Journal of Novel Physiotherapies
Sarig Bahat et al., J Nov Physiother 2019, 9:1
DOI: 10.4172/2165-7025.1000403
Research Article
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Isokinetic Profile of Elbow Flexor and Extensor Muscles in Climbers and Non-Climbers

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Received date: December 19, 2018; **Accepted date:** January 10, 2019; **Published date**: January 16, 2019

Abstract

Background: Sport climbing places high mechanical demand on the elbow, which is the third most common region to be injured in climbing. It has been suggested that overuse injuries are associated with disrupted muscle balance. However, little is known about the muscle balance around the elbow.

Aim: To investigate moment and work profile of the elbow flexors and extensors in climbers and non-climbers.

Methods: Climbers (n=16) and non-climbers (n=18) volunteered to participate in the study. Each participant was examined bilaterally for concentric elbow flexion and extension muscle forces. Experimental equipment included the isokinetic dynamometer at speeds of 60°/sec and 180°/sec. Outcome measures included peak moment, average moment, total work and average work. Flexion/extension ratio was calculated for all measures.

Results: Elbow extensor muscles were significantly stronger than the elbow flexors in both groups ($p<0.001$), with a flexor/extensor total work ratio ranging from 0.76-0.86. Surprisingly, no significant group differences were found for any measure between climbers and non-climbers.

Conclusion: This study did not demonstrate a difference in elbow muscle work and moment between climbers and non-climbers, but did show elbow extensors were stronger than flexors. It may be that isokinetic testing is not sensitive to the functional strength developed in climbing and further research is needed to integrate additional functional strength evaluations.

Keywords: Elbow; Isokinetic work; Climbers; Muscle force ratio

Introduction

Although climbing is a relatively new sport, its popularity has grown rapidly over the past decade [1]. The International Federation of Sport Climbing (IFSC) estimates that about 250 million people climb regularly worldwide, and that about 3,000 people experience climbing for the first time every day in the USA (http://www.ifsc-climbing.org) [2].

Urban climbing facilities (climbing gyms) have become common in major cities and it is no longer an esoteric sport [3].

In contrast to traditional climbing when a fall could result in serious injury or even death, today's safety measures such as fixed anchors and advanced ropes made this sport relatively safe and thus, popular.

As safety is no longer a major concern, the sport climbing athlete can focus on the difficulty of the climb and push the physical limits of the body beyond what was previously considered possible.

In the last 24 years, sport climbing has become competitive, with a world cup circuit. Today, professional athletes train regularly and compete all over the world.

The standards for climbing difficulty have increased in the past 20 years, and range from 4 to 9b [4].

A common method of increasing the level of difficulty is to climb on routes that have an overhang (Figure 1). Consequently, body weight is shifted from the lower extremities to the upper extremities. Increased weight bearing by the upper extremities increases the relative risk of sustaining upper extremity injuries [5].

Figure 1: Modern outdoor climbing- photograph of a climber navigating an overhang. *Figure was provided by the second author (OB).

The elbow is the third most frequently injured sites among these athletes. Injuries to the elbow, including lateral and medial epicondylalgia, pronator teres syndrome, and supinator syndrome seem to be related to overuse injuries, which account for 93% of all climbing injuries [6-10].

It has been suggested that overuse injuries are associated with disrupted muscle balance, which is the normal ratio of agonist verses antagonist muscles. Muscle imbalance is defined as dominance of the agonist muscle over the antagonist at a given joint movement [11]. During movement around a joint, co-contraction of the agonist and antagonist muscles occurs. A normal balance of force is crucial for protecting the joint [12,13].

Several studies have investigated the muscle forces around the knee and shoulder joints [14-20]. However, there is little information in the literature about the muscle balance of the elbow joint, which has an extensive role in upper limb function, especially in sports like climbing, which depend on upper limb strength.

Isokinetic tests of the agonist/antagonist concentric torque and work are often used to assess muscle strength [11,15]. Muscle balance of the elbow joint has been measured isokinetically in various sports.

Ellensbecker and Roetert examined the forces around the elbow joint in professional male and female tennis players [21] and found a flexor/extensor ratio of 0.96 for males and 0.93 for females [21,22], assessed female volleyball players and found lower ratios in a similar pattern, showing that the extensor muscle group in those athletes was stronger (flexor/extensor ratio=0.49) versus the control group (flexor/extensor ratio=0.65) [22].

Current findings in climbers and controls are almost identical to the ratio results showed in judo athletes and controls, with no significant differences between groups (0.81) [23].

Although the number of climbers is increasing, and the sport places high physical demands on the elbow joint, knowledge about the strength profile of this region in these athletes is scant. Therefore, this study was conducted to expand the biomechanical understanding of the relationships of elbow muscle forces in climbers.

The aim of this study was to compare the work and moment muscle ratios of the elbow flexors and extensors in climbers to those of individuals who do not perform sports that require upper limb strength.

It is hoped that analyzing the strength profile of the elbow in these athletes will help to understand the adaptations required by this sport, or guide to further research in the field to direct training strategies, and possibly lead to new approaches to prevent common climbing injuries.

Materials & Methods

Participants

The climbers were recruited from climbing clubs in the city of Haifa, Israel. The non-climbers group was recruited from the university. All participants were healthy males, 18-40 years of age. Inclusion criteria for the climbers were at least three years of experience in climbing and a minimum of twice weekly training at an indoor climbing facility.

Inclusion criteria for the non-climbers were not performing an upper limb sport on a regular basis and no history of intensive, upper limb training in the past two years.

Exclusion criteria for both groups were a report of acute pain in one of the upper limb joints, a rheumatoid condition, fractures, osteoporosis, anti-inflammatory drug use one month prior to the study, and neurological, mental or cardiovascular disorders.

The study was approved by the Institutional Review Board (IRB) of the University of Haifa and all participants were asked to provide informed consent prior to testing.

Procedure

Elbow flexor and extensor forces were measured with an isokinetic dynamometer (Biodex 3 Medical Systems, Inc, Shirley, NY, USA) for both dominant and non-dominant hands. Calibration of the device was performed prior to each participant's measurement according to manufacturer's instructions for elbow testing.

The subject was positioned in sitting on the isokinetic chair with the trunk strapped to the seat as instructed by the manufacturer. The non-tested hand held the chair. The investigator, who is a licensed physiotherapist, conducted all tests.

Prior to isokinetic testing, all subjects performed a 5-minute upper limb warm up on a hand ergometer. Sub-maximal trials were performed on the isokinetic dynamometer to familiarize participants with the dynamometer machine and testing procedure.

After the warm up, 5 repetitions of maximal concentric elbow flexion and extension were conducted.

The isometric testing was performed at velocities of 60°/s and 180°/s. These angular velocities were selected to best reflect the functional nature of sport climbing, which is overall a slow sport in nature, with occasional fast, dynamic movements.

The dominant hand was tested first, then the non-dominant hand. A 10 minute rest was allowed between hands. Outcome measures included peak torque, peak work, average peak torque, average work and total work of all 5 repetitions for the elbow flexors and extensors.

All measurements were recorded using Biodex software (Biodex Medical Systems, New York, NY, USA).

Data Analysis

The results of the five repetitions for each muscle group were averaged for each outcome measure, and were normalized for the subject's body mass. Concentric moment and work ratios were defined as concentric flexion/extension.

A multivariate analysis model was constructed to compare speeds of 60°/s and 180°/s, muscle groups, dominant and non-dominant hands and climbers vs. non-climbers. Statistical analysis included ANOVA with post-hoc Tukey test and was performed using SPSS version 20 and SAS ver. 9.3. P-value was set at 0.05.

Results

Thirty-four males volunteered for the study, 16 climbers and 18 non-climbers. The climbers had a mean of 7.78 ± 1.16 years of experience in the sport. Over the past three years, they practiced climbing an average of 10.33 ± 5.32 hours per week. Climbing levels ranged from 7a to 8b+, which is considered recreational to elite levels.

Anthropometric characteristics of the groups are presented in Table 1. There were no significant differences in age, weight, height and BMI between climbers and non-climbers.

Measure	Non climbers (n=18) Mean ± SD	Climbers (n=16) Mean ± SD
Age (years)	26.50 ± 3.40	28.37 ± 4.60
Height (cm)	176.67 ± 5.30	174.38 ± 6.60
Weight (kg)	70.33 ± 13.33	68.70 ± 5.90
BMI	22.67 ± 3.67	22.56 ± 1.17
BMI - body mass index=body mass (kg)/height² (m)		

Table 1: Anthropometric characters of the groups.

The absolute torque and work results for the climbers and non-climbers, measured at 60°/sec and 180°/sec are presented in Table 2. Although absolute torque and work values for the climber group seemed greater than for the non-climbers, there was no significant difference in any of the normalized outcome measures at both tested speeds.

In both groups, the extensor muscle group was stronger than the flexor muscles in all parameters, at both test speeds (p<0.001) (Figure 2).

Torque and work ratio (flexion/extension) data for peak torque, average torque, total and average works for both speeds are presented in Table 3.

No significant differences between groups were found for peak torque, average torque, total and average work ratio of the elbow flexors and extensors at either speed.

In addition, the muscle strength ratio did not differ significantly between the dominant hand and non-dominate hands in either group. Peak torque ratio at 60°/sec was 0.83 ± 0.16 for the dominant hand and 0.81 ± 0.17 for the non-dominant hand in climbers and 0.82 ± 0.07 for the dominant hand and 0.84 ± 0.11 for the non-dominant hand in non-climbers (Table 3).

		Dominant Hand				Non dominant Hand			
		Non climbers (n=18)		Climbers (n=16)		Non climbers (n=18)		Climbers (n=16)	
		Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion
Measured at 60°/sec	Peak torque (N·m)	57.69* (14.25)	47.21 (12.09)	61.15* (17.29)	49.74 (13.51)	58.37* (13.04)	47.06 (11.64)	60.22* (17.54)	50.33 (14.4)
	Peak work (J)	91.49* (27.15)	76.05 (21.2)	99.26* (28)	83.19 (25.22)	95.73* (21.36)	75.07 (20.5)	98.34* (29.12)	79.46 (24.57)
	Total work (J)	437.53* (103.53)	355.36 (99.02)	455.75* (127.3)	393.08 (120.77)	440.79* (99.44)	348.51 (101.99)	453.74* (128.51)	372.65 (119.51)
	Average peak torque (N·m)	53.82* (13.03)	43.49 (11.3)	56.13* (15.68)	47.19 (12.75)	53.47* (11.83)	43.79 (11.59)	54.79*± (15.05)	46.46 (14.38)
	Average work (J)	87.51* (20.71)	71.07 (19.81)	91.15* (25.46)	78.62 (24.16)	88.16* (19.89)	69.7 (20.34)	90.75* (25.7)	74.53 (23.9)
Measured at 180°/sec	Peak torque (N·m)	44.51* (13.14)	35.45 (9.41)	48.85* (13.95)	39.2 (10.8)	46.51* (9.75)	36.4 (9.65)	47.58* (14.41)	36.65 (12.60)
	Peak work (J)	74.14* (21.04)	54.97 (15.1)	80.53* (23.43)	63.13 (19.32)	75.36* (17.85)	56.66 (16.00)	77.41* (20.5)	58.82 (18.8)
	Total work (J)	337.39* (94.99)	260.26 (71.86)	364.35* (121.08)	294.12 (93.05)	357.84* (83.52)	265.46 (75.56)	361.50* (96.8)	277.98 (89.41)
	Average peak torque (N·m)	40.69* (11.93)	32.99 (8.78)	44.49* (13.86)	35.97 (9.7)	43.32* (9.72)	33.56 (9.24)	44.21* (12.85)	34.45 (11.8)
	Average work (J)	67.48* (19.00)	52.05 (14.37)	72.87* (24.22)	58.82 (18.61)	71.57* (16.7)	53.09 (15.11)	72.30* (19.36)	55.6 (17.88)
Mean (standard deviation) values are presented for peak torque, peak work, total work, average peak torque and average work. *Significant differences between flexor and extensor muscle group (p<0.001)									

Table 2: Isokinetic results for climbers and non-climbers, in both hands, measured at 60°/sec and 180°/sec angular velocities.

		Non-climbers (n=18)		Climbers (n=16)	
		Dominant	Non-dominant	Dominant	Non-dominant
		(Mean ± SD)	(Mean ± SD)	(Mean ± SD)	(Mean ± SD)
Measured at 60°/sec	Peak torque ratio	0.83 ± 0.16	0.81 ± 0.17	0.82 ± 0.07	0.84 ± 0.11
	Average peak torque ratio	0.82 ± 0.15	0.82 ± 0.17	0.84 ± 0.08	0.84 ± 0.11
	Total work ratio	0.81 ± 0.13	0.79 ± 0.16	0.86 ± 0.08	0.81 ± 0.10
	Average work ratio	0.81 ± 0.13	0.79 ± 0.16	0.85 ± 0.08	0.81 ± 0.09
Measured at 180°/sec	Peak torque ratio	0.81 ± 0.15	0.79 ± 0.19	0.81 ± 0.09	0.77 ± 0.16
	Average peak torque ratio	0.82 ± 0.14	0.78 ± 0.18	0.82 ± 0.10	0.77 ± 0.15
	Total work ratio	0.77 ± 0.12	0.74 ± 0.15	0.81 ± 0.08	0.76 ± 0.11
	Average work ratio	0.78 ± 0.12	0.74 ± 0.15	0.81 ± 0.08	0.76 ± 0.11

Table 3: Elbow flexor/extensor ratio at 60°/sec and 180°/sec testing velocity.

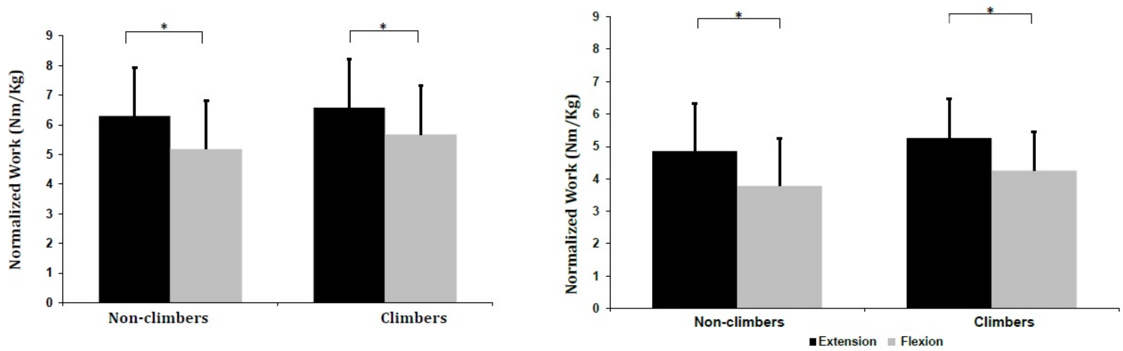

Figure 2: Normalized total work of the elbow flexors (gray) versus the extensors (black) at 60°/sec (left panel), and 180°/sec angular velocity (right panel). *Indicate significant differences p<0.001; Nm- Newton per meter.

Discussion

The main findings of this study were that the elbow extensors produced greater torque and work than the elbow flexors. Results showed peak torque ratio of 0.81-0.84 (at 60°/sec, Table 3). This is in agreement with previous studies: Maquet et al. [24] examined 40 sedentary women isokinetically, for elbow flexion and extension torque, with similar ratio findings (flexor/extensor ratio=0.81-0.83). Similar ratio findings were reported in studies of judo (0.81) [23], and somewhat smaller ratio in volleyball (flexor/extensor ratio=0.59-0.61) [22].

Complimentary evidence regarding the strength of the elbow extensor vs. flexor muscle groups comes from research on elbow muscles. The physiological cross sectional area (PCSA) of the elbow muscles (which defined as the muscle volume divided by the length of the muscle fibers) measured in cadavers, showed that triceps brachii has the largest PCSA of the elbow muscles and can produce the greatest muscle force of all elbow muscles [3,25]. Another study used magnetic resonance imaging (MRI) and demonstrated that the triceps brachii has greater torque potential than any other elbow muscle and its PCSA is 1.9 times greater than the elbow flexor muscles (biceps brachii, brachialis, brachioradialis) [26]. A study in climbers, looking at shoulder flexor and extensor muscle strength, established the greater strength of the shoulder extensors over the flexors [27]. The triceps brachii is a synergist to shoulder extension movement, but it is also a strong elbow extensor. Therefore, it is possible that this dual role contributed to the fact the elbow extensors in climbers were stronger than the flexors.

The results of these studies are in agreement with our findings, indicating that elbow extensors are stronger than elbow flexors. This is consistent across other sports that involve the upper limbs.

In addition, climbing can be regarded as a symmetrical, bilateral sport that requires participation of all 4 limbs. Accordingly, we hypothesized that climbers would exhibit symmetrical strength, which was indeed found. These findings are in agreement with previous findings in swimmers [17], and even in tennis players [21], suggesting that elbow flexor-extensor muscle strength is symmetric and is not influenced by lateral dominance in trained athletes.

In contrast to the study hypotheses, the results did not demonstrate significant differences in torque and work between climbers and non-climbers.

The fact that no differences were found between climbers and non-climbers is consistent with previous studies that showed no differences in grip strength between recreational climbers and non-climbers [28,29]. However, since our climbers trained in average 10.33 weekly hours, which is more than what is considered recreational, we were surprised with the lack of group differences. This can be explained by our assessment tool consisted of isokinetic dynamometer testing performed in an open kinetic chain, that is not functional testing for climbing. Climbing involves a closed kinetic chain pattern. It may be that the isokinetic testing used in this study could not evaluate the relevant, unique muscle strength achieved by climbers.

Further research is needed in a larger sample, including additional functional measures relevant to climbing, such as pull-ups, grip strength, and climbing grades.

To the best of our knowledge, this is the first study to investigate elbow muscle torque and work in climbers. Therefore, additional studies are needed to characterize strength ratios around the joints of the upper limb in climbers. This study did not support the assumption that climbers would have increased elbow strength as compared with non-climbers, but additional larger studies are needed to confirm this finding and to expand the investigation of this special population.

Conclusion

This study contributes new isokinetic findings regarding the elbow flexor/extensor torque and work ratio in climbers vs. non-climbers. In spite of the fact that the elbow joint is the third most commonly injured region of the body in climbing, the climber's elbow muscles have seldom been investigated. Climbers and trainers should be aware to the main finding in this study showing elbow extensor muscles are stronger than flexor muscles in about 20% when recommending various exercise regimes.

Competing Interests

The authors declare no competing interests.

Funding

This study was not supported by external funding.

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