JBACHS
Journal of Basic and Clinical Health Sciences

J Basic Clin Health Sci 2022; 6: 25-32
https://doi.org/10.30621/jbachs.894910
RESEARCH ARTICLE

A COMPARISON OF THE MUSCLE ACTIVATION, PROPRIOCEPTION AND ANTHROPOMETRIC CHARACTERISTICS OF THE DOMINANT AND NON-DOMINANT WRISTS

Meral Sertel[1], Tezel Yildirim Sahan[2], Sabiha Bezgin[3], Muhammet Ayhan Oral[1], Ayse Abit Kocaman[1], Saniye Aydogan Arslan[1], Cevher Demirci[4], Birhan Oktas[5]

[1] Kirikkale University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Kirikkale, Turkey
[2] University of Health Science, Gulhane Faculty of Physiotherapy and Rehabilitation, Ankara Turkey
[3] Hatay Mustafa Kemal University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Hatay, Turkey.
[4] Balikesir University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Balikesir, Turkey.
[5] Kirikkale University, Faculty of Medicine, Department of Orthopedics and Traumatology, Kirikkale, Turkey

Address for Correspondence: Tezel Yildirim Sahan, **E-mail:** fzttezel@gmail.com
Received: 11.02.2021; **Accepted:** 04.11.2021; **Available Online Date:** 27.01.2022
©Copyright 2021 by Dokuz Eylül University, Institute of Health Sciences - Available online at https://dergipark.org.tr/en/pub/jbachs

Cite this article as: Sertel M, Yildirim-Sahan T, Bezgin S, Oral MA, Abit-Kocaman A, Aydogan-Arslan S, Demirci C, Oktas B. A Comparison of the Muscle Activation, Proprioception and Anthropometric Characteristics of the Dominant and Non-Dominant Wrists. J Basic Clin Health Sci 2022; 6: 25-32.

ABSTRACT

Purpose: Manual asymmetry refers to tendency that is in favor of hand to perform manual tasks requiring skills, it is important in every sensory and motor function. This study aimed to compare the muscle activation, proprioception, and anthropometric characteristics of the dominant and non-dominant wrists.

Methods: In the study, forty young individuals aged between 18-25 years, who volunteered to participate, were included. As anthropometric measurements, the upper extremity length measurement forearm length measurement, hand length measurement wrist diameter measurement, hand width, shape and digit index measurements were performed, respectively. The muscle strength of wrist flexor and extensor muscles was measured by a hand dynamometer, while their muscle activations were measured by electromyography. The arm carrying angle was evaluated by a universal goniometer.

Results: The mean age of the individuals included in the study was 22.51 ± 0.35 years. In the right dominant individuals, when the dominant and non-dominant sides were compared, a statistically significant difference was found between flexor muscle activations, muscle strength, and hand width (p<0.05). No difference was detected between the digit and shape indices, proprioception, wrist diameter, forearm length, cubital angles, and upper extremity length (p>0.05).

Conclusion: Finding the dominant side's wrist flexor muscle activations, extensor muscle strength, and hand widths better in young individuals showed that the dominant side was frequently used in daily living activities. The difference was seen that the non-dominant side would be weaker and at higher risk of deformity with increasing age and in the presence of any rheumatic, orthopedic, and neurologic diseases.

Keywords: Wrist, Muscle Activation, Proprioception, Anthropometric Characteristics

INTRODUCTION

The hand and wrist are among the most advanced anatomical structures of the body. For the optimal function, the hand and wrist must work in harmony. The wrist joint also forms the basis of the functional movements of the hand and fingers, and it is essential for strengthening the fine motor control of the fingers and hand. For this reason, it is important to determine the wrist muscle activation, joint movement positions, and anthropometric characteristics such as length, strength, and width. Since anthropometric characteristics will affect the architectural structure of the muscle, it helps in determining the individual's functions in daily life, under which conditions and which tissues will be overloaded, and which diseases he/she may be prone to (1,2). Furthermore, anthropometric characteristics may vary depending on age, gender, body structure, and the activities that individuals frequently perform (3). Among the anthropometric characteristics of the wrist, the arm length, forearm length, hand length, and third finger length are the most determinative among the length measurements (4).

The wrist motor coordination, manual dexterity, muscle strength, and sensitivity are essentials for the adequate performance of manual tasks. Manual asymmetry refers to the tendency that is in favor of a hand to perform manual tasks requiring skills, and it is important in every sensory and motor function. Therefore, the hand is one of the most critical components affecting the functionality of the upper extremity. Within the hand functions, the grip is an important function for the continuity of daily living activities (5). For this reason, grip strength is accepted as an objective measurement in the evaluation of the hand, wrist, and upper extremity performance. Grip strength provides data that can assist physiotherapists and occupational therapists in monitoring the patient's clinical status, setting treatment goals, assessing the effectiveness of treatment, and measuring the level of competence required for work (6).

The surface electromyography signal has been started to be widely used to assess muscle performance in the last decade. Surface EMG (sEMG) is a method that is painless, needle-free, and easy to apply. It is regarded as an auspicious method in terms of providing information about general muscle activity and evaluating muscle fatigue. Therefore, surface EMG (sEMG) is frequently used in field studies such as biomechanics, kinesiology, exercise education, rehabilitation, medical exercise therapy, ergonomics, etc., and in controlling and evaluating human performance. sEMG has a wide range of applications ranging from isometric muscle contractions under normal and pathological conditions to the evaluation of specific motor skills and high dynamic muscle movements during exercise. Surface electrodes are placed on the surface of the skin to detect sEMG myoelectric signals (7).

One of the most important mechanisms involved in providing the optimal position of the wrist for a function is also proprioception. Proprioception is a sense that affects the joint position and movement formed with the stimulation coming from different structures such as muscle, tendon, joint capsule, and skin (8). Studies show that the position, anthropometry, and sensation of the wrist affect hand functions and daily life activities. Kılıç et al showed that rheumatoid arthritis disease affects wrist position, and this situation causes lower hand function in these people. Inadequate hand functions influence the performance of activities for these individuals (2). In another study, Zapartidis et al stated that the anthropometric characteristics of the upper extremity contribute to specific motor capabilities and physical fitness (3). Nicolay et al showed that no significant differences existed between healthy males' and females' hands in measures of relative endurance. They emphasize that the dominant hand was significantly stronger than the opposite hand, but also fatigued more rapidly (5). In the literature, the number of studies evaluating the wrist muscle activation, proprioception, and anthropometric characteristics all together is very limited. With this study, we aim to fill this gap in the literature by comparing the dominant and non-dominant wrist position, anthropometric characteristics, and proprioception sense.Therefore, we aimed to compare the muscle activation, proprioception, and anthropometric characteristics of the dominant and non-dominant wrists.

MATERIALS AND METHODS

Young individuals, who were students at the Faculty of Health Sciences of Kırıkkale University and who volunteered to participate in the study, were included in the study. Informed consent was obtained from all individual participants included in the study. To determine the sample size, the study used the mean and standard deviation scale scores that Nicolay et al (2005), found comparing hand width on dominant and nondominant sides in their study with healthy young individuals (5). The sample of the study was determined as 40 healthy young adults using a power analysis with a two-tailed significance level, effect size of 0.5, error rate of 5%, and a confidence interval of 95% and with a population representing a power of 80%. 40 young individuals, who met the inclusion criteria, were included in the study. Healthy individuals aged between 18-25 years, who used the right hand dominantly, accepted to participate in the study, had normal sequencing in the upper extremity, and had no cooperation and communication problems (individuals with the mini-mental test score> 24), were included in the study (8).

Patients with an active infection, malignancy, multiple organ failure, and terminal disease status, a history of fracture in the upper extremity in the last three months, severe hearing and vision loss, orthopedic or neurological problems affecting the shoulder, elbow, forearm, wrist, and hand, operation history that would prevent the normal activation of shoulder, arm, forearm muscles and muscles around the wrist, barriers to moving the arm independently and actively, muscle strength below the value of 3 when evaluated as motor, and problems such as diabetes, tremor, or B12 deficiency were excluded from the study.

All individuals included in the study were given detailed information about the purpose and methodology of the study, and their consent to participate in the study was obtained. Our study, which was discussed by Kırıkkale University, Clinical Research Ethics Committee, was found to be ethically appropriate (Decision No: 05.03).

Forty young individuals, who participated in the study, were evaluated by the face-to face interview method. Firstly, sociodemographic information of the individuals, such as age, height, weight, and gender, was questioned. As anthropometric measurements, the upper extremity length measurement (a distance from the acromion process to the third finger by a tape measure), forearm length measurement (a distance between the olecranon and the radius styloid process), hand length measurement (a distance between the distal tip of the 3rd finger and the radius styloid process, from the dorsal of the hand by a tape measure), wrist diameter measurement (a distance between the radius styloid and ulna styloid process by a caliper), hand width (a distance between the 2nd and 5th fingers over the hand volar surface) measurements were performed, respectively (9). The shape index was obtained by multiplying the hand width (mm) by 100 and dividing it by the hand length (10). The digit index was obtained by multiplying the length of the third finger (mm) by 100 and dividing it by the hand length (4). The arm carrying angle was evaluated by a universal goniometer as the angle between the long axis of the arm and the long axis of the forearm (11).

The muscle strength of the wrist flexor and extensor muscles was measured by a hand dynamometer (Baseline Push-Pull Dynamometer, Digital Hydraulic, New York, USA). During the measurement, while the individual forced his/her elbow and wrist separately in the direction of flexion and extension, the physiotherapist came across him/her and tried to break the strength. In the meantime, the amount of measurement was determined as a digit on the display of the dynamometer. The measurements were repeated three times and then averaged (12).

The muscular activations of the wrist flexor and extensor muscles were measured by a Delsys Trigno Avanti Wireless surface EMG system (Delsys, Inc., Boston, MA, USA) system with 2 channels. Surface EMG electrodes were used for the Trigno Avanti EMG sensor. Surface electrodes were placed at the motor point of the muscles. Sampling rate for EMG data was performed at 1000 Hz, with a bandwidth of 20–400 Hz, the common-mode rejection ratio was greater than 80 Db and the root mean square was calculated using EMG Works 4.0 analysis software (Delsys, Boston, MA, USA). Before placing the electrodes, the skin was cleaned according to the criteria determined by the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) (13).

The measurements were recorded when the individual tried to flex and extend the wrist. For this purpose, firstly, the maximum voluntary contraction (MVC) values were calculated in muscle test positions, which are the positions where the muscle showed the most activation. This is the position that was the muscle test position when individuals sitting near the bed and with 90-degree elbow flexion and neutral position of wrist. In each position, the individuals were requested to maintain the position against manual resistance in opposite side of flexion and extension way that there would be a maximum isometric contraction for 5 seconds. During the measurement, the participants were encouraged verbally for a maximum effort. All the measurement were done by the same 10 years of experienced physiotherapist. The MVC value of each muscle was measured in 3 repetitions, and a resting time of 30 seconds was given between the repetitions. The highest value was recorded (7,13).

The sensation of proprioception was measured by an electrogoniometer (Baseline Digital Absolute Axis Goniometer) when the eyes were closed, by asking the individual to bring the wrist to the determined angle values during the movement of the wrist in the direction of flexion and extension. The visual inputs were blocked with a mask. These angle values were taken as 45 degrees as determined in the literature. By measuring with an electrogoniometer, the deviation amounts were determined (14,15).

Statistical Analysis

In the study, statistical analyses were performed using the SPSS version 19.0 for Windows (IBM SPSS Statistics for Windows, Version 19.0, IBM Corp., Armonk, NY, USA) package program.Normal distribution of data was tested and confirmed with the visual (histogram and probability graphs) and analytical methods(Shapiro–Wilk and Kolmogorov Smirnov test). The t-test was used in the dependent groups to compare the difference between the arithmetic means of the dominant and non-dominant sides of the individuals (two related groups) involved in the study. The data were presented as mean ± standard deviation. Data were considered statistically significant at $p<0.05$ (16).

RESULTS

The demographic data of the participants were presented in Table 1. The mean age of the individuals included in the study was 22.51 ± 0.35 years. The anthropometric characteristics, cubital angles, muscle strength, proprioception, and muscle activations of the dominant and non-dominant sides of the individuals were compared (Table 2). When the dominant and non-dominant sides in the right dominant individuals were compared, a difference was found between flexor muscle activations, muscle strength, and hand width ($p<0.05$). No difference was found between proprioception, wrist diameter, forearm length, cubital angles, upper extremity length digit and shape indices ($p>0.05$).

DISCUSSION

In this study, which we conducted in order to compare the wrist extensor muscle strength, flexor muscle activations, proprioception, and anthropometric characteristics between the dominant and non-dominant sides in the right dominant young and healthy individuals, a difference was found between the wrist flexor muscle activations, extensor muscle strength, and hand widths of the dominant and non-dominant sides. However, no difference was observed between the cubital angle, forearm and upper extremity lengths, proprioception, wrist diameters, and digit and shape indices. This study we think that we fill the gap in the literature by comparing the dominant and non-dominant wrist position, anthropometric characteristics, and proprioception sense in healthy younger adults.

Muscle strength is demonstrated with many motor units carrying out their duty, and muscle activation is demonstrated with the grading of the activity values of motor units. Thus, muscle strength is associated with muscle activation (17). In their study, Rudroff et al. showed that the angular value of the elbow joint

Table 1. Demographic Characteristics of Participants

Variables	Mean±SD	
Age(year)	22,51±0,35	
Height (cm)	170,53±0,15	
Weight (kg)	65,77±1,90	
BMI (cm^2/kg)	22,19±0,42	
	Dominant Side Mean± SD	**Non-Dominant Side Mean± SD**
Cubital angle (degree)	9,86±0,56	10,15±0,61
Upper extremity length (cm)	73,61± 0,78	73,38±0,81
Forehand length (cm)	44,28±0,47	44,14±0,50
Hand length (cm)	18,63±0,22	18,46 ± 0,21
Wrist diameter (mm)	49,13±0,74	48,97±0,77
Digit index	54,05 ±0,51	54,46 ±0,47
Shape index	49,16±0,63	48,61±0,52
Hand width (cm)	9,17±0,17	8,98±0,16

Cm: sentimeter,kg: kilogram; BMI: Body Mass Index; mm: millimeter,SD: Standart Deviation

Table 2. Comparison of Dominant and Non-Dominant Side

	Mean ± SD		t	p
MVC Flexion (Left-Right)	-11.535	24.203	-3.052	**0.004***
MVC Extansion (Left-Right)	-1.619	18.990	-0.546	0.588
Proprioception (Left-Right Wrist Flexion)	-0.102	6.407	-0.103	0.919
Proprioception (Left-Right Wrist Extension)	-0.637	7.709	-0.530	0.599
Muscle Strength(Left- Right Wrist Extansors)	-2,688	4,726	-3,642	0.001*
Muscle Strength (Left- Right Wrist Flexors)	-1,845	1,821	-1,784	0.356
Diameter (Left-Right Wrist)	0.195	1.676	0.745	0.461
Cubital Angle (Left-Right)	0.268	2.061	0.833	0.410
Hand Width (Left-Right)	-0.182	0.290	-4.031	**0.000***
Digit Index (Left-Right)	-0.378	2.571	-0.943	0.352
Shape Index (Left-Right)	-0.577	2.396	-1.542	0.131
Forearm Length (Left-Right)	0.146	1.091	0.859	0.396
Upper Extremity Length (Left-Right)	-0.195	0.980	-1.275	0.210

*p<0,05, t test, MVC: Maximum Voluntary Contractions

was related to muscle activation and muscle strength (17,18). The result of the study is parallel with our study. However, in our study, while there was a difference in strength in the extensors, no difference was observed in the flexors. We have the opinion that this situation is caused since grip type activities are more commonly used in daily life, especially in individuals in this age group. We think that the reasons for observing more deformity and problems in the flexor direction and dominant side of individuals in later ages, especially in individuals with rheumatic disease, may be revealed with this study (19).

In this study, the intensive use of the dominant side observed in healthy young individuals continues by increasing in later ages. Therefore, it should be emphasized that the non-dominant sides of individuals should also be strengthened and that the flexors may be strong due to excessive use, and their extensors may remain weak. In conclusion, it is vital to strengthen the extensors to prevent muscle imbalance also on the dominant side in addition to the non-dominant side in healthy individuals. In the literature, studies reported that the muscle strength imbalance is associated with problems such as shoulder problems and tendon injuries (20). On the other hand, Boz et al stated that hand and wrist anthropometrics were found to be independent risk factors for carpal tunnel syndrome (4). Thus, the imbalance of flexor and extensor muscles is important situation and, since our study confirmed wrist muscles imbalance, it also sheds light on future studies.

The position of the wrist joint affects the ability of the fingers to perform the maximum flexion and extension and grip capability (21). The detailed measurement of wrist proprioception and associating it with hand functions will bring a different perspective on hand and wrist rehabilitation. Therefore, the determination of proprioception is as important as determining muscle strength. Muscle strength is also influenced by changes in the muscle length during contraction besides the firing of motor units (22). When the length-tension relationship of the muscle is considered, the highest amount of tension is revealed at different angles and positions of the joint (23,24). (16,25). As a result of our study, while the muscle strength on the dominant and non-dominant sides of the wrist showed a difference, proprioception values were similar. Proprioceptive impairment is likely to affect daily life of people with some neurologic and orthopedic disorders. We find here similar between dominant and non-dominant hand in healthy young adults. We believe that this is caused by the fact that our study was performed in healthy individuals and that there was no loss of sensation in individuals. We think that there is no difference between the dominant and non-dominant hand, since multi-sensory integration of information from muscle spindles, Golgi tendon organs, and cutaneous receptors of joints and arms can be achieved in healthy individuals. In this study, it was found that the proprioceptive features of the dominant and non-dominant hand were similar.

In the studies conducted both in healthy individuals and in athletes, the anthropometric characteristics of the hand-wrist and forearm are demonstrated to be effective in both the daily life and sportive performance of individuals (27,2). Even, Boz et al. (4) demonstrated in their study that the anthropometric characteristics of the hand and wrist were a risk factor for carpal tunnel disease. Azam Maleki- Ghahfarokhi et al. showed in their study conducted in healthy individuals aged 19-30 years that on both the dominant and non- dominant sides, the hand, forearm, and arm lengths were associated with the grip strength of different grip types (28). In our study, there was no difference between the anthropometric characteristics of the hand and forearm in dominanat and non-dominant sides of healthy individuals. There was a difference only hand width between dominant and non-domianant hands. We think that this is caused by the fact that we included in the study individuals who were healthy and young in the close age range and who did not have a profession in which the hand was used actively. In the future, studies comparing muscle strength, proprioception, and anthropometric characteristics among wide age and diseases groups may be conducted.

In this study results there is no difference between extensor muscle activations, the difference between extensor muscle strength. We think that this is because of the evaluation method of muscle strength. Dynamometer could not show the difference between dominant and non-dominant hands in healthy individuals. This condition is one of the limitations of this study. On future studies about this topic more detailed analysis can be used for the muscle strength evaluation.

In the studies conducted in the literature, it has been observed that there are different opinions about the muscle strength around the wrist in left dominant and right dominant individuals. While the dominant side was stronger in right dominant individuals, some researchers, who compared the dominant side and the non-dominant side in left dominant individuals, showed that they had equal strength (29), and some others found that the left, i.e. the dominant side was stronger (30). Therefore, we included only right dominant individuals in our study and eliminated this difference of opinion. This situation is one of the strong aspects of our study.

Finding that the wrist flexor muscle activations, extensor muscle strength, and hand widths of the dominant side were better in healthy individuals demonstrated that it was used frequently in daily living activities, but the non-dominant side was used less than the dominant side. This difference suggested that the non-dominant side would be weaker and at higher risk of deformity with increasing age and in the presence of any rheumatic, orthopedic, or neurological diseases. Therefore, in order to take early measures also in young and healthy individuals, their awareness should be increased, and they should be encouraged to use their non-dominant sides as much as dominant sides during daily living activities.

This study has some limitations. First, the evaluation of muscle strength with a hand dynamometer among healthy individuals could not showed the difference between dominant and non-dominant hands. The second and most important limitation is the absence of different age groups.

Acknowledgments: Some parts of this research are represented as an oral presentation at the 9th National Prosthesis-Orthotics Congress with international participation.

Author contributions: Conceptualization,T.Y.Ş., S.A.A., C.D., A.A.K., M.A.O.and B.O.; Methodology, M.S., S.B., C.D., and M.A.O.; Software, T.Y.Ş. and S.A.A.; Formal Analysis, S.A.A., M.S., and C.D.; Investigation, A.A.K., T.Y.Ş., and M.S.; Resources, M.S., S.A.A., and T.Y.Ş.; Data Curation, S.B., A.A.K., B.O., M.S., and T.Y.Ş.; Writing – Original Draft, C.D., M.S., T.Y.Ş, M. A.O., and B.O.; Writing – Review & Editing, M.S., S.A.A., C.D., and T.Y.Ş.; Supervision, C.D., M.S., S.B., A.A.K., S.A.A., and T.Y.Ş.

Conflict of Interest: The authors declare that they have no conflict of interest. Statement of Informed Consent: Informed consent was obtained from all individual participants included in the study.

Ethical approval: This study, which was approved by Kırıkkale University, Clinical Research Ethics Committee (Decision No: 05.03). All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Funding: This research was supported with 2018/041 project number by Kırıkkale University Individual Research Project.

Peer-review: Externally peer-reviewed.

REFERENCES

1. Neumann DA, Bielefeld T. The carpometacarpal joint of the thumb: stability, deformity, and therapeutic intervention. J Sports Med 2003; 33: 386-399.
2. Kilic MC, Calik BB, Cobankara V, Balkarli A. The Relationship Between Hand Function and Activity Performance in Patients with Rheumatoid Arthritis. Age 2018; 32: 57-59.
3. Zapartidis I, Vareltzis I, Gouvali M, Kororos P. Physical fitness and anthropometric characteristics in different levels of young team handball players. The Open Sports Sci J. 2009; 2: 22-28.
4. Boz C, Ozmenoglu M, Altunayoglu V, Velioglu S, Alioglu Z. Individual risk factors for carpal tunnel syndrome: an evaluation of body mass index, wrist index and hand anthropometric measurements. Clin Neurol Neurosurg 2004; 106: 294-299.
5. Nicolay CW, Walker AL. Grip strength and endurance: Influences of anthropometric

variation, hand dominance, and gender. Int J Int Ergon 2005; 35: 605-618.
6. Wu S-W, Wu S-F, Liang H-W, Wu Z-T, Huang S. Measuring factors affecting grip strength in a Taiwan Chinese population and a comparison with consolidated norms. Appl Ergon. 2009; 40: 811-815.
7. Meekins GD, So Y, Quan D. American Association of Neuromuscular & Electrodiagnostic Medicine evidenced-based review: Use of surface electromyography in the diagnosis and study of neuromuscular disorders. Muscle Nerve 2008; 38: 1219-24.
8. Smetacek V, Mechsner F. Making sense. Nature 2004; 432: 21-26.
9. Otman AS.Basic evaluation principles in treatment movements. Pelikan publishing; 2014.
10. Kulaksiz G, Gozil R. The effect of hand preference on hand anthropometric measurements in healthy individuals. Ann Anat 2002; 184: 257-265.
11. Paraskevas G, Papadopoulos A, Papaziogas B, Spanidou S, Argiriadou H, Gigis J. Study of the carrying angle of the human elbow joint in full extension: a morphometric analysis. Surg Radiol Anat 2004; 26: 19-23.
12. Tayyab S, Shehzad A, Waqas S, Asim HM. Association of Hand Grip Strength and with Writing Speed (Endurance) Among the Students. Ann KEMed Uni 2019; 2: 25-31.
13. Warnock B, Gyemi DL, Brydges E, et al. Comparison of Upper Extremity Muscle Activation Levels Between Isometric and Dynamic Maximum Voluntary Contraction Protocols. Int J Kinesiol Sports Sci 2019; 7: 21-29.
14. Rawes M, Richardson J, Dias J. A new technique for the assessment of wrist movement using a biaxial flexible electrogoniometer. J Hand Surg AM 1996; 21: 600-603.
15. Zaffagnini S, Visani AA, Marcacci M. Estimating the elbow carrying angle with an electrogoniometer: acquisition of data and reliability of measurements. Orthopedics (Online) 2008; 31(4): 370.
16. Mowery BD. The paired t-test. Pediatr Nurs 2011; 37: 32-40.
17. Rudroff T, Jordan K, Enoka JA, Matthews SD, Baudry S, Enoka RM. Discharge of biceps brachii motor units is modulated by load compliance and forearm posture. Exp Brain Res 2010; 202(1): 111-20.
18. Garmirian LR, Dewald JP, Acosta AM. Reduction in voluntary activation of elbow and wrist muscles in individuals with chronic hemiparetic stroke. bioRxiv 689364; doi: https://doi.org/10.1101/689364.
19. Shiri R, Varonen H, Heliövaara M, Viikari-Juntura E. Hand dominance in upper extremity musculoskeletal disorders. J Rheumatol 2007; 34: 1076-82.
20. Sansone V, Maiorano E, Applefield RC, Gandola M, Negrini F. Strength reduction in unilateral shoulder pain: Is the healthy side really healthy in rotator cuff disease? Am J Phys Med Rehabil 2019; 98: 382-6.
21. Lee J-A, Sechachalam S. The effect of wrist position on grip endurance and grip strength. The J Hand surgery 2016; 41: 367-73.
22. Ikeda N, Inami T, Kawakami Y. Stretching Combined with Repetitive Small Length Changes of the Plantar Flexors Enhances Their Passive Extensibility while Not Compromising Strength. J Sports Sci Med 2019; 18: 58-68.
23. Seven B, Cobanoglu G, Oskay D, Atalay-Guzel N. Test–Retest Reliability of Isokinetic Wrist Strength and Proprioception Measurements. J Sport Rehabil 2019;28;32-6.
24. Pilbeam C, Hood-Moore V. Test–retest reliability of wrist joint position sense in healthy adults in a clinical setting. Hand Ther 2018; 23: 100-109.
25. Hagert E, Garcia-Elias M, Forsgren S, Ljung B-O. Immunohistochemical analysis of wrist ligament innervations in relation to their structural composition. J Hand Surg 2007; 32: 30-6.
26. Dianat I, Asadi B, Jafarabadi MA. Wrist ulnar/radial torque strength measurements among Iranian population: the effects of age, gender, Body Mass Index and hand dominance. Work 2016; 53: 279-84.
27. Jimenez-Olmedo JM, Penichet-Tomás A, Ortega Becerra M, Pueo B, Espina Agulló JJ. Relationships between anthropometric parameters and overarm throw in elite beach handball. Hum Mov 2019; 20: 16-24.
28. Maleki-Ghahfarokhi A, Dianat I, Feizi H, Asghari-Jafarabadi M. Influences of gender, hand dominance, and anthropometric characteristics on different types of pinch strength: A partial least squares (PLS) approach. Appl Ergon 2019; 79: 9-16.

29. Bohannon RW. Grip strength: a summary of studies comparing dominant and nondominant limb measurements. Percept Mot Skills 2003; 96: 728-30.
30. Hepping AM, Ploegmakers JJ, Geertzen JH, Bulstra SK, Stevens M. The influence of hand preference on grip strength in children and adolescents; a cross-sectional study of 2284 children and adolescents. PloS one, 10(11), e0143476,https://doi.org/10.1371/journal.pone.0143476