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Effect of Wrist Resistance Training on Motor Control and Strength in Young Males

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ABSTRACT

The aim of the present study was to investigate the effects of 6-week wrist resistance training on wrist torque control. Nineteen subjects were randomly assigned to either the wrist training group (n=9) or the control group (n=10). The training group performed wrist exercises for six directions (flexion, extension, pronation, supination, radial deviation, and ulnar deviation) while the control group did not. Testing for the isometric torque control error, one-repetition maximum (1-RM) strength, and isokinetic maximum torque (angular velocity of 60°/s wrist movements) were conducted before and after six weeks of resistance training and after every two-week interval of training. The wrist training group showed significant decreases in isometric torque control error in all six directions after the 2-week resistance training, while the control group did not show significant increase or decrease. The training group showed significant increases in the maximum strength in all six directions assessed by 1-RM strength and isokinetic strength tests after the 4-week resistance training, while the control group did not show any statistically significant changes. This study shows that motor control ability significantly improves within the first two weeks of resistance training, while the wrist strength significantly improves within the first four weeks of resistance training in wrist training group compared to the control.

Keywords : Wrist Resistance Training, Motor Control, Strength

I. Introduction

Wrist control and strength are critical factors in performing everyday and sporting activities.

In everyday activities such as turning door knobs/handles and pouring drinks, adequate wrist control and strength is necessary to successfully complete these activities. In sporting activities such as tennis, golf, or badminton, adequate wrist control and strength is necessary to skillfully perform these activities. Activities involving the wrist require specific combinations of movements - flexion, extension, pronation, supination, radial deviation, and ulnar deviation (O'Driscoll, Horii, Ness, Cahalan, Richards, & An, 1992).

Whether in sport activities or everyday activities, individuals should control wrist torque and efficiently generate a large magnitude of torque with three degrees-of-freedom (DoF) at the wrist (flexion-extension, ulnar-radial deviations, and pronation-supination) to maximize performance. Furthermore, relative to other joints (e.g. the knee joint), the wrist has significantly less muscle mass controlling the joint (Linscheid & Dobyns, 1985). Thus, strength training of the wrists cannot be over emphasized for people performing everyday activities and racquet sport athletes to optimally develop control, strength, and power of the wrist.

Wrist strength can help prevent individuals from experiencing wrist injuries or injury-related discomfort (Ellenbecker, Roetert, & Riewald, 2006), which is not surprising since wrist injuries often arise from weak muscle strength (Jaworski, Krause, & Brown, 2010) or lack of control/strength as the wrist moves through the range of motion. In recreational and sports activities, where the wrist is exposed to repetitive loads, wrist injuries account for an estimated 350 wrist injuries per 10,000 individuals per year (Angermann & Lohmann, 1995; Angermann & Lohmann, 1993; Chung & Spilson, 2001; Larsen, Mulder, Johansen, & Stam, 2004). There has also been documentation to show that the risk of injury increases for individuals performing heavy manual labor (Lindau, Aspenberg, Arner, Redlundh-Johnell, &

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Hagberg, 1999). In activities such as baseball bat swinging, golf club swinging, and tennis racquet swinging, the ulnar deviation with ball contact can result in ulno carpal impingements with partial tears of the triangular fibrocartilage (Linscheid & Dobyns, 1985).

We previously found increases in force and torque control of the fingers after strength training (Shim, Hsu, Karol, & Hurley, 2008). The generalizability of increased wrist control with strength training must also be examined.

Injuries to the joint arise from a sudden change in the applied load, such that the tissues of the hands and wrist experience a large disruption. Wrist control and strength is necessary to prevent this large disruption.

To our knowledge, not many studies in the scientific literature are published on wrist control and strength in response to resistance training. Therefore, the purpose of this study was to examine changes in wrist torque control and strength with six weeks of strength training. We hypothesize that with strength training, wrist isometric torque control error and isokinetic maximum strength torque value will increase.

II. Methods

1. Experimental Approach to the Problem

This study was designed to measure mainly two characteristics of wrist motor performance: isometric torque control and isokinetic maximum strength. Both groups, training and control <Table 1>, were evaluated during visits at weeks 0, 2, 4, and 6 where all three characteristics of wrist performance were measured. The training group received wrist resistance training per the protocol in <Table 2> below between evaluation visits while the control group received no training. Assessments for wrist strength and control of sub-maximal accurate torque in flexion, extension, pronation, supination, radial deviation, and ulnar deviation were performed on separate days over the course of 72 hours. This method has been utilized in order to maximize performance for all tests by enabling adequate recovery in between testing sessions. We asked subjects to refrain from any excessive physical activity during these three days of testing.

2. Subjects

Nineteen right-handed, young males with no previous history of serious upper extremity or hand injuries participated in this study as consenting subjects. The mean (±*SE*) age, height, body mass, hand length, and hand width of the subjects were 24.1 (±0.2) years, 174.8 (±1.4) cm, 68.7 (±1.3) kg, 17.3 (±0.2) cm, and 9.5 (±0.1) cm, respectively. Handedness was determined by the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were randomly assigned to either the wrist training or control groups <Table 1>. Nine subjects in the wrist training group and ten subjects in the control group completed the study. Physical characteristics of the subjects were not statistically different across the groups. Each subject was familiarized with the training protocol, testing procedures and equipment prior to wrist training and data collection. All subjects gave informed consent based on the procedures approved by the University's Internal Review Board (IRB).

Table 1. Physical characteristics of the subjects

	Training group (n=9)	Control group (n=10)	*p*-value
Age (years)	23.9±0.3	24.3±0.4	0.142
Height (cm)	176.2±2.3	173.6±1.6	0.183
Body mass (kg)	68.6±1.7	68.9±2.1	0.133
Hand length (cm)	17.7±0.4	16.9±0.2	0.266
Hand width (cm)	9.5±0.2	9.5±0.2	0.332

Values are mean ± *SE* (standard error)

Table 2. Wrist resistance training program

Period (s)	Exercise	Sets × Repetitions
1-2 weeks	Pronation	3 × 3-5
	Supination	3 × 3-5
	Flexion	3 × 3-5
	Extension	3 × 3-5
	Radial deviation	3 × 3-5
	Ulnar deviation	3 × 3-5
3-4 weeks	Pronation	3 × 6-8
	Supination	3 × 6-8
	Flexion	3 × 6-8
	Extension	3 × 6-8
	Radial deviation	3 × 6-8
	Ulnar deviation	3 × 6-8
5-6 weeks	Pronation	3 × 8-10
	Supination	3 × 8-10
	Flexion	3 × 8-10
	Extension	3 × 8-10
	Radial deviation	3 × 8-10
	Ulnar deviation	3 × 8-10

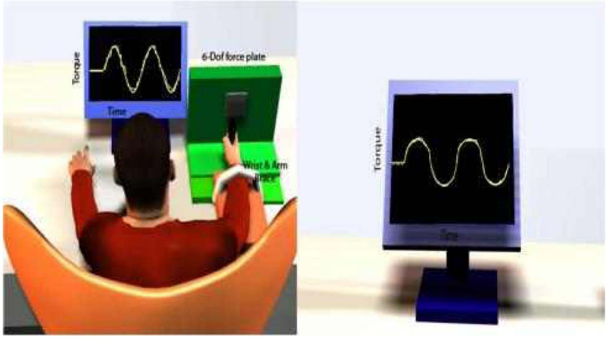
3. Procedures

1) Training

A wrist training device, made of aluminum alloy <Figure 1>, was constructed and used for all training experiments. The load of the wrist training device was adjusted to determine each subject's initial one-repetition maximum (1-RM) by

(a) (b) (c)

Figure 1. A wrist training device for (a) supination and (c) pronation resistance exercises from (b) the neutral position



(a) (b)

Figure 2. (a) Experimental setting for wrist supination torque measurements and (b) computer screen showing the torque template (white sinusoidal curve) and the actual torque produced by a subject (yellow curve).

adding or removing small weights (100 g). The 1-RM was used to determine the training load.

The training load of the device was adjusted such that the peak static torque was 70% of the 1-RM for each wrist exercise(Carroll, Barton, Hsu, & Lee, 2009). Subjects then performed six wrist exercises- flexion, extension, pronation, supination, radial deviation, and ulnar deviation with the wrist training device. To perform four of these exercises (flexion, extension, ulnar deviation and radial deviation), subjects were asked to stand with their shoulder and elbow fully extended and the wrist in neutral alignment. To perform pronation and supination, subjects were asked to be seated and place their forearm in a forearm brace so that the shoulder was flexed and abducted approximately 35° and the elbow was flexed with the forearm parallel with the floor. Each repetition lasted approximately four seconds-two seconds of the concentric phase and two of the eccentric phase. One repetition involved rotating the device through the full range of motion.

For the first two weeks of training, subjects performed three sets of 3-5 repetitions for each exercise. During the third and fourth week, subjects performed three sets of 6-8 repetitions for each exercise <Table 2>. During the fifth and sixth week, subjects performed three sets of 8-10 repetitions for each exercise. The training group had three training session for each week over 6 weeks with professional trainer. The control group did not receive training in between evaluation time points. For the duration of the six-week training program, subjects were instructed to maintain “normal” dietary habits.

2) Test of isometric torque control error as a measure o f wrist motor control

This assessment was performed before and after six weeks of resistance training and after each two-week interval of training. The subjects sat on a chair and placed their right upper arm into a wrist-forearm brace fixed to a table while watching a computer screen <Figure 2(a)>. First, the subject’s maximum voluntary force (MVF) was measured in flexion, extension, pronation, supination, radial deviation, and ulnar deviation. For the wrist torque control task, the computer screen showed a sinusoidal time profile of torque <Figure 2(b)> and the subjects were instructed to follow the templates with a cursor of torque being produced over a 12s period. Signals from the sensors were conditioned, amplified, and digitized at 100 Hz using a 16-bit A/D board (PCI 6034E, National Instruments Corp.) and a custom software program made in LabVIEW (LabVIEW 7.1, National Instruments Corp.). A desktop computer (Dimension 4700, Dell, Inc.) with a 19-in. monitor was used for data acquisition. After recording the torques, the data were processed and analyzed in MatLAB (MatLAB 7, MathWorks, Inc.). The torques data were digitally low-pass filtered with a second-order, zero-lag Butterworth filter at 25 Hz cutoff frequency. The maximum amplitudes of the torque profile was ±20% of the subject’s maximum isometric torque (MVF). The three positive-negative torques included flexion-extension, pronation-supination, and radial-ulnar deviations. Each subject performed 12 trials for each sinusoidal profile.

The absolute deviation of the torque produced by the subject from the torque template (root-mean-square error or RMSE) was calculated and averaged over the whole time series to estimate the accuracy of the task.

$$\mathrm{RMSE} = \left(\sum_{trial=1}^{12} \left[\int_{t=0}^{6} \left| F(t) - F_{target} \right| / \Delta t \right] / n \right) / MVE$$

F(t) is the time trajectory of torque produced by a subject, $F_{target}(t)$ is the target torque (i.e., sinusoidal torque profile), and Δt is 12 seconds with which the analysis was performed (Δt=12). The average absolute difference between the time trajectory of the produced torque and target torque was calculated across time and trials. The calculated errors were normalized by the maximum voluntary force (MVF).

For each torque production task, two directions of torque which share the same axis of rotation were combined in the task (i.e., flexion-extension, pronation-supination, and radial-ulnar deviations)

3) Test of peak isokinetic torque as a measure of wrist strength

The maximum isokinetic torque production task about the wrist joint was also performed on a Kin-Com dynamometer (Model 125E plus, Chattecx, TN). The subject sitting on a chair was stabilized by a seatbelt strap and a crossed shoulder harness. The right upper arm was placed into a wrist-forearm brace fixed to a table and the forearm was fastened by Velcro straps. The subjects secured their right hand on a grip handle attached to the Kin-Com load cell and rested in a neutral position. Isokinetic strength was tested on the dynamometer at the constant angular velocity of 60º/s. In each trial, the subjects performed maximum concentric torque and were given at least 5 minutes between trials in an attempt to minimize fatigue. Isokinetic peak torques during flexion, extension, pronation, supination, radial deviation, and ulnar deviation were quantified and considered as the maximum isokinetic strength.

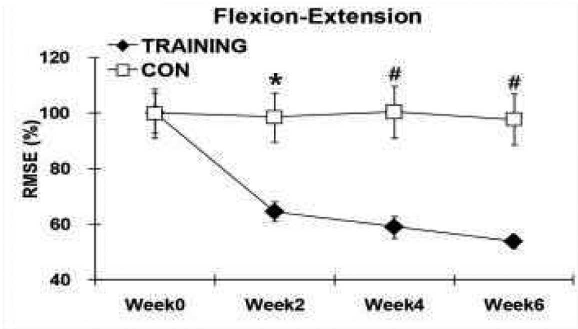
4. Statistical Analysis

For statistical analysis, both RMSE and peak torque values at different measurements were normalized by the cross-subject averages at the baseline (Week 0) (Keen, Yue, & Enoka, 1994; Shim et al., 2008). All values are expressed as means (±SE). Two-way repeated-measures (RM) ANOVAs were performed with the between-subject factor which will be referred to as GROUP (2 levels: wrist training group and control group) and the within-subject factor which will be referred to as SESSION (4 levels: week 0, week 2, week 4, and week 6). The critical value for significant difference was set at $p<0.05$.

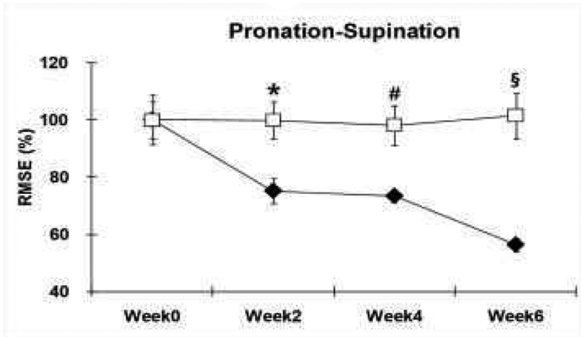
III. Results

1. RMSE

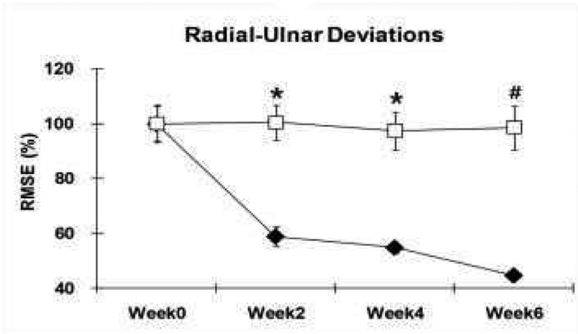
RMSE values decreased with the resistance training in the wrist training group, while the values did not show significant increase or decrease in the control group <Figure 3(a)-(c)>. The statistically significant difference between the training and control group was found after two weeks of training and the difference became greater as the training period was extended. This result was supported by the two-way RM ANOVAs with the between-subject factor, GROUP (2 levels), and the within-subject factor, SESSION (4 levels), which showed significant GROUP effects for flexion-extension ($F_{[1,17]}$=14.1, $p<.01$), pronation-supination ($F_{[1,17]}$=13.6, $p<.01$), and radial-ulnar deviation ($F_{[1,17]}$=6.6, $p<.05$), SESSION effects for flexion-extension ($F_{[3,51]}$=25.9, $p<.001$), pronation- supination ($F_{[3,51]}$=9.8, $p<.001$), and radial-ulnar deviation ($F_{[3,51]}$=26.0, $p<.001$), and significant GROUP×SESSION interactions for flexion- extension ($F_{[3,51]}$=23.3, $p<.001$), pronation-supination ($F_{[3,51]}$= 10.6, $p<.001$), and radial-ulnar deviation task ($F_{[3,51]}$= 23.1, $p<.001$).



(a)



(b)



(c)

Figure 3. Isometric torque control error assessed by RMSE values of wrist training group and control group for (a) flexion-extension, (b) pronation-supination, and (c) radial-ulnar deviations. Week 0 represents the initial week before the training. Weeks 2, 4, and 6 represent the times of measurement after 2, 4 and 6 weeks of wrist training, respectively. All values were normalized by each group's average RMSE values measured at Week 0. The following represent statistically significant GROUP effect: *:p<.05;#:p<.01;§:p<.001.

2. Peak isokinetic torque as a measure of wrist strength

The isokinetic maximum strength, assessed by the normalized peak torque of all six-directional torques (i.e., flexion, extension, pronation, supination, radial deviation, and ulnar deviation) during 60°/s isokinetic wrist movements, increased with the resistance training in the training group <Figure 4(a)-(f)>, while the control group did not show any statistically significant changes. The statistically significant difference between the training and control group was found after four weeks of training and the difference became generally greater as the training period was extended. This result was supported by the two-way RM ANOVA's with the between-subject factor, GROUP (2 levels), and the within-subject factor, SESSION (4 levels), which showed significant GROUP effects for flexion ($F_{[1,17]}$=4.8, p<.05), extension ($F_{[1,17]}$=4.7, p<.05), pronation ($F_{[1,17]}$=10.6, p<.01), supination ($F_{[1,17]}$=6.1, p<.05), radial deviation ($F_{[1,17]}$=6.9, p<.05), and ulnar deviation ($F_{[1,17]}$=6.9, p<.05), SESSION effects for flexion ($F_{[3,51]}$=5.9, p<.01), extension ($F_{[3,51]}$=3.7, p<.05), pronation ($F_{[3,51]}$=7.7, p<.001), supination ($F_{[3,51]}$=5.4, p<.01), radial deviation ($F_{[3,51]}$=6.4, p<.01), and ulnar deviation ($F_{[3,51]}$=6.4, p<.01),

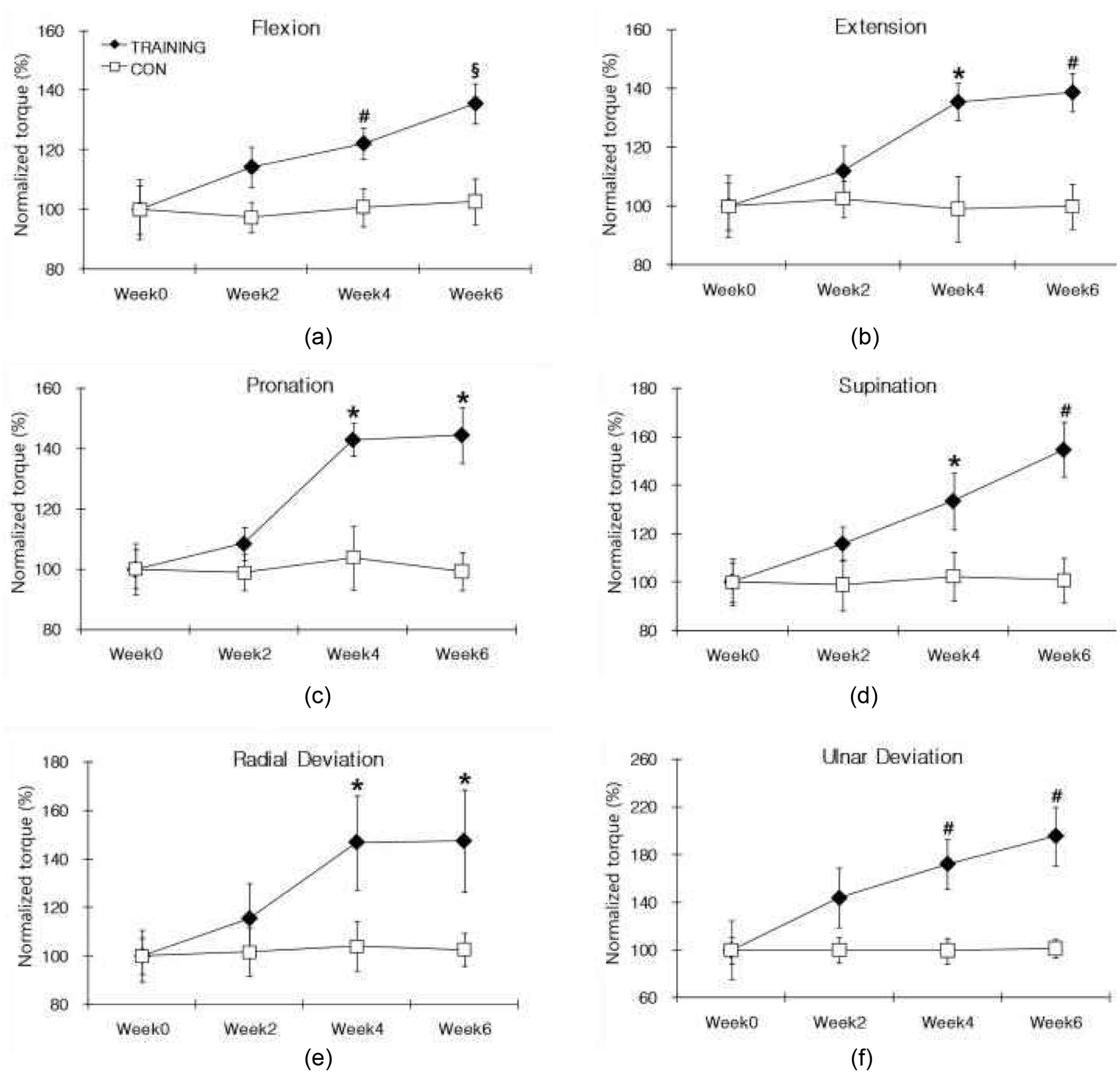


Figure 4. Isokinetic maximum strength torque values of wrist training group and control group for (a) flexion, (b) extension, (c) pronation, (d) supination, (e) radial deviation, and (f) ulnar deviation. Week 0 represents the initial week before the training and Weeks 2, 4, and 6 represent the times of measurement at 2 and 4 weeks during the 6-week training and right after the training. All values were normalized by each group's average isokinetic maximum torque values measured at Week 0. The following represent statistically significant GROUP effect: *:p<.05;#:p<.01;§:p<.001.

and significant GROUP×SESSION interactions for flexion ($F_{[3,51]}$=4.1, p<.05), extension ($F_{[3,51]}$=4.3, p<.01), pronation ($F_{[3,51]}$=6.3, p<.01), supination ($F_{[3,51]}$=4.8, p<.01), radial deviation ($F_{[3,51]}$=6.2, p<.01), and ulnar deviation ($F_{[3,51]}$=6.2, p<.01).

IV. Discussion

This study was conducted to determine whether a wrist resistance training program, consisting of progressive repetition of all degrees of motion of the wrist (flexion, extension, pronation, supination, radial deviation, and ulnar deviation) over six weeks, would significantly improve the isometric torque control and isokinetic maximum strength torque.

We hypothesized that with wrist resistance training, both wrist control and strength would increase. The results support our hypothesis. The training group showed a significant decrease in isometric torque control error at each 2-week interval (Weeks 2, 4, and 6) in all coupled measurements, with the most significant improvement at the 6-week time point compared to the control group. These data also indicate that the wrist motor control capabilities as quantified in this study significantly increased starting in the first two weeks of training and continuing to improve throughout the entire 6-week resistance training program. Specifically, the flexion-extension and radial-ulnar deviation measurements revealed the most improvement at Week 2 compared to the pronation-supination measurements.

However, the pronation-supination measurement for the Week 6 evaluation had the highest significance of improvement in the training group compared to the other directions. These findings demonstrate that resistance training may provide beneficial effects on wrist torque control, especially in the pronation-supination directions which are common in day-to-day activities as well as in racket sports.

Conversely, the training group did not show significant improvement in their isokinetic maximum strength after the first two weeks of resistance training in any of the six directions. Instead, significant improvement in maximum strength was noted at the Week 4 and Week 6 evaluation time points for the training group.

For each test and evaluation time point, the control group showed neither substantial increases nor decreases in isometric torque control and isokinetic maximum strength. We have concluded from this study that with resistance training, wrist motor control ability significantly improves within 2 weeks and wrist strength significantly improves within 4 weeks, compared to the control group.

These findings are consistent with Szymanski, Szymanski, Molloy, & Pascoe (2004) where the authors showed that wrist strength in the dominant hand of high-school baseball players improved in all six directions with wrist and forearm training. Although interim time point data were not provided for comparison to our study, their study concluded that a 12-week training program is effective for a healthy, non-injured athlete. Furthermore, the authors reported that the ten-repetition maximum (10-RM) for ulnar deviation in the wrist training group had the highest percentage increase in strength for the dominant hand compared to all other directions. Other studies have shown significant improvements in isometric force of an intrinsic hand muscle after a 12-week training program in the elderly (Keen et al., 1994) and increases in 1-RM of the wrist after a 4-week strength training program in healthy subjects (Carroll, Barton, Hsu, & Lee, 2009). In addition, our results are consistent with previous studies of the finger joint that show strength improvements within 2 weeks (Shim et al., 2008) and increases in finger-pinch force control in 6 weeks (Keogh, Morrison, & Barrett, 2007).

Carroll, Riek, & Carson (2001) indicates that “resistance training induces adaptations that can influence the manner in which trained muscles are recruited by the CNS during related functional tasks. Adaptations at a number of sites in the neuromuscular system are likely to contribute to changes in movement execution and control.” Barry & Carson (2004) further describe how neural adaptations are primary means by which power and strength are enhanced. Although this study did not directly capture neuromuscular adaptations of wrist resistance training, our findings demonstrate that neural adaptations likely occurred with wrist resistance training given the rapid improvement in motor control within the first two weeks.

The progressed improvements in the wrist control and strength throughout the 6 weeks of training is encouraging for both athletes and non-athletes, and it is suggested that future studies are performed with longer training periods in order to investigate the optimal training period for peak performance. The lab tests performed in this study to evaluate wrist control and strength have limitations, as the former was an isometric test and latter was an unrealistic isokinetic test. Therefore, it is also suggested that the future studies evaluate more realistic motor actions such as racket sports.

V. Conclusions and Suggestions

The wrist training group showed significant decreases in isometric torque control error in all six directions after the 2-week resistance training, while the control group did not show significant increase or decrease. The training group showed significant increases in the maximum strength in all six directions assessed by 1-RM strength and isokinetic strength tests after the 4-week resistance training, while the control group did not show any statistically significant changes.

There were several limitations to this study. The study was limited to right-handed subjects only and, therefore, did not account for any differences in results for left-handed subjects. This study also did not capture the effect of wrist resistance training on the subjects' non-dominant hand which as Szymanski, et al (2004) will yield different results compared to dominant hand training. Furthermore, since this study enrolled younger adult males only, we do not have data on adult female subjects or an older adult population which Barry & Carson (2004) describes need specialized resistance training strategies to maximize the benefits. Our study was limited to the wrist and did not take into consideration any training to the elbow or shoulder joints which are also involved when evaluating the total effect to the body of rehabilitation and athletic training programs. Lastly, a longer-term study would be beneficial to determine how effective the wrist training protocol is for improving wrist control and strength.

We also wanted to assess whether this training protocol, using the wrist training device, would improve wrist strength and control in a relatively young, healthy patient population in order to get a baseline determination on whether this protocol would be beneficial for either rehabilitation of patients recovering from wrist injury or training of athletes seeking to improve wrist performance in future studies. "Research that seeks to identify these principles has the potential to enhance our basic understanding of the neural basis of movement control and learning, as well as provide important information to assist the design of resistance training programmes in practical settings such as rehabilitation and athletic training (Carroll et al., 2001)."

Future studies are needed to determine if this 6-week wrist resistance training program will effectively enhance the wrist strength/control for racquet sport athletes and patients recovering from wrist injuries.

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