20°/s	30F– 15E
		30°/s	45F– 30F –0

^a Bold digits are designated as maximal forces and significant ranges of wrist positions.

could be approximately neutral as defined by Esch and Lepley (1974).

After considering this situation, all wrist positions where maximal grip forces and wrist torque occurred and significant ranges of wrist positions found in the study could be modified as shown in Table 3.

Most wrist positions for maximal grip force and wrist torque fell between 30° of flexion and 15° of extension and significant ranges were between 45° of flexion and 30° of extension. These inconsistent wrist positions for maximal hand forces and broader ranges of maximal force even in slow angular velocities may be due to the lack of stability of the wrist and the decrement of hand forces under the isokinetic condition. In other words, lower force in the isokinetic condition, which is much less than that in the isometric condition, could last longer in wide angle of wrist positions and maximal forces could occur around neutral while hand and forearm muscles are complicatedly interacting with each other, especially in the increased angular velocities.

In conclusion, the results of the study are similar to those of other researches for the effects of wrist position, force exertion direction, and angular velocities. The study also describes the pattern of the significant range of wrist position including simultaneous maximal grip and wrist forces in the isokinetic condition.

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