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Forearm muscle strength training and muscle activation during isometric, concentric and eccentric contractions by plyometric exercise

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Abstract
This study investigated effects of plyometric training (6 weeks, 3 sessions/week) on maximum voluntary contraction (MVC) strength and neural activation of the wrist Extensors during isometric, concentric and eccentric contractions. Thirty participants were randomly assigned to the Trained or untrained group for this study. Maximum voluntary torques (MVT) during the different types of contraction were measured at 110° wrist flexion (180°=full extension). The interpolated twitch technique was applied at the same wrist joint angle during isometric, concentric and eccentric contractions to measure voluntary activation. In addition, normalized root mean square of the EMG signal at MVT was calculated. The shot put throwing distance was measured after the training. After training, MVT increased by 15 N-m 26 N-m, and 26N-m ($P \leq 0.015$) for isometric, concentric and eccentric MVCs compared to controls, respectively. The strength enhancements were associated with increases in voluntary activation during isometric, concentric and eccentric MVCs by 8.4%, 7.6% and 10.2% ($P \leq 0.031$) respectively. Given the fact that the training exercises consisted of eccentric muscle actions followed by concentric contractions, it is in particular relevant that the plyometric training increased MVC strength and neural activation of the forearm muscle regardless of the contraction mode.

Keywords: Plyometric training, maximum voluntary torque, electromyography, interpolated twitch technique

1. Introduction

The result of many studies has proved that plyometric training, boost the isometric maximum voluntary contraction (MVC) strength [1, 2]. However, only few studies concentrated neuromuscular adaptions [3, 4]. MVC strength of FCU in plyometric training was improved activation of agonistic muscles and muscular adaptions which showed by the many study results [5].Concerning to the result of plyometric training on isometric MVC strength of Wrist extensors, studies showed mismatched results. While some studies observed an increase in MVC strength after 8 weeks of training another experiment failed to show strength enhancements following a 15-week training period. The strength attainment of the wrist extensors in the first studies mentioned were due to neural and muscular adaptations, i.e. an improved voluntary activation of the forearms [6], assessed with the interpolated twitch technique as well as an increased single-fiber cross-sectional area and contractile function of chemically skinned single muscle fibers.

Past research in measuring the ability to voluntarily activate a muscle after a period of plyometric training using the interpolated twitch technique has been performed under Isometric testing conditions [7, 8]. Therefore, hardly anything is known about changes in MVC Strength and voluntary activation of the forearms during concentric and eccentric Contractions after a plyometric training regimen. Because plyometric exercises has of eccentric contractions followed by concentric muscle actions (stretch-shortening cycle) [9], it is of interest whether or not this kind of training influences MVC strength and voluntary activation more during dynamic contractions than during isometric contractions.

Therefore, we investigated the effects of 6-week plyometric training on neuromuscular function of the forearms during isometric, concentric and eccentric MVCs. In particular, the neural drive to the wrist extensors during static and dynamic MVCs was measured by using the interpolated twitch technique and the root mean square of the EMG signal normalized to the maximal M-wave (Mmax). Putative training-related changes at the muscle level were assessed by analyzing the twitch torque signal induced by transcutaneous electrical stimulation of the radial nerve. Furthermore ball throwing speed was measured.

We hypothesized that there would be a training-related increase in forearm MVC strength during isometric, concentric and eccentric contractions and an association between these changes and muscle activation. In view of the length of the training period, it was thought that contractile function of the wrist extensors would not change. Furthermore, we expected training-related effects on the ball throwing speed.

2. Material and Methods

2.1 Subjects demography

Effect size for MVC strength of past published papers, gives the suggestion of significance level of 0.05 and sample size of .80 indicate that total of 30(20 Males, 10 Females) volunteers are required in this study. The Subjects were no history upper limb injury and no more musculoskeletal disorder and none of them had ever performed a systematic plyometric training program before.

The participants were randomly assigned to an intervention group (Males-10 Females-6) and a control group (Males-10, Females-4) using randomization by a computer-generated table of random numbers.

Table 1: Mean and SD of Subjects demography

Group	Interventional		Control	
Variables	Male(n=10)	Female(n=6)	Male(n=10)	Female(n=4)
Age	24±3.2	24±1.2	26±1.2	26±2.4
Height(m)	1.80± 4.3	1.70± 6.2	1.80± 4.3	1.70± 6.2
Weight (kg)	75± 2.4	73.2±2.2	75± 2.4	73.2±2.2

All study participants were recreational active (moderate exercise 3 times per week, activities included forward throw, wall chest pass, strength training of the upper extremities and different sport games) and none of them had ever performed a systematic plyometric training program before. The participants were asked to avoid caffeine and alcohol consumption in the 24 h and strenuous exercise in the 48 h prior to the measurements. The study was approved by the Institution ethics committee. All participants gave written informed consent prior to enrollment.

2.2 Training method

The intervention group trained 3 times a week for 6 weeks. The plyometric training consisted of overhead forward throw, wall chest pass, Depth push-Ups and plyometric pull-upsetc. During the first week, participants had to perform 3 sets of different exercises with 10 repetitions per set. In the following 3 weeks participants performed 12 repetitions per set. After 4 weeks of training, participants had to perform 5 sets with 15 repetitions per set. The rest interval between the excise was 10 s so that the participants could concentrate on every single jump and the rest interval between sets was 3 min. The participants were instructed to perform the excise with maximal effort in order to achieve explosive force production and maximal throwing performance. In every training session, the individual throwing distance was measured during 1 set of the different exercises. The results were immediately transmitted to the participants. The control group was asked to maintain their individual level of physical activities.

Neuromuscular function of the wrist extensors of the right hand and ball throwing speed was assessed prior to and after the 6-week plyometric training. Throughout the testing sessions, participants were comfortably seated in a standardized position on a HUMACNORM dynamometer. Neuromuscular tests consisted of supramaximal electrical stimulations of the radial nerve at rest and during isometric, concentric and eccentric MVCs. The contraction sequences were randomized. In addition, throwing length was estimated on a separate day. All participants underwent a standardized warm-up on a cycle ergometer for 5 min prior to the throwing tests.

Transcutaneous electrical stimulation of the radial nerve in the forearm was used to assess neuromuscular function of the forearm as described previously. Briefly, the radial nerve was stimulated using a cathode ball electrode. The anode was a self-adhesive electrode fixed over the forearm. The electrical stimuli were single and paired rectangular pulses (1 ms duration and 1 ms duration, 10 ms apart, 400V, respectively). The inter stimulus intervals (ISI) were provided by MATLAB 2014a program. The testing procedure included electrical stimulation (ISI was randomized between 6 and 7s) with increasing current intensity until identification of Mmaxof the Flexor carpi ulnaris, (FCU) muscle. Mmax responses were elicited with supramaximal stimulation intensity. Resting twitch torques was evoked prior to the MVCs using supramaximal single and doublet stimuli.

2.3 EMG and Torque signal Collection and processing

Surface EMG electrodes were used to record muscle activity of muscles of the right hand as described previously. The raw EMG signal is stored in Biopac MP36 Bio amplifier at the sampling rate of 10Khz and are preprocessed using a band pass filter (10-500Hz) and a notch filter of 50Hz issued to remove motion artifacts, high frequency noise and power line interference. Further preprocessing and interpretation is carried out using in MATLAB2014a, with system of I3 processor core 3.4GHz, 4GB RAM, Windows10, 64 bit operating system. Both, the EMG and torque signals were sampled at 3 kHz and stored on a hard drive for later analysis with a custom built based program.

Torque signals were measured using a HUMAC NORM dynamometer. The participants were seated with a wrist joint angle of 80°. The measurements during the isometric condition were performed at 110° wrist flexion. In the concentric and eccentric MVC trials, testing was performed between 90° and 175° wrist flexion at a velocity of 25°/s, while the electrical stimuli were delivered at 110°. The participants ‘wrist joints were aligned with the axis of the dynamometer.

During isometric, concentric and eccentric MVC strength testing, participants were instructed to exert maximal voluntary wrist extensions against the lever arm of the dynamometer. Participants were thoroughly instructed to act as forcefully and as fast as possible. They were motivated by strong verbal encouragement and online visual feedback about the instantaneous dynamometer torque provided on a digital oscilloscope. A rest period of at least 1 min was allowed between the trials. Before each isometric, concentric and eccentric MVC, participants performed MVC familiarization trials. The participants performed three to five MVCs for each contraction mode (isometric, concentric and eccentric). The maximal attempts were recorded until the coefficient of variance of the best three trials was below 5%.

For familiarization purposes, participants performed up to four throws. When the coefficient of variance of three subsequent throw was below 5%, was considered. The participants were instructed to perform the throw with maximal effort to achieve explosive force production and maximal throw lengths. Care was taken that the participants did not bend their elbow and wrist joints actively before landing in order to avoid artificial prolongation of flight time. A rest period of at least1 min was allowed between the throws. The three lengthiest throw were taken for further analysis.

Torque signals were corrected for the effect of gravity. Resting twitch torques was analyzed regarding their peak torque, i.e. the highest value of twitch torque signal. Mmax amplitudes were measured peak-to-peak and averaged. The three best isometric, concentric and eccentric MVCs, respectively, were retained for analysis. On the basis of the torque-time curves of the MVC trials, maximum voluntary torque (MVT) was determined, i. e. the highest torque value for the isometric contraction and the torque values immediately before the application of the electrical stimuli for the concentric and eccentric contractions. Muscle activation during MVC was analyzed by calculating the root mean square of the amplitude of the EMG signal (RMS-EMG) over a time interval of 512ms at MVT, i. e. 512ms around the MVT for the isometric contraction and 512ms prior to the electrical stimuli for dynamic contractions. Muscle activity of FCR, FCU, ECRL and ECU was normalized to the corresponding Mmax values (RMS-EMG/Mmax). Furthermore, RMS-EMG/Mmax was averaged across FCU, FCR, ECRL and ECU to calculate forearm activation at MVT (Q RMS-EMGMVT/Mmax).The calculation of voluntary activation for the isometric contraction was done with the formula:

$$\text{Percentage of Voluntary activation} = 1 - \frac{\text{Superimposed Switch}}{\text{Control Twich}} \times 100$$

Thirty participants volunteered to participate. Unfortunately, two participants dropped out due to illness unrelated to the study. Thus, data from 28 participants are presented. Data were checked and the statistical approach comprised the analysis of covariance (ANOVA) with baseline measurement and gender entered as covariates. This approach provides an estimate for the difference between groups which is the variable of interest in randomized controlled trials.

In addition, it has been proposed that TWO WAY-ANOVA with baseline adjustment remains the optimum statistical method forthe analysis of continuous outcomes in randomized controlled trials. The level of significance was established at $P \leq 0.05$.and was used for statistical analysis. Data obtained at baseline are presented as mean values ± standard deviation and those obtained after 6 weeks of training are given as baseline-adjusted means ± baseline-adjusted standard deviation. If appropriate, data are presented as difference between means (95% confidence interval). Sample size and effect size (f) were calculated with the statistical software package in the twoways ANOVA.

3. Results

Table 1: Shows the findings of the neuromuscularand strength tests at before training which includes Peak switch torque, Evoked potentials, Maximum volumetric torque, Voluntary Activation and RMS-EMG$_{MVT}$/Mmax ratio of Isometric, Concentric and Eccentric contraction.

Before training		
Parameter	**Trained Group**	**Untrained Group**
Peak Switch Torque (N-m)		
Supramaximal Single	17.2± 6.4	15.8±5.2
Supramaximal doublet	42.6± 5.3	38.4±6.8
Evoked Potentials (mV)		
Mmax in FCU	8.24± 3.44	8.91±6.23
Mmax in FCR	7.82± 5.26	6.74±3.78
Mmax in ECRL	10.46± 6.24	9.58±8.21
Mmax in ECU	9.25± 3.58	9.41±4.47
Maximum volumetric Torque (N-m)		
Isometric	156± 43	149±34
Concentric	108±38	102±16
Eccentric	172± 56	159±48
Voluntary Activation in %		
Isometric	84.1± 3.4	80.4±2.2
Concentric	65.8± 5.4	64.8±8.3
Eccentric	76.2± 4.8	72.6±5.2
RMS-EMG$_{MVT}$/M$_{MAX}$ ISO		
Flexor carpi ulnaris	0.064± 0.043	0.072±0.026
Flexor carpi radialis	0.063± 0.015	0.057±0.039
Extensor carpi radialis longus	0.071± 0.030	0.065±0.028
Extensor carpi ulnaris	0.085± 0.018	0.078±0.012
RMS-EMG$_{MVT}$/M$_{MAX}$ CON		
Flexor carpi ulnaris	0.114± 0.035	0.097±0.046
Flexor carpi radialis	0.195± 0.021	0.126±0.051
Extensor carpi radialis longus	0.052± 0.032	0.047±0.027
Extensor carpi ulnaris	0.058± 0.041	0.052±0.032
RMS-EMG$_{MVT}$/M$_{MAX}$ ECN		
Flexor carpi ulnaris	0.039± 0.013	0.047±0.021
Flexor carpi radialis	0.046± 0.026	0.051±0.016
Extensor carpi radialis longus	0.090± 0.035	0.081±0.024
Extensor carpi ulnaris	0.094± 0.048	0.086±0.032
Throwing Distance(feet)	55	0.008

Table 2: Shows After 6 weeks training, isometric, concentric and eccentric MVTs were significantly increased

Phase	Increase in Torque (N-m)	P-Value	Sample Size
Isometric	15	0.015	0.461
Concentric	22	0.018	0.581
Eccentric	26	0.013	0.650

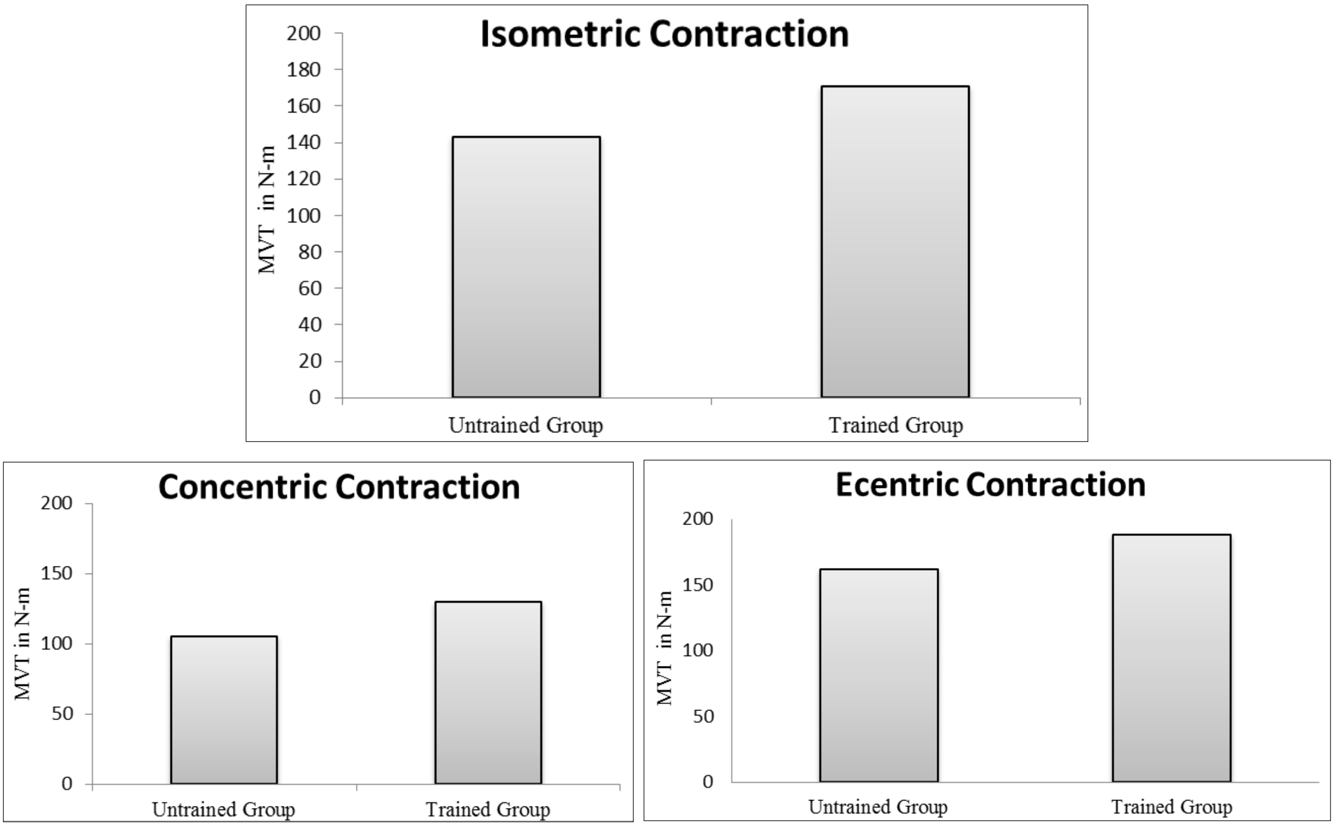
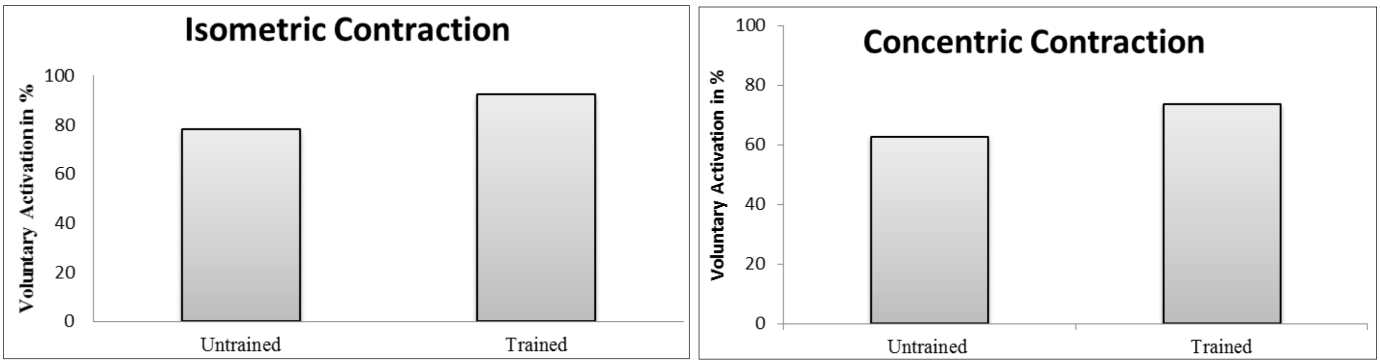


Fig 1: Increase of MVT after 6 – week training compared with untrained group (P≤0.015)

Table 3: Shows the increase of voluntary activation in Isometric, Concentric and Eccentric contraction

Phase	Increase in Voluntary Activation (%)	P-Value	Sample Size
Isometric	8.4	0.081	0.632
Concentric	7.6	0.165	0.225
Eccentric	10.2	0.058	0.750



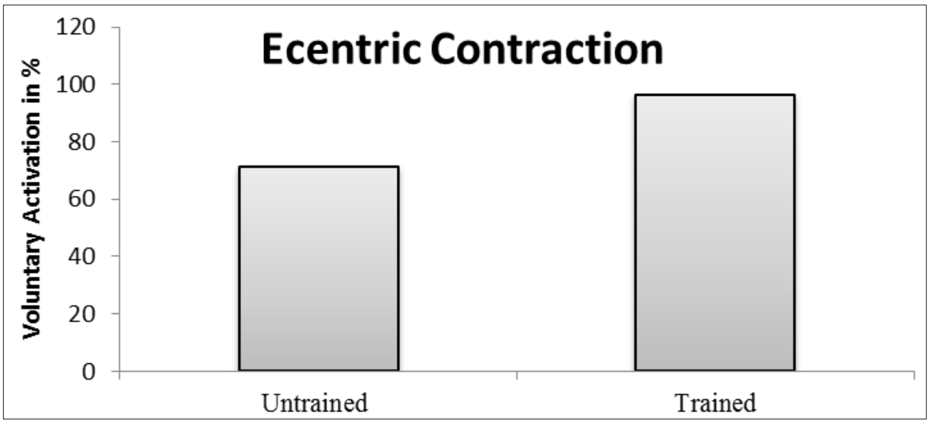


Fig 2: Increase of Voluntary activation compared with untrained group (P≤0.108)

Table 4: Shows the increase of QRMS-EMGMVT/Mmax ratio of FCU in Isometric, concentric and Eccentric contraction of FCU

Phase	QRMS- EMGMVT/Mmax	P-Value	Sample Size
Isometric	0.064	0.004	0.632
Concentric	0.118	0.015	0.756
Eccentric	0.039	0.010	0.825

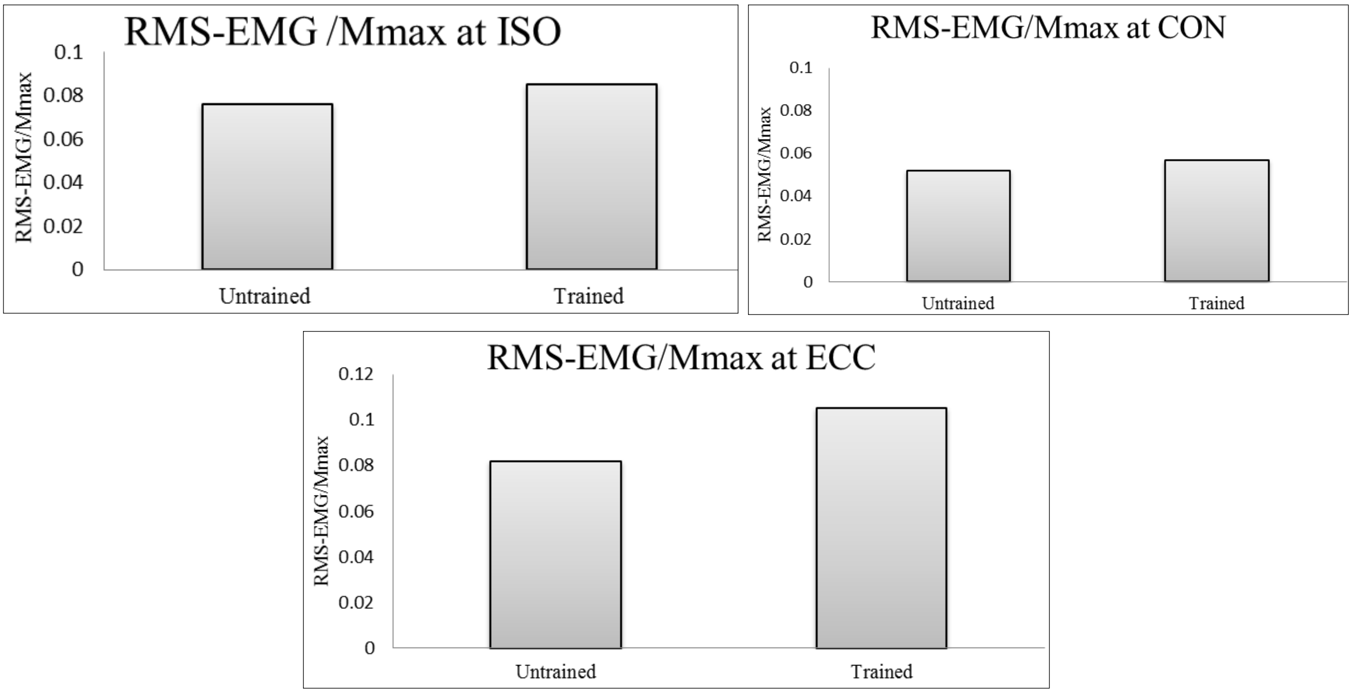


Fig 3: RMS-EMG/Mmax Ratio of FCU muscle (P≤0.01)

Table 5: After 6-week training the change of MVT, Voluntary activation and RMS-EMGMVT/Mmax ratio in Isometric, Concentric and Eccentric Contraction

After training			
Parameter	**Trained Group**	**Untrained Group**	**P-Value**
Peak Switch Torque (N-m)			
Supramaximal Single	16.1± 5.2	14.3±3.2	0.621
Supramaximal doublet	55.2± 4.3	51.4±2.4	0.712
Evoked Potentials (mV)			
Mmax in FCU	10.54± 2.64	9.11±6.53	0.426
Mmax in FCR	7.95± 4.36	6.92±2.62	0.735
Mmax in ECRL	10.82± 8.44	9.39±4.21	0.652
Mmax in ECU	9.82± 4.42	9.68±4.52	0.529
Maximum volumetric Torque (N-m)			
Isometric	171± 43	143±23	0.026
Concentric	130±28	105±48	0.193
Eccentric	188± 42	162±43	0.015
Voluntary Activation (%)			
Isometric	92.5± 3.2	78.4±3.2	0.029
Concentric	73.6± 5.4	62.6±6.7	0.005

Eccentric	96.4± 6.2	71.4±8.3	0.021
RMS-EMGMVT/MMAX ISO			
Flexor carpi ulnaris	0.064± 0.043	0.078±0.023	0.183
Flexor carpi radialis	0.063± 0.015	0.054±0.028	0.178
Extensor carpi radialis longus	0.071± 0.030	0.064±0.028	0.251
Extensor carpi ulnaris	0.085± 0.018	0.076±0.014	0.193
RMS-EMGMVT/MMAX CON			
Flexor carpi ulnaris	0.118± 0.035	0.097±0.046	0.161
Flexor carpi radialis	0.121± 0.026	0.126±0.051	0.307
Extensor carpi radialis longus	0.048± 0.032	0.047±0.027	0.159
Extensor carpi ulnaris	0.057± 0.045	0.052±0.032	0.182
RMS-EMGMVT/MMAX ECN			
Flexor carpi ulnaris	0.039± 0.016	0.048±0.045	0.306
Flexor carpi radialis	0.087± 0.028	0.088±0.028	0.241
Extensor carpi radialis longus	0.140± 0.028	0.081±0.049	0.278
Extensor carpi ulnaris	0.105± 0.056	0.082±0.042	0.261
Throwing Distance (feet)	65		0.005

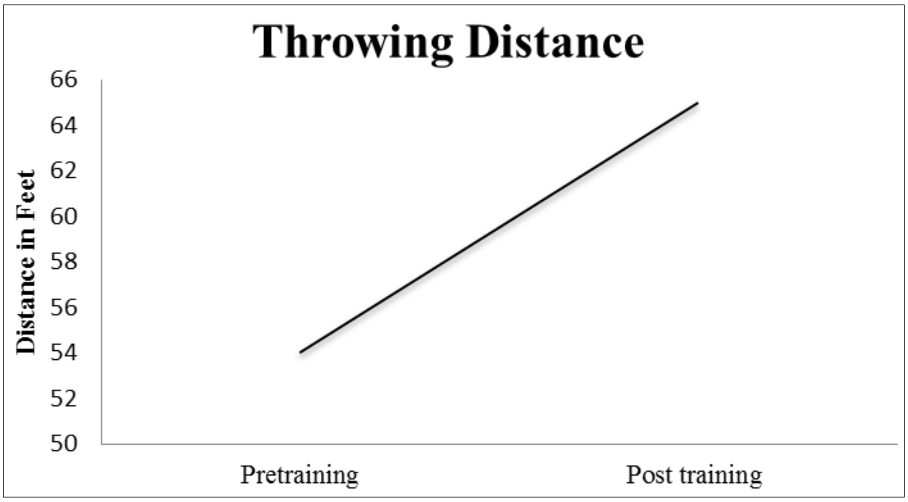


Fig 4: The increase of throwing distance in shot put training (P≤0.005)

4. Discussion

The present study analyzed the neuromuscular function of the wrist extensors following a 6-week period of plyometric training. Data indicate that the training regimen increased isometric, concentric and eccentric MVC strength due to an increased neural drive to the forearm (each *f* > 0.45). The contractile function of the wrist extensors, assessed by radial nerve stimulation at rest remained unchanged. In addition, throwing distance was increased after the intervention.

To the best of our knowledge, this is the first study analyzing the effects of plyometric training on MVC strength and voluntary activation during isometric, concentric and eccentric contractions in forearms. Isometric MVC strength was significantly enhanced following the training (group difference 12%). This is in accordance with the results of previously published studies that reported increased isometric MVC strength after plyometric training [10, 11]. Concentric and eccentric MVC strength was increased as well (group difference 13.3% and13.1%, respectively), indicating that the training increased strength regardless of the type of contraction [12].

Our data on the volumetric concentric and eccentric MVT of the forearm due to an increased neural drive to the agonistic muscles. The voluntary activation during the different types of contraction seems to be relatively low in the present study, but is comparable to those observed during isometric MVCs of the wrist extensors at a similar wrist angle [13]. The normalized muscle activity tended to increase following the training and supports the findings for voluntary activation.

These data and the unchanged peak twitch torque of the forearm indicate that the training regimen induced mainly neural adaptations. The authors have shown that15 and 8 weeks of plyometric training improved isometric MVC strength of the flexors and extensors of forearm respectively [11]. These training-related changes were accompanied by increased muscle activation. Neither study found measurable changes at the muscle level. In contrast, studies have found that neural and muscular changes contribute to increased strength after plyometric training. The inconsistent results might be due to the different exercises performed during the training and the dissimilar durations of the training periods. However, the cited studies have not analyzed the effect of the training regimen on dynamic MVC strength. The results of the present study reveal that plyometric training is able to modulate MVC strength via an increased voluntary activation during concentric and eccentric contractions as well. Voluntary activation of muscles by the central nervous system generally depends on the excitability of cortical neurons and spinal α-moto neurons [14]. However, the contribution of cortical and spinal centers to the neural drive differs depending on the type of contraction [15]. It has been shown that motor evoked potentials and H-reflexes evoked during eccentric voluntary contractions are smaller than those obtained during isometric and concentric voluntary contractions. Therefore, it may be that the training induced specific adaptations at the supraspinal and/or spinal level depending on the contraction mode. In addition, the sensitivity of the muscle spindles as well as the extent of presynaptic inhibition of IA afferents might have changed in response to the training regime as shown previously. Because contractile properties provide only a crude estimation of changes at the muscle level, adaptations within the muscle cannot be completely ruled out.

It has been shown that neural adaptations mainly contribute to the early strength gains during a training period [16]. In view of the length of the training intervention in this study; it is most likely that primarily neural adaptations were responsible for the increased MVC strength during isometric, concentric and eccentric contractions. Based on the results of studies that have analyzed the effects of concentric and eccentric training on muscle strength, it is known that concentric training increases mainly concentric strength, and eccentric training leads to a more pronounced increase in eccentric strength. In the present study, plyometric exercises performed during the training consisted of an eccentric phase rapidly followed by a concentric muscle action. This type of training led to similar gains in strength and neural activation during isometric, concentric and eccentric contractions. Throwing distance was increased following the training. This is in accordance with the results of previously published studies that reported increased throwing distance after plyometric training.

5. Conclusion

Our data indicate that plyometric training is able to increase isometric, concentric and eccentric MVC strength of the wrist extensors due to enhanced neural drive to the muscles. Peak twitch torque data indicate that no training-related changes at the muscle level occurred. The mechanisms for an improved voluntary activation after the training may involve an increase in α-motoneuron firing frequency and/or recruitment during MVC. Because voluntary activation of muscles by the nervous system depends on the excitability of cortical neurons and spinal α-motoneurons, it may be that the training induced specific adaptations at the supraspinal and/or spinal level.

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