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Original Article

Force of Arm Muscles in Recreational Athlets

Radulović Nikola [1]
Pavlović Ratko [2*]
Mihajlović Ilona [3]
Nikolić Siniša [4]
Canli Umut [5]
[1,3] *University of Novi Sad, 21000 Novi Sad, Serbia*
[2]*University of East Sarajevo, 71123 East Sarajevo, BIH*
[4]*Institute "Dr Miroslav Zotovic", 78000 Banjaluka, BIH*
[5]*Tekirdağ Namık Kemal University, Türkiye*

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Abstract

The study assessed the maximal and relative force manifesting (depending of forearm mass and circumference) of arm muscles (of dominant and subdominant arm) by two-angle testing: protocol test 1 - 90˚ (PT1) and protocol test 2 - 180˚ (PT2). The study included 25 recreational male athletes, aged 25-26 whose dominant arm was right arm. Through application of the dependent t-test, a statistically significant difference was confirmed in the variables of maximal force, protocol test 1 (PT1) - dominant (right) and subdominant (left) hand (p=0.02) favouring the right dominant hand. Relative force, protocol test 1(PT1) - right and left hand with regard to mass (p=0.02) favouring the right hand. Relative force, right and left hand with regard to the forearm circumference, protocol test (p=0.02), favouring the dominant right arm. In conclusion, is a difference in left and right arm force manifesting in male recreational athletes, but also that body mass and forearm circumference significantly affect force manifested, at the elbow joint angle of 90˚ (PT1).

1. Introduction

The maximum strength that a person can exert in any type of movement or motion is defined by multiple factors. The factors are closely related to morphological and physiological characteristics, gender, age, movement skills

* *E-mail*: pavlovicratko@yahoo.com, tel.+387 65-934-131

(Eleftherios & Blazevich, 2022; Silva-Santos, Guerra, Valdiviesso & Amaral, 2024), inter-muscular and intra-muscular coordination, strength mechanisms, and the optimal biomechanics of movement techniques (Čoh & Bošnjak, 2010; Bellumori, Jaric & Knight, 2013; Assmann, Steinmetz, Schilling & Saul, 2020; Jouira, Rebai, Alexe, & Sahli, 2024).

The manifestation of muscle strength, force, and speed is a subject of research in applied physiology and human locomotion. The most commonly studied aspects are the relationships between muscle force and strength relative to speed during the shortening of individual muscles. Additionally, the relationships are analyzed during the performance of complex motor tasks (Alexe, Grigore, Larion, & Alexe, 2012). It is a fact that an increase in muscle force leads to a decrease in the velocity of its shortening. Some studies (Yamauchi & Ishii, 2007; Yamauchi, Mishima, Nakayama & Ishii, 2009) suggest that their relationship, derived through the application of external loads during the performance of complex motor tasks, could approximate a linear relationship. According to Eleftherios & Blazevich (2022), several biomechanical factors are involved in the manifestation of human strength (neural control, physiological and biomechanical parameters of the muscle).

To understand this ability, it is necessary to analyze the factors on which it depends, such as the muscle cross-sectional area, the number of engaged muscle fibers, and movement proficiency (Bojsen-Møller, Magnusson, Rasmussen, Kjaer & Aagaard, 2005). Muscle strength is often studied through the analysis of graphical records of force manifestation under isometric contractions. Values obtained through such measurements may include maximum force, force generated in a unit of time, and the time required to achieve maximum force.

Neural control affects the maximal output strength of muscles by determining the quality and quantity of motor units that will be engaged in muscle contraction (recruitment) and the activation frequency of individual motor units (Bohannon, 2015; Haff & Triplett, 2018). In general, muscle force is greater when more motor units are involved in contraction, when the motor units are larger, and when the activation frequency is higher (Bohannon, 2015, Trybulski et al., 2022). Most progress in strength exertion achieved during the first few weeks of resistance training is attributed to neural adaptations (Klawitter, Hackney, Christensen, Hamm, Hanson & McGrath, 2023; Langford et al., 2024). The human brain finds a way to generate greater force with the same amount of contractile tissue. If all other factors are identical, the force a muscle can express depends more on the cross-sectional area than on the muscle volume and tendon composition (Haff & Triplett, 2018; Methenitis et al., 2019). It has been shown that during maximal contraction muscles can generate forces ranging from 23 to 145 psi (16–100 N/cm^3) of muscle cross-sectional area (Ishida & Watanabe, 2013). This large range can partly be explained by variations in the organization and orientation of sarcomeres relative to the muscle's longitudinal axis. The study problem focuses on the manifestation of muscle force in the elbow and wrist joints, analyzing its expression depending on body mass, forearm circumference, and changes in the angle of the elbow joint (180° and 90°).

2. Material and methods

The aim of the study is to detect differences in the manifestation of muscle force (absolute and relative) of the dominant and subdominant arm in the elbow joint depending on the joint angle, body mass, and forearm circumference in recreational athletes.

Research hypothesis:

1. It started from the assumption that the elbow angle will affect the manifestation of the maximum force of the arm muscles, in favor of test protocol 1 (PT1), in the dominant and subdominant hand.
2. It was based on the assumption that the elbow angle will influence the expression of the relative strength of the arm muscles in favor of test protocol 1 (PT1).
3. The circumference of the forearm will affect the relative force exerted by the arm muscles.

This is an empirical, cross-sectional study, utilizing bibliographical method, as well as statistical method for data processing. The experimental method of data collection enabled the testing of muscle force through standardized motor tests using sophisticated equipment.

Participants

The sample included 25 male participants (body height: 180.80±10.10 cm; body weight: 78.58±11.13 kg), aged 25–26 years, from Sjenica (Republic of Serbia), all with dominant right arm. The average circumference of the dominant (right) arm was 27.02±3.08 cm, while the subdominant (left) arm measured 26.95±2.56 cm. The participants were characterized as recreational athletes, capable of training or competing (healthy individuals), and training no more than five hours a week. Each participant signed an informed consent form for participation in the study and consent for testing.

Sample of variables

The following morphological characteristics were measured:

- Body height (cm)
- Body weight (kg)
- extended left and right forearm circumference (cm)

A standardized test protocol was used on a dynamometer with the following variables:

1) Maximum force PT1 of the dominant (right) arm (N),
- Relative force PT1 of the dominant (right) arm (N),
- Maximum rate of force development of the dominant (right) arm PT1 (s) – Time F_{max} test 1,
- Maximum force PT1 of the subdominant (left) arm (N),
- Relative force PT1 of the subdominant (left) arm (N),
- Maximum rate of force development of the subdominant (left) arm PT1 (s) – Time F_{max} test 1,
- Maximum force PT2 of the dominant (right) arm (N),
- Relative force PT2 of the dominant (right) arm (N),

- Maximum rate of force development of the dominant (right) arm PT2 (s) – Time F_{max} test 2,
- Maximum force PT2 of the subdominant (left) arm (N),
- Relative force PT2 of the subdominant (left) arm (N),
- Maximum rate of force development of the subdominant (left) arm PT2 (s) – Time F_{max} test 2,
- Relative force of the dominant (right) arm vs. forearm circumference PT1,
- Relative force of the dominant (right) arm vs. forearm circumference PT2,
- Relative force of the subdominant (left) arm vs. forearm circumference PT1,
- Relative force of the subdominant (left) arm vs. forearm circumference PT2.

Testing Protocol

Measurements were conducted following standard ISAK protocols. For each participant, a personal file containing all data was created, after which the data were transferred into matrices and subjected to mathematical and statistical processing. The testing was conducted by electronic dynamometer (Hand Dynamometer, www.vernier.com/bta) with accompanying software (LabQuest Stream). The dynamometer software recorded the exerted forces and the time required to achieve and maintain maximum force levels. It also generated force distribution charts as a function of test duration. A maximum isometric voluntary contraction test of hand flexors was conducted on both the left and right arms, but using different test protocols with varying elbow joint angle, as follows:

1. Protocol test 1 – elbow joint angle of 90° (PT1)
2. Protocol test 2 – elbow joint angle of 180° (PT2)

The mean circumference of the forearms (dominant and subdominant) of all participants was measured before measuring the forces by dynamometer.

Maximal and relative muscle strength of the arms and the time interval of force exertion were measured on participants in seated position, with back resting against the backrest and the feet on the floor for measuring the hand muscle strength. The forearm was resting on a surface, the elbow joint bent at a 90˚ angle (PT1), and the hand holding the dynamometer in a neutral position. This position allowed for the isolation of the body part and muscle group to be tested, without the involvement of other muscles that could affect the value of the generated force.

The second test protocol (PT2) was similar to the first, except that the angle of the elbow joint was 180˚. The starting position for the testing was the same – participants were seated, with the back resting against the backrest and the feet on the floor. The tests were conducted using the dominant (right) and subdominant (left) hand under varying test conditions involving changes in the elbow joint angle at 90˚ and 180˚.

Statistical data processing

The data were processed using descriptive and comparative statistical methods. Descriptive statistics included the calculation of the mean and standard deviation (SD). To determine the quantitative differences between the dominant and subdominant arm within the system of motor variables, a dependent samples t-test was applied. Values less than 0.05 were considered statistically significant (*Sig.<0.05). All calculations were performed using the software SPSS for Windows, version 20.0.

3. Results and Discussions

The results of the study are integrated in the form of relevant statistical parameters and presented in five tables.

Table 1. *Differences in maximum force of the Right and Left arm PT1 (90°) vs. PT2 (180°)*

	Variables	Mean ± SD	Diff. Mean	t	P
1	Maximum force PT1 – Right arm (N)	339.41 ± 107.94	25.61	2.81	0.02*
	Maximum force PT1 - Left arm (N)	313.80 ± 95.60			
2	Maximum force PT2 - Right arm (N)	328.15 ± 118.47	4.47	0.38	0.71
	Maximum force PT2 – Left arm (N)	323.68 ± 109.45			

The maximum force of the right and left arm using PT1 showed significant differences, in favour of the right arm (p=0.02; t=2.81) and a numerical difference of 25.61N. (Table 1). In PT2, no statistically significant differences were observed between the right and left arm (p=0.71), although a difference in the mean values (4.47 N) was observed, favouring the dominant arm (Table 1).

Table 2. *Differences in relative strength of the Right arm relative to the mass of the Left arm PT1 (90°) vs. PT2 (180°)*

	Variables	Mean ± SD	Diff. Mean	t	P
1	Rel.. force PT1 of the Right arm vs body mass (N)	4.23 ± 1.06	0.31	2.72	0.02*
	Rel.. force PT1 of the Left arm vs body mass (N)	3.92 ± 0.94			
2	Rel.. force PT2 of the Right arm vs body mass (N)	4.07 ± 1.16	0.06	0.37	0.71
	Rel.. force PT2 of the Left arm vs body mass (N)	4.01 ± 0.68			

The relative force of the right and left arms in relation to body mass PT1 showed a significant difference in favour of the dominant right arm (p=0.02; t=2.72) with a minimal difference (0.31N).

In PT2, no statistically significant differences were observed between the right and left arms in relative force in relation to body mass (p=0.71), with a negligible difference (0.06 N), but in favour of the right dominant arm (Table 2).

Table 3. *Differences in relative force of the Right and Left arm PT1 (90°) vs. PT2 (180˚) depending on forearm circumference*

	Variables	Mean ± SD	Diff. Mean	t	p
1	Rel. force of the Right arm vs forearm circumf. PT1	12.38 ± 3.05	0.82	2.51	0.02*
	Rel. force of the Left arm vs. forearm circumf. PT1	11.56 ± 2.75			
2	Rel. force of the Right arm vs. forearm circumf. PT2	11.92 ± 3.32	0.07	0.16	0.87
	Rel. force of the Left arm vs. forearm circumf. PT2	11.85 ± 2.89			

Table 3 defines the relative force of the right and left arm in relation to forearm circumference. PT1 significantly confirms dominance and a statistically significant difference (p=0.02; t=2.51) in favour of the right dominant arm, with a difference of 0.82N. The application of PT2 did not confirm statistically significant differences between the right and left arm (p=0.87), with a minimal difference in means (0.07 N) in favour of the right hand.

Table 4. *Differences in maximum and relative force of the Right arm PT1 (90°) vs. PT2 (180˚) body mass and in relation to forearm circumference*

	Variables	Mean ± SD	Diff. Mean	t	p
1	Max. force PT1 - Right arm (N)	339.41 ± 107.94	11.26	1.21	0.24
	Max. force PT2 - Right arm (N)	328.15 ± 118.48			
2	Rel.. force PT1 of the Right arm vs body mass (N)	4.23 ± 1.06	0.16	1.33	0.20
	Rel.. force PT2 of the Right arm vs body mass (N)	4.07 ± 1.16			
3	Rel.. force of the Right arm vs. forearm circumf. PT1	12.38 ± 3.05	0.46	1.36	0.19
	Rel.. force of the Right arm vs. forearm circumf. PT2	11.92 ± 0.32			

The differences in the force exerted by the dominant hand across different test protocols were also analysed (Table 4). The maximum force of the right hand in PT1 and PT2 did not significantly differ (p=0.24), and no significant difference was found in the relative force measured in PT1 and PT2 for the right hand in relation to body mass (p=0.20).

Certain differences in means were observed (11.26 N) for maximum force and in relative force in relation to body mass (0.16 N). In the third analysed variable, the relative force of the dominant hand in relation to forearm circumference, no statistically significant differences were observed in PT1 and PT2 (p=0.19), although a slight difference in means (0.46 N) was noted in favour of the dominant hand in PT1 (Table 4).

Table 5. *Differences in maximum and relative force of the Left arm PT1 (90°) vs. PT2 (180˚) body mass and in relation to forearm circumference*

	Variables	Mean ± SD	Diff. Mean	t	p
1	Maximum force PT1 - Left arm (N)	313.80 ± 95.61	-9.89	-0.79	0.44
	Max. force PT2 - Left arm (N)	323.68 ± 109.45			
2	Rela.. force PT1 of the Left arm vs body mass (N)	3.92 ± 0.94	-0.10	-0.64	0.53
	Rel.. force PT2 of the Left arm vs body mass (N)	4.02 ± 0.98			
3	Rel.. force of the Left arm vs. forearm circumf. PT1	11.56 ± 2.75	-0.29	-0.66	0.52
	Rel.. force of the Left arm vs. forearm circumf. PT2	11.85 ± 2.89			

Table 5 analyses the differences in the force exerted by the left subdominant arm in different test protocols. When testing the maximum force of the left arm depending on the test protocol, it was found that there were no statistically significant differences between the two test protocols (p=0.44).

Similarly, no statistically significant differences were found in relative force between PT1 and PT2 (p=0.53), nor in the relative force of the left arm in relation to forearm circumference between PT1 and PT2 (p=0.52). Minimal differences in means were found in all three variables in favour of PT2: -9.89 N in the variable assessing the maximum force, -0.10 N in the relative force variable between PT1 and PT2 in relation to body mass, and -0.29 N in the variable for relative force of the subdominant arm in relation to forearm circumference.

Discussions

The aim of the study was to detect differences in the manifestation of muscle force (absolute and relative) of the dominant and subdominant arm depending on the elbow joint angle, body mass, and forearm circumference in recreational athletes from Sjenica (Republic of Serbia).

Several studies have published normative data on the maximum grip strength for different populations measured by various measurement methods (Häger-Rossi & Rosblad, 2002). If we take the maximum grip strength of the participants in this study and compare it with those from similar studies (Dopsaj et al., 2011; Kljajić et al., 2012), we can see that male participants they have less grip strength in both hands. A lower average value of maximum male strength was recorded compared to previous studies. However, the differences should be taken with caution, as the participants in the current study are recreational athletes, while the participants in the referenced studies are individuals undergoing police training.

In the current study, the development of grip strength among male participants, recreational athletes from Sjenica, the average value for the dominant (right) arm observed was 339±107.94 N. Compared to participants from the Police Academy of similar age, the same arm has significantly lower values (Dopsaj et al., 2011).

Participants from the Police Academy achieved nearly double the maximum force of the right dominant hand (599.19±52.33N vs. 339±107.94N) and nearly double the force of the left subdominant hand (313.41±95.61N vs. 560.31±60.05N). Such data in favor of the Police Academy participants can be linked to their lifestyle and training regimen. Other explanation would be that it can be attributed to the greater engagement of finger muscles when handling weapons, as well as during martial arts regularly practiced as part of their training and education. Daily weapons handling and regular training regularly clearly lead to the overall strength and arm muscle strength levels being much higher than those of recreational athletes of the same age.

The literature provides ample evidence of the general rule that the dominant arm is approximately 10% stronger than the subdominant arm (Häger-Rossi & Rosblad, 2002; Günther, Bürger, Rickert, Crispin & Schulz, 2008; Fernandes et al., 2014), both in men and women. Our study shows that in male participants, the dominant arm generated 7.55% greater maximal force compared to the subdominant arm, indicating that it is stronger. The results of the current study align with the aforementioned rule and the findings of researchers in this field.

Since one arm is always dominant, muscle asymmetry of the arms occurs. The right arm of healthy adults tends to be faster (Elliott, Heath, Binsted, Ricker, Roy, and Chua, 1999), more precise (Roy, Kalbfleisch & Elliott, 1994), and stronger (Elliott et al., 1999) than the left arm. The error in achieving the defined hand grip strength can be considered from two aspects.

The first aspect relates to the manifestation of strength in the dominant and subdominant hands, which can be attributed to the greater use of the right dominant hand in adults throughout life. Muscles that are used more frequently on a daily basis exhibit better intra-muscular and inter-muscular coordination, with faster activation of motor neurons, which directly influences the manifested force. During voluntary muscle contraction, motor units are activated in a systematic order, leading to a gradual increase in force in the muscle according to the so-called size principle. Thus, the small alpha motor neurons, which innervate slow muscle fibers (type I), are activated first. However, if a greater level of muscle force is required, after the slow muscle fibers, there is a gradual activation of larger alpha motor neurons and fast muscle fibers (type II). The size principle is a rule that applies to all types of muscle contractions (Cormie, McGuigan & Newton, 2011), and this was also true in this testing, where all available motor neurons had to be activated in order to produce maximal force.

In daily activities, more frequent use of one arm implies a greater manifestation of force in that arm compared to the other. This happens because the muscles and their muscle fibers are better coordinated, activate more quickly, and thereby generate greater strength due to daily increased strain and higher tone. At the resting length of the muscle, the actin and myosin filaments are positioned next to each other, allowing for the maximum number of potential binding sites to be available. Under such conditions, the muscle can generate the greatest force. When the muscle is significantly stretched compared to its resting length, the actin and myosin filaments move apart, reducing the number of potential binding sites, which creates unfavorable conditions for generating maximum force. When the muscle contracts and significantly shortens compared to its resting length, the actin filaments overlap, reducing the number of potential binding sites between actin and myosin, which in turn decreases the ability to generate force. The recruitment of a greater number of muscle fibers in the contraction, which also contributes to a higher force generated during the movement, depends on neural control. In order to stimulate such coordinated action between the nervous system and muscles, a stimulation, such as an adequate training, is required.

If we make a connection between these data and the results indicating difference in the manifestation of maximum muscle force depending on the mass of the subject and especially forearm circumference, then the obtained results should be viewed from the perspective of muscle cross-sectional area. The size, or the surface area, of the physiological cross-section of the muscles is associated with the manifestation of force in the cranial extremities.

The maximal force exhibited by each muscle fiber is directly related to the size of its cross-sectional area, regardless of its type (Silva-Santos, Guerra, Valdiviesso & Amaral, 2024). Since strength is directly responsible for the manifestation of force, this means that a muscle fiber with a larger cross-sectional area can produce greater strength (MacIntosh & Holash, 2000; Methenitis et al., 2019).

In conclusion, it is evident that a muscle with a larger physiological cross-section generates greater force, and consequently greater strength. It follows that a larger forearm circumference is responsible for a greater manifestation of both relative and absolute strength during the PT1 (90˚) test.

The results of the study also confirmed the presence of the manifestation of relative strength of the right and left arm, which is determined by body mass and forearm circumference at an elbow joint angle of 90˚ (PT1). These results confirm previous claims regarding the difference in strength of the upper extremities, the right and left arm, and the impact of body mass on the manifestation of strength, aligning the results with those of Budziareck, Pureza, Duarte, and Barbosa-Silva (2008) and Bohannon (2015), who suggest that maximum grip strength depends on morphological parameters, primarily body mass and BMI.

The results obtained regarding the difference in arm muscle strength in participants engaged in recreational sports suggest that there is an opportunity to work on the strength of the other (subdominant) hand and the need for greater engagement of symmetrical muscle groups in order to maintain body muscle balance. In this way, a reliable measurement procedure has been established, enabling the diagnosis of the level of functional and work capacity of the examined contractile properties of the hand. The obtained data should and can be used for measuring the mentioned capacities in individuals with different levels of training.

Future research could focus on the rate of maximal muscle force and its exertion within a specific time interval. The results of the study conducted on participants from Sjenica indicate that the mechanical properties of muscles can be examined during the performance of complex motor tasks, as such tasks activate multi-joint systems and muscles through the application of various external loads.

The results indicate that there is a difference in the manifestation of muscle strength between the dominant and subdominant arm muscles in recreational athletes. Complex motor tasks could also be developed into relatively simple and ecologically valid tests for assessing the force, speed, and strength capacity of the muscular system.

4. Conclusions

Based on the obtained research results, when analysing the development of maximum strength, relative strength in relation to body mass, and relative strength in relation to forearm circumference using the Hand Grip Strength (HGS) test, it can be concluded that there are statistically significant differences in the variables of maximum force PT1—right and left hand (p=0.02), in favour of the dominant hand. Statistically significant differences were also recorded in the variables of relative force in the test protocol for the right and left arm in relation to body mass (p=0.02), in favour of the dominant arm. There are statistically significant differences in the variable of relative force for the right dominant and left subdominant arm in relation to forearm circumference PT1 (p=0.02), in favour of the right arm. In the other analysed domains, no statistically significant differences were observed using the dependent samples t-test (p>0.05). It was also confirmed that body mass plays a significant role in the development of hand grip strength, especially considering the dominant (right) and subdominant (left) arm, and that the average forearm circumference influences hand grip strength in PT1.

A limitation of the study was the small sample size and the absence of left-handed athletes, which could have provided a more comprehensive understanding of the research.

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