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# Functional Dimorphism and Characteristics of Maximal Hand Grip Force in Top Level Female Athletes

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**A B S T R A C T**

*The aim of this work is to determine functional dimorphism ($F_{max}Nd/DoHG_{iso}$) and model characteristics at maximal isometric hand grip force ($F_{max}HG_{iso}$) in top level female athletes. 275 top level female athletes were tested from Taekwondo, Synchronised Swimming, Track and field, Table tennis, Volleyball, Karate, Skiing, Handball, well-trained students (students of the Academy for Criminalistic and Police studies – ACPS) and Control group. In order to assess the $F_{max}HG_{iso}$, we used standardised equipment, i.e., a sliding device that measures isometric finger flexor force, with a tensiometric probe fixed inside the device. The average values of $F_{max}HG_{iso}$ and relative force measured by allometric and classic method for dominant and non-dominant hand grip for the total sample were 381.87±60.28, 344.63±55.60 N; 24.06±3.50, 21.72±3.28 N/$BM^{0.667}$; 0.62±0.10, 0.56±0.09 N/BM. The average value of $F_{max}Nd/DoHG_{iso}$ was 0.9030±0.0797. General Significant difference was established between subsamples for the measurement characteristics at the level of Wilks' Lambda 0.476, F=3.276, p=0.000. Maximal average value $F_{max}HG_{iso}$ for non-dominant and dominant hand is found in Karate (372.04 ±46.71, 407.04±71.31 N) and minimal in Table tennis (282.00±56.00, 304.00±58.51 N). The minimal index value of $F_{max}Nd/DoHG_{iso}$ was found in Control group 0.8771±0.0877. Considering defined classification of $F_{max}Nd/DoHG_{iso}$, we classified the examinees from different sports in 4 groups: dominant symmetry of functional hand grip relations (Skiing> 0.9595); symmetry (Table tennis and Taekwondo 0.9288 to 0.9594); average (Karate, Volleyball, ACPS, Track and field 0.8980 to 0.9287); asymmetry (Control, Synchronised swimming and Handball 0.8674 to 0.8979). The results obtained can be used to determine criteria decisions from the aspect of diagnostic procedures, metric aspect, medical aspect.*

***Key words**: isometric force, hand grip, functional dimorphism, top level female athletes*

## Introduction

Hand grip is very important, although often underestimated force component. In many sports hand grip is often established as a secondary function. However, the researches show that the hand grip force is very important component, especially in some sports: Climbing, Judo, Weightlifting, Wrestling, Tennis, Field hockey´s, Pin bowling, etc[1-7].

The researchs of contractile characteristics of hand grip muscles are wide-spreaded considering the fact that the hand grip force (and the muscles involved in the grip) is positively related to other muscle groups, including the legs; the hand grip force also presents an indicator for valid evaluation of the overall body strength[8]. Additionally, the measurement equipment for assessing maximal isometric hand grip force ($F_{max}HG_{iso}$) is very easy to use, and it is related to examinees´ age, health condition or training status[1,2,4,6,7,9,10]. The aim of these diverse studies was to define basic model characteristics considering descriptive, functional and sexual dimorphism at maximal isometric hand grip force in well-trained athletes for the analytic and diagnostic purposes[1,2,4,6,10,11]. Besides, a few studies have been done in order to define basic descriptive model characteristics considering descriptive, functional and sexual dimorphism at basic explosive isometric hand grip force, especially for the purpose of the sport training[12,13].

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From the practical viewpoint, corresponding contractile characteristics of hand grip, especially level of maximal force, present an indicator of development capacity of the basic actively functional extremity, i.e. the arm, where the hand, anatomically a specialized organ, characterizes the end of the kinetic chain. From the point of view of cybernetics in sport and with the goal of developing a method for control and evaluation of physical abilities[14], it is necessary to define models for evaluation of actual development condition of the given extremity and its corresponding muscle groups. These models help in the classification and diagnostic definition of the development level or contractile ability deficit in order to provide relevant information which influences operative and strategic training decisions[15].

The aim of this work is to define functional dimorphism and basic model characteristics at the level of $F_{max}HG_{iso}$ for both hands in top level female athletes. The given results will define the influence of individual sport on the observed contractile characteristics for both hands, and the level of adaptation in different sports regarding natural level of functional dimorphism.

## Materials and Methods

### *Subjects*

For the purpose of this research, 275 top level senior female athletes were tested from 10 different sports: Taekwondo (N=22), Volleyball (N=46), Skiing (N=4), Handball (N=74), Synchronised swimming (N=12), Table tennis (N=6), Karate (N=11), Track and field (N=9), healthy and well-trained students of Academy for Criminalistic and Police Studies (ACPS) (N=58), and Control group – untrained, physically active, healthy population of the same age (N=33). Basic anthropometric data of the tested examinees were: TV = 171.77±7.18 cm, TM = 63.49±8.40 kg, BMI = 21.47±2.13, Age = 21.36±3.82 years. All tests were performed in the Laboratory for assessing the basic motoric status within the study subject of Special Physical Education at Academy for Criminalistic and Police Studies in Belgrade and in the Laboratory for assessing the basic motoric status of The Republic Institute for Sport between 2003 and 2007, using the same procedure and the same equipment[10,11].

### *Testing procedure*

Testing procedure was conducted under the professional and ethical standards and recommendations defined by American College of Sports Medicine[16]. In order to assess the $F_{max}HG_{iso}$, we used standardised equipment, i.e., a sliding device that measures isometric finger flexor force, with a tensiometric probe fixed inside the device. The tensiometric probe was connected to the force reader showed the precision of ±0.1 N. An earlier study established a high statistical validity of the measuring equipment used at the level of 0.961, while the reliability of the measuring method was at the level of 0.991. Therefore, both testing procedure applied and the results obtained can be considered as representative[9,10,17]. All examinees were tested keeping with earlier described procedures[8,10,11] after 2–3 minutes of independent warm-up, with the examinee standing in the upright position and holding the measuring device with the probe in the hand tested, with the arm resting in the natural posture alongside the body, while the other arm was resting alongside the body or the hand of the other arm was leaning against the thigh. The hand holding the device with the probe was approximately 10 cm away from the body. The examinees were not allowed to move from the initial position during the test trial, nor could they lean the hand or the device against the thigh or another solid object. We used power grip, where all the fingers are flexed around the object. The power grip isn't only the simplest grasping movement, but also the grip where we can produce a higher level of force than with the others, such as the precision grip, the manipulative grip, various tool grips, various types of pinch, etc[6,18–20].

### *Variables*

The measurement range was defined using the following 7 variables:

- maximal isometric non-dominant hand grip force – $F_{max}NdHG_{iso}$, in N
- maximal isometric dominant hand grip force – $F_{max}DoHG_{iso}$, in N
- relative value of maximal isometric hand grip force –
  - allometric method: – $F_{allom}NdHG_{iso}$, in $N/BM^{0.667}$
  - allometric method: – $F_{allom}DoHG_{iso,}$ in $N/BM^{0.667}$
  - classic method: – $F_{rel}NdHG_{iso}$, in N/BM
  - classic method: – $F_{rel}DoHG_{iso}$, in N/BM
- functional dimorphism – functional relationship between maximal hand grip force of non-dominant and dominant hand – $F_{max}Nd/DoHG_{iso}$, in Index Number.

Maximal isometric hand grip allometric partialisation was done by applying the following procedure[21–23]:

$$F_{allomiso} = F_{maxiso} / BM^{0.667}$$

Where: $F_{allomiso}$ are the maximal isometric hand grip force values after allometric partialisation, in index number ($N/BM^{0.667}$); $F_{maxiso}$ is the maximal isometric hand grip force, in N; BM is body mass, in kg.

Maximal isometric grip classic partialisation was done by applying the following procedure[10,23]:

$$F_{reliso} = F_{maxiso} / BM$$

Where: $F_{reliso}$ are the maximal isometric hand grip force values after classic partialisation, in index number (N/BM); $F_{maxiso}$ is the maximal isometric hand grip force, in N; BM is body mass, in kg.

### *Statistical analysis*

Statistical methods used in this procedure were the descriptive statistical method, Student's t-test, as well as

the multivariate statistical method – General Linear Method – multivariate procedure[24]. Descriptive comparison between different sports were performed using Z score standard, where the data gained from the research conducted on Control group – untrained, physically active, healthy population of the same age and the same environment were used as a standard criterion. All statistic analysis were done by the application of software package SPSS for Windows, Release 11.5.0 (Copyright© SPSS Inc., 1989–2002).

## Results

The results of the descriptive statistics are shown in Table 1. Regarding the obtained descriptive parameters, we can conclude that the results belong to a considerably homogeneous group[24], since the values of the variation coefficient (cV%) fall within the range between 9.15% for the variable $F_{max}Nd/DoHG_{iso}$ and 16.35% for the variable $F_{rel}NdHG_{iso}$.

The average values of $F_{max}HG_{iso}$ for dominant and non-dominant hand for the total sample were 381.87±

**TABLE 1**
DESCRIPTIVE STATISTIC ANALYSIS FOR THE TOTAL SAMPLE TESTED

| | Total sample descriptive statistics N=275 | | | | | | |
|---|---|---|---|---|---|---|---|
| | $F_{max}NdHG_{iso}$ (N) | $F_{max}DoHG_{iso}$ (N) | $F_{max}Nd/DoHG_{iso}$ (index number) | $F_{allom}NdHG_{iso}$ ($N/BM^{0.667}$) | $F_{allom}DoHG_{iso}$ ($N/BM^{0.667}$) | $F_{rel}NdHG_{iso}$ (N/BM) | $F_{rel}DoHG_{iso}$ (N/BM) |
| X | 344.63 | 381.87 | 0.9030 | 21.72 | 24.06 | 0.5588 | 0.6187 |
| SD | 55.60 | 60.28 | 0.0797 | 3.28 | 3.50 | 0.0913 | 0.0971 |
| cV% | 16.13 | 15.78 | 8.83 | 15.11 | 14.53 | 16.35 | 15.69 |
| Min | 200.00 | 230.00 | 0.6731 | 13.81 | 15.50 | 0.3325 | 0.3683 |
| Max | 500.00 | 591.83 | 1.0711 | 30.58 | 37.81 | 0.8062 | 0.9765 |

X – average values, SD – standard deviation, cV% – variation coefficient, Min – minimum, Max – maximum, $F_{max}NdHG_{iso}$ – maximal isometric non-dominant hand grip force, $F_{max}DoHG_{iso}$ – maximal isometric dominant hand grip force, $F_{max}Nd/DoHG_{iso}$ – functional dimorphism, $F_{allom}NdHG_{iso}$ – relative value of maximal isometric non-dominant hand grip force by allometric method, $F_{allom}DoHG_{iso}$ – relative value of maximal isometric dominant hand grip force by allometric method, $F_{rel}NdHG_{iso}$ – relative value of maximal isometric non-dominant hand grip force by classic method, $F_{rel}DoHG_{iso}$ – relative value of maximal isometric dominant hand grip force by classic method

**TABLE 2**
DESCRIPTIVE STATISTIC ANALYSIS REGARDING THE DIFFERENT SPORTS

| | Descriptive statistics *per* sports (X±SD) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $F_{max}NdHG_{iso}$ (N) | $F_{max}DoHG_{iso}$ (N) | $F_{maxiso}Nd/DoHG$ (index) | $F_{allom}NdHG_{iso}$ ($N/BM^{0.667}$) | $F_{allom}DoHG_{iso}$ ($N/BM^{0.667}$) | $F_{rel}NdHG_{iso}$ (N/BM) | $F_{rel}DoHG_{iso}$ (N/BM) |
| Taekwondo (N=22) | 353.64±58.60 | 357.73±52.37 | 0.9564±0.0590 | 22.87±2.82 | 23.16±2.54 | 0.5961±0.0758 | 0.6038±0.0712 |
| Volleyball (N=46) | 333.60±49.43 | 370.13±54.94 | 0.9039±0.0702 | 20.14±2.96 | 22.33±3.16 | 0.5069±0.0828 | 0.5617±0.0871 |
| Handball (N=74) | 356.53±52.76 | 406.35±62.45 | 0.8830±0.0901 | 22.13±3.02 | 25.18±3.42 | 0.5654±0.0873 | 0.6428±0.0961 |
| Synchronised Swimming (N=12) | 284.17±41.88 | 323.33±34.20 | 0.8787±0.0940 | 18.66±2.88 | 21.19±2.08 | 0.4897±0.0851 | 0.5559±0.0684 |
| Skiing (N=4) | 383.33±17.00 | 400.00±37.42 | 0.9618±0.0495 | 22.95±2.23 | 23.97±3.23 | 0.5744±0.0736 | 0.6003±0.0968 |
| Table Tennis (N=6) | 282.00±56.00 | 304.00±58.51 | 0.9297±0.0923 | 19.04±2.88 | 20.54±3.02 | 0.5066±0.0702 | 0.5465±0.0739 |
| ACPS (N=58) | 360.87±50.68 | 394.21±53.78 | 0.9173±0.0658 | 22.44±2.96 | 24.53±3.25 | 0.5726±0.0797 | 0.6262±0.0888 |
| Control (N=33) | 316.28±53.16 | 360.25±44.95 | 0.8771±0.0877 | 21.17±3.89 | 24.11±3.53 | 0.5606±0.1113 | 0.6383±0.1061 |
| Karate (N=11) | 375.95±46.71 | 420.34±71.31 | 0.9007±0.0562 | 24.46±3.03 | 27.32±4.35 | 0.6378±0.0820 | 0.7120±0.1125 |
| Track and fields (N=9) | 347.25±53.83 | 374.24±49.26 | 0.9270±0.0565 | 23.00±2.44 | 24.81±2.12 | 0.6055±0.0526 | 0.6535±0.0455 |

X – average values, SD – standard deviation, $F_{max}NdHG_{iso}$ – maximal isometric non-dominant hand grip force, $F_{max}DoHG_{iso}$ – maximal isometric dominant hand grip force, $F_{max}Nd/DoHG_{iso}$ – functional dimorphism, $F_{allom}NdHG_{iso}$ – relative value of maximal isometric non-dominant hand grip force by allometric method, $F_{allom}DoHG_{iso}$ – relative value of maximal isometric dominant hand grip force by allometric method, $F_{rel}NdHG_{iso}$ – relative value of maximal isometric non-dominant hand grip force by classic method, $F_{rel}DoHG_{iso}$ – relative value of maximal isometric dominant hand grip force by classic method, ACPS – healthy and well-trained students of Academy for Criminalistic and Police Studies, Control – untrained, physically active, healthy population of the same age

**TABLE 3**
STATISTICAL SIGNIFICANT DIFFERENCES BETWEEN ALL VARIABLES BY SPORT

| Partial differences between the observed variables in the tested groups | | | | |
|---|---|---|---|---|
| Dependent Variable | (I) sub-sample | (J) sub-sample | MAD (I-J)* | p** |
| $F_{max}DoHG_{iso}$ (maximal isometric dominant hand grip force) | Handball | Taekwondo | 48.61* | 0.016 |
| | | Synchronised swimming | 83.07* | 0.000 |
| | | Table tennis | 102.34* | 0.001 |
| | | Volleyball | 36.23* | 0.026 |
| | | Control | 46.09* | 0.004 |
| | ACPS | Synchronised swimming | 70.88* | 0.003 |
| | | Table tennis | 90.20* | 0.008 |
| | Karate | Synchronised swimming | 97.01* | 0.002 |
| | | Table tennis | 116.34* | 0.002 |
| $F_{max}NdHG_{iso}$ (maximal isometric non--dominant hand grip force) | Handball | Synchronised swimming | 72.35* | 0.000 |
| | | Table tennis | 74.53* | 0.034 |
| | | Control | 40.23* | 0.010 |
| | ACPS | Synchronised swimming | 76.69* | 0.000 |
| | | Table tennis | 78.86* | 0.019 |
| | | Control | 44.58* | 0.004 |
| | Karate | Synchronised swimming | 91.79* | 0.001 |
| | | Table tennis | 93.95* | 0.017 |
| | | Control | 59.67* | 0.045 |
| | Taekwondo | Synchronised swimming | 69.47* | 0.009 |
| | Skiing | Synchronised swimming | 99.16* | 0.044 |
| $F_{maxiso}Nd/DoHG$ (functional dimorphism) | Taekwondo | Handball | 0.0735* | 0.005 |
| | | Control | 0.0792* | 0.011 |
| $F_{rel}DoHG_{iso}$ (relative value of maximal isometric dominant hand grip force by classic method) | Karate | Synchronised swimming | 0.1559* | 0.002 |
| | | Table tennis | 0.1655* | 0.018 |
| | | Volleyball | 0.1502* | 0.000 |
| | Control | Volleyball | 0.0766* | 0.012 |
| | ACPS | Volleyball | 0.0644* | 0.017 |
| $F_{allom}DoHG_{iso}$ (relative value of maximal isometric dominant hand grip force by allometric method) | Handball | Synchronised swimming | 3.98* | 0.004 |
| | | Table tennis | 4.65* | 0.038 |
| | | Volleyball | 2.86* | 0.000 |
| | ACPS | Volleyball | 2.19* | 0.030 |
| | Karate | Taekwondo | 4.16* | 0.027 |
| | | Synchronised swimming | 6.11* | 0.000 |
| | | Table tennis | 6.78* | 0.002 |
| | | Volleyball | 4.99* | 0.000 |
| $F_{rel}NdHG_{iso}$ (relative value of maximal isometric non-dominant hand grip force by classic method) | Taekwondo | Synchronised swimming | 0.1064* | 0.029 |
| | | Volleyball | 0.0891* | 0.004 |
| | Handball | Volleyball | 0.0585* | 0.015 |
| | Karate | Synchronised Swimming | 0.1480* | 0.002 |
| | | Volleyball | 0.1310* | 0.000 |
| $F_{allom}NdHG_{iso}$ (relative value of maximal isometric non-dominant hand grip force by allometric method) | Taekwondo | Synchronised swimming | 4.21* | 0.007 |
| | | Volleyball | 2.72* | 0.031 |
| | Handball | Synchronised swimming | 3.48* | 0.015 |
| | | Volleyball | 1.98* | 0.028 |
| | ACPS | Synchronised swimming | 3.77* | 0.006 |
| | | Volleyball | 2.29* | 0.008 |
| | Karate | Synchronised swimming | 5.79* | 0.000 |
| | | Table tennis | 5.40* | 0.027 |
| | | Volleyball | 4.31* | 0.002 |

*MAD – mean absolute differences between subsamples, **$p<0.005$.

60.28 N and 344.63±55.60 N, respectively. $F_{max}Nd/DoHG_{iso}$ was at the level of 0.9030±0.0797. The average values of the measured relative hand grip force by the allometric method for the dominant and non-dominant hand were 24.06±3.50 N/BM$^{0.667}$ and 21.72±3.28 N/BM$^{0.667}$, respectively. The classic method yielded 0.6187±0.0971 N/BM and 0.5588±0.0913 N/BM, for the dominant and non-dominant hand, respectively.

The results of the descriptive statistic regarding different sports are shown in Table 2. The maximal average value $F_{max}DoHG_{iso}$ was measured in Karate and was 420.34 ±71.31 N and minimal in Table tennis 304.00±58.51 N. The maximal average value $F_{max}NdHG_{iso}$ was measured in Skiing and was 383.33±17.00 N and minimal in Synchronised swimming 284.17±41.88 N (Table 2). $F_{max}Nd/DoHG_{iso}$ was measured at a level of maximal average value in Skiing and was 0.9618±0.0495 and minimal in Control 0.8771±0.0877 (Table 2). The maximal average value $F_{allom}DoHG_{iso}$ was measured in Karate and was 27.32 ±4.35 N/BM$^{0.667}$ and minimal in Table tennis 20.54±3.02 N/BM$^{0.667}$. The maximal average value $F_{allom}NdHG_{iso}$ was measured in Karate and was 24.61±3.03 N/BM$^{0.667}$ and minimal in Synchronised swimming 18.66±2.88 N/BM$^{0.667}$ (Table 2). The maximal average value $F_{rel}DoHG_{iso}$ was measured in Karate and was 0.7078±0.1125 N/BM and minimal in Table tennis 0.5465±0.0739 N/BM. The maximal average value $F_{rel}NdHG_{iso}$ was measured in Karate and was 0.6468±0.0820 N/BM and minimal in Synchronised swimming 0.4897±0.0851 N/BM (Table 2).

Multivariate statistical analysis established a significant difference for all contractile characteristics at the level of Wilks' Lambda 0.476, F=3.276, p=0.000, among the observed subsamples in different sports. Statistically significant difference was also established for all tested contractile subfields regarding the function of the observed subsamples of different sports: $F_{max}DoHG_{iso}$ F=6.650, p=0.000; $F_{max}NdHG_{iso}$ F=6.028, p=0.000; $F_{max}Nd/DoHG_{iso}$ F=2.918, p=0.003; $F_{allom}DoHG_{iso}$ F=5.884, p=0.000; $F_{allom}NdHG_{iso}$ F=5.373, p=0.000; $F_{rel}DoHG_{iso}$ F=5.393, p=0.000; $F_{rel}NdHG_{iso}$ F=5.000, p=0.000. The results of partial differences between the observed contractile variables among different sports are shown in Table 3.

In relation to $F_{max}HG_{iso}$, the $F_{max}Nd/DoHG_{iso}$ was established using t-test for different sports. The results indicated statistically significant difference between the dominant and non-dominant hand at the level of t values 4.524 p=0.001 in Synchronised swimming, in favour of the dominant hand; in Track and field t=3.523 p=0.008; Volleyball t=8.538 p=0.000; Handball t=10.383 p=0.000; ACPS t=9.372 p=0.000; Control t=7.863 p=0.000; Karate t=4.305 p=0.002.

In relation to $F_{max}HG_{iso,}$ the results indicated the functional dimorphism for the sample tested between the dominant and non-dominant hand at the level of significance F=2.918 p=0.003, in favour of the dominant hand. For the sample tested the $F_{max}Nd/DoHG_{iso}$ was established at the index level of 0.9030. In other words, the

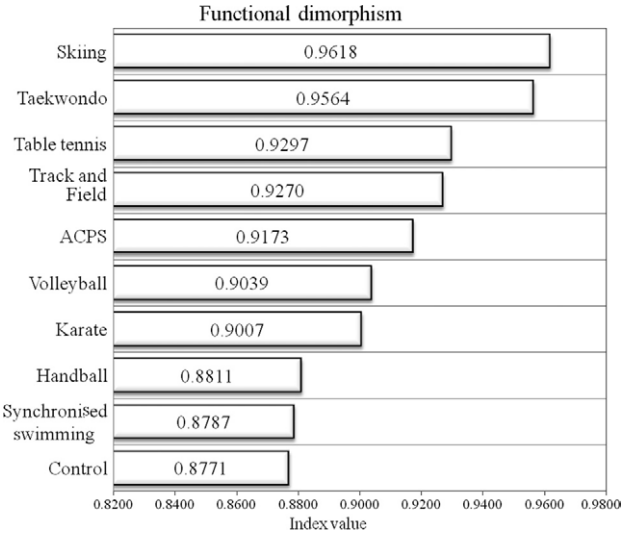


*Fig. 1. Functional dimorphism.*

$F_{max}HG_{iso}$ of the non-dominant hand was at the level of 90.30% of the $F_{max}HG_{iso}$ of the dominant hand.

With the obtained values of the functional dimorphism in regard to maximal hand grip force $F_{max}Nd/DoHG_{iso}$ (Figure 1), it was possible to establish the maximal index values in Skiing – 0.9618 (in other words, the $F_{max}HG_{iso}$ of the non-dominant hand is at the level of 96.18% of the $F_{max}HG_{iso}$ of the dominant hand), in Taekwondo – 0.9564, Table tennis – 0.9297, Track and field – 0.9270, ACPS – 0.9173, Volleyball – 0.9039, Karate – 0.9007, Handball – 0.8811, Synchronised swimming – 0.8787, and in Control – 0.8771. According to the obtained index values of $F_{max}Nd/DoHG_{iso}$ in different sports, using metric procedure for defining sport norms[11,23], it was possible to establish ranges of $F_{max}Nd/DoHG_{iso}$ regarding the $F_{max}HG_{iso}$, which we used to classify the examinees from different sports in following five categories: dominant asymmetry of $F_{max}Nd/DoHG_{iso}$ (index value is above 0.8673), asymmetry of the $F_{max}Nd/DoHG_{iso}$ (index value is from 0.8674 to 0.8979), normal/average value of $F_{max}Nd/DoHG_{iso}$ (0.8980 to 0.9287), symmetry of $F_{max}Nd/DoHG_{iso}$ (0.9288 to 0.9594) and dominant symmetry of $F_{max}Nd/DoHG_{iso}$ regarding $F_{max}HG_{iso}$ (index value is higher than 0.9595) (Table 4). Considering the categorization and the

**TABLE 4**
NORM VALUES FOR ASSESSING THE STATUS OF FUNCTIONAL DIMORPHISM

| Norm values for assessing the status of functional dimorphism | |
|---|---|
| | Index value |
| Dominant symmetry | >0.9595 |
| Symmetry | 0.9288 to 0.9594 |
| Normal/average value | 0.8980 to 0.9287 |
| Asymmetry | 0.8674 to 0.8979 |
| Dominant asymmetry | <0.8673 |

obtained results, we can conclude (Table 4, Figure 1) that the tested Karatekas, Volleyball players, ACPS and Track and field athletes belong to the category of natural normal/average $F_{max}Nd/DoHG_{iso}$. Control group, Synchronised swimmers and Handball players are in the category of asymmetry of $F_{max}Nd/DoHG_{iso}$. Table tennis players and Taekwondokas are in the category of symmetry of $F_{max}Nd/DoHG_{iso}$ and the Skiers are in the category of dominant symmetry of $F_{max}Nd/DoHG_{iso}$ regarding the $F_{max}HG_{iso}$.

### *Results in relation to Z score*

Figures 2–8 present standardised differences of the observed hand grip force variables regarding the different sports. The standard criterion represents the values of criterion Control group – untrained, physically active and healthy population of the same age.

Values of standardised differences (Figure 2) between the criterion population and individual sports are at the level of 56.25 N or 15.61% (Table tennis) of deficit to 46.79 N or 12.99% (Karate) of sufficiency in relation to the variable $F_{max}DoHG_{iso}$. Values of standardised differences (Figure 3) between the criterion population and individual sports are at the level of 34.28 N or 10.84% (Table tennis) of deficit to 67.05 N or 21.20% (Skiing) of sufficiency in regard to the variable $F_{max}NdHG_{iso}$ criterion.

Values of standardised differences (Figure 4) are between 3.57 N/BM$^{0.667}$ or 14.89% (Table tennis) of deficit and 2.82 N/BM$^{0.667}$ or 11.70% (Karate) of sufficiency in relation to the variable $F_{allom}DoHG_{iso}$ criterion. Values of standardised differences (Figure 5) are between 2.52 N/BM$^{0.667}$ or 11.88% (Synchronised swimming) of deficit and 3.44 N/BM$^{0.667}$ or 16.24% (Karate) of sufficiency in relation to the variable $F_{allom}NdHG_{iso}$ criterion.

Values of standardised differences (Figure 6) are between 0.0919 N/BM or 14.39% (Table tennis) of deficit

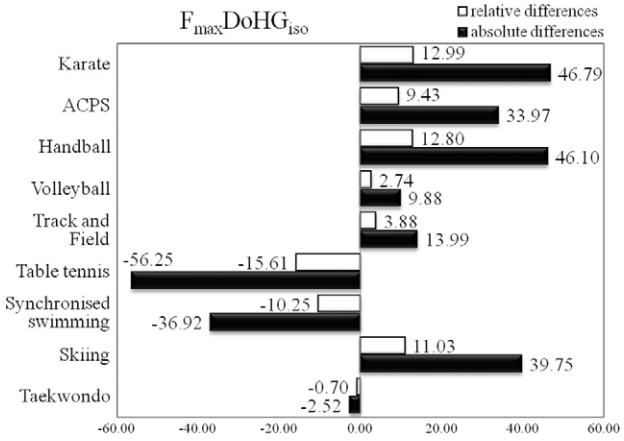


*Fig. 2. Standardised differences of maximal isometric dominant hand grip force – $F_{max}DoHG_{iso}$. Relative differences – in %, absolute differences – in N.*

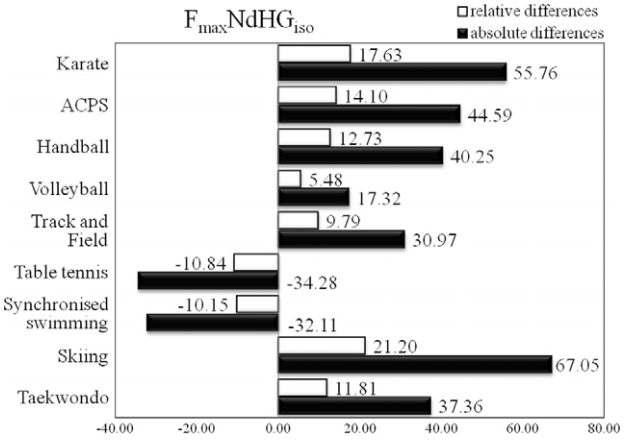


*Fig. 3. Standardised differences of maximal isometric non-dominant hand grip force –$F_{max}NdHG_{iso}$. Relative differences – in %, absolute differences – in N.*

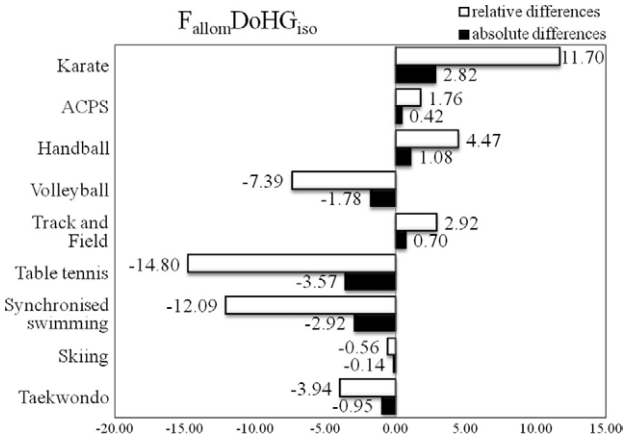


*Fig. 4. Standardised differences of relative value of maximal isometric dominant hand grip force after allometric partialisation – $F_{allom}DoHG_{iso}$. Relative differences – in %, absolute differences – in N/BM$^{0.667}$.*

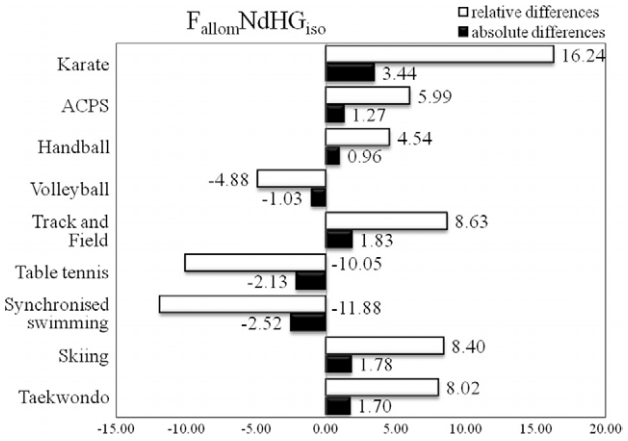


*Fig. 5. Standardised differences of relative value of maximal isometric non-dominant hand grip force after allometric partialisation – $F_{allom}NdHG_{iso}$. Relative differences – in %, absolute differences – in N/BM$^{0.667}$.*

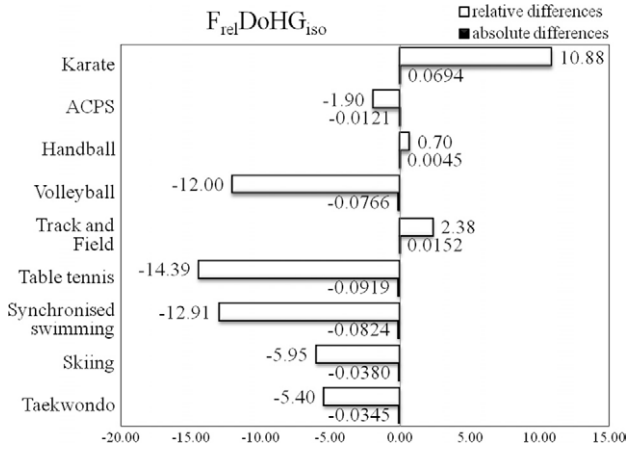


*Fig. 6. Standardised differences of relative value of maximal isometric dominant hand grip force after classic partialisation – $F_{rel}DoHG_{iso}$. Relative differences – in %, absolute differences – in N/BM.*

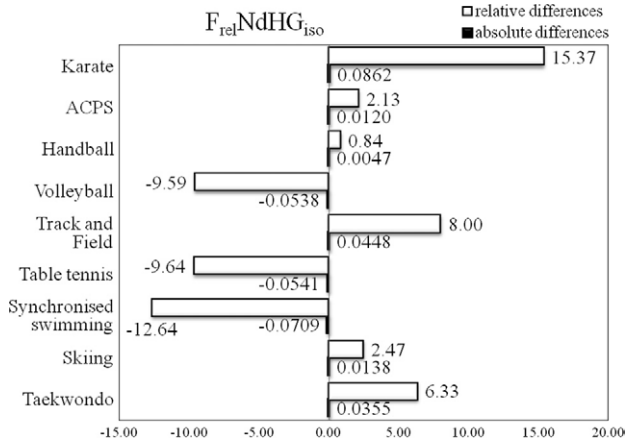


*Fig. 7. Standardised differences of relative value of maximal isometric non-dominant hand grip force after classic partialisation – $F_{rel}NdHG_{iso}$. Relative differences – in %, absolute differences – in N/BM.*

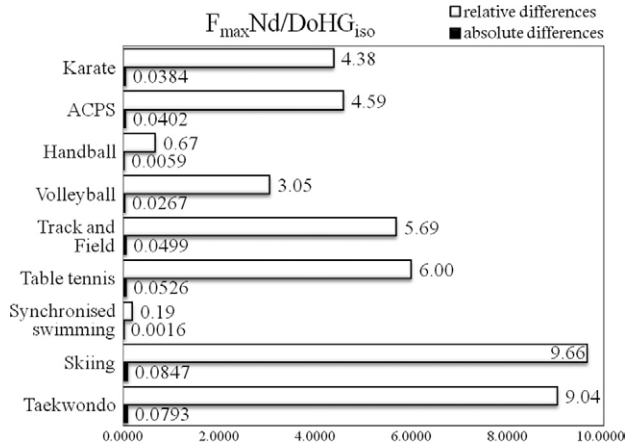


*Fig. 8. Standardised differences of functional dimorphism – functional relationship between maximal hand grip force of non-dominant and dominant hand – $F_{max}Nd/DoHG_{iso}$. Relative differences – in %, absolute differences – in index values.*

and 0.0694 N/BM or 10.88% (Karate) of sufficiency in relation to the variable $F_{rel}DoHG_{iso}$ criterion. Values of standardised differences (Figure 7) are between 0.0709 N/BM or 12.64% (Synchronised swimming) of deficit and 0.0862 N/BM or 15.37% (Karate) of sufficiency in relation to the variable $F_{rel}NdHG_{iso}$ criterion.

Values of standardised differences (Figure 8) are 0.0016 or 0.19% (Synchronised swimming) to 0.0847 or 9.66% (Skiing) of sufficiency in relation to the variable $F_{max}Nd/DoHG_{iso}$ criterion.

## Discussion

The highest average value of $F_{max}DoHG_{iso}$ was measured in Karate, Handball and Skiing (420.34±71.31; 406.35±62.45; 400.00±37.42 N respectively), which is understandable considering the nature of these sports. Similar results, except in handball, were obtained for the non-dominant hand grip. The highest values of the non-dominant hand grip force were measured in Skiing and Karate (383.33±17.00; 375.95±46.71 N, respectively). Besides, the fact that the lower value of non-dominant hand grip force was measured in Handball isn't suprising. In sports like Handball, where the dominant hand is frequently used, both in training and competition, functional dimorphism was measured at the level of assymetry of functional dimorphism and the average value of 0.8830. In some previous researchs, it was found that tennis players had significant asymmetry in grip strength. The dominant hand in female tennis players produced 25% more force than the opposite hand[4]. Throw and ball manipulation with dominant hand in handball contributed that this sport was clasified as a sport with the asymetry of functional dimorphism. Besides, the results of the research[14,15] indicated that the general factor of specific motor abilities in handball were predominantly defined by the speed of movement without ball as a crucial role, followed by the strength of throw, ball manipulation and speed of movement with ball. One of the minimal standardised difference of $F_{max}Nd/DoHG_{iso}$ in regard to Control group was established in Handball and was 0.67% or 0.0059 in index value. On the other hand, the maximal standardised difference of $F_{max}Nd/DoHG_{iso}$ regarding the Control group was established in Skiing and was 9.66% or 0.0847 in index value. The reason for the established differencies based on relation of maximal force between dominant and non-dominant hand, especially between Handball and Skiing probably lies in fact that in sport in which both hands are equally used, in training sessions and competitive games, measured contractile characteristic of hand muscles between dominant and non-dominant are synchronised (Figure 1). Important part in Skiing play Ski poles (»stocks«) which are used by skiers to improve balance and timing. Important role and different types of stocks, specific position and holding the stock strongly with both hands in order not to drop it while passing the gate in Skiing probably contributed the specific adaptation which resulted in loss of functional domi-

nation of one hand or in equalising disabillity in both hands, for the level of maximal isometric hand grip force.

Regarding the tested sample, the lower average values of both absolute and relative indicator of the dominant and non-dominant maximal isometric hand grip force were measured in Table tennis and Synchronised swimming. Synchronised swimming is a water sport that combines elements of swimming, ballet, and gymnastics and is performed by individual athletes as well as by teams of athletes performing as a coordinated unit. Basic position and technical elements in Synchronised swimming demand great strenght especially in the lower body musculature. Synchronised swimmers training includes usage of free weights, machine circuit training, and plyometric routines in order to enhance leg strength, prepare the athletes to move decisively and explosively in the water. Synchronised swimmers are engaged in training that focuses on the development of the strength and the flexibility of the core area of the body, as the abdominal, lumbar (low back), groin, and gluteal muscles. Therefore, as a result of selection and training adaptation, contractile characteristics of the upper body are at the lowest level in relation to the other tested sports.

In relation to the average value of both non-dominant and dominant hand, the lowest absolute and relative allometric values of hand grip force is measured in Table tennis players (avg $F_{max}HG_{iso}$= 293.00 N and avg $F_{allom}HG_{iso}$=19.79 N/$BM^{0.667}$). Considering the categorization and the obtained results, Table tennis players are in the category of symmetry of $F_{max}Nd/DoHG_{iso}$. Although Table tennis players use dominant hand for different styles of recket holding, there are numerous offensive and defensive strokes, but the racket is only 150 g and the players do not use all the strenght while holding the racket. This could be the reason for lower values of the absolute and relative isometric hand grip force in this sports and the fact that the functional dimorphism is at the level of symmetry.

On the other hand, regarding the average values of the total sample, in sports such as Taekwondo and Track and field, the average and under average value of maximal isometric hand grip force were established. In Taekwondo, which is a martial art, the emphasis is on leg techniques, whereas the arm techniques are forbidden. Besides, the results of some researches obtained in testing that was consisted of back squat and bench press[25] indicated that the elite female Taekwondo athletes had low body fat, highly developed flexibility and high relative maximal strength. In Track and field the role of leg muscles in disciplines the measured sample belong to is more important than the role of hand grip muscle. However, if we observe the area of relative value of maximal isometric hand grip force in Taekwondo and Track and field tested sample, the lower standardised differences in regard to average values of the total sample were established in hand grip relative values (Table 2, Figure 9). Many authors recommend that the performance of test of exerting external force should be presented per $kg^{2/3}$ (i.e., b=0.67)[21,23,26]. The results of our research showed that

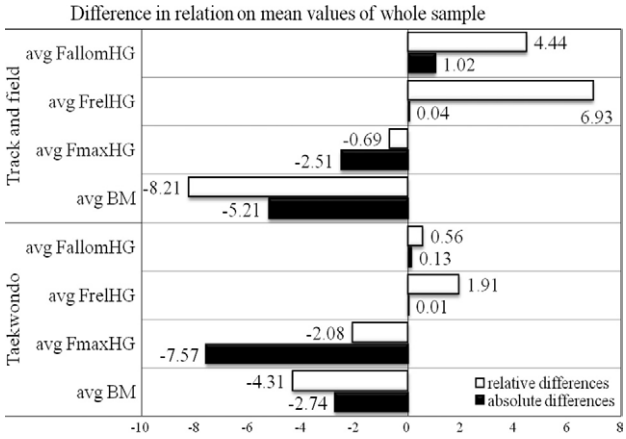


*Fig. 9. Influence of Body mass on average values of relative hand grip force in regard to average values of the total sample. avg $F_{max}HG$ – average values of maximal hand grip force, avg$F_{rel}HG$ – average values of relative hand grip force by classic method, avg$F_{allom}HG$ – average values of relative hand grip force by allometric method, avgBM – average values of body mass.*

both in classic and allometric partialisation low mean values of Body mass measured in Track and field and Taekwondo (8.21% and 4.31% of deficit in relation of total sample, respectively) have strong influence on less standardised differences of relative values in regard to average values for the total sample (Figure 9). Values of standardised differences (Figure 9) in relation for total sample are 7.57 N or 2.08% (avg$F_{max}$HG) of deficit to 0.01 N/BM or 1.91% (avg$F_{rel}$HG) of suficiency in Taekwondo and 2.51 N or 0.69% (avg$F_{max}$HG) of deficit to 0.04 N/BM or 6.93% (avg$F_{rel}$HG) of suficiency in Track and field.

In our previous research[11], as a result of adaptation to long-term training load specificity on maximal force, strength and power, the values which were above the average in elite strength male athletes were established in relation to other sports. A comparison with the results published by others researchers, shows a positive correlation with our results. For example, Power Lifters usually perform heavy-resistance training programmes over the years, may have produced long term training-induced increases in the maximal voluntary neural drive to the muscles associated with increased rapid neural activation of motor units and/or selective hyperthropy or transformation of tipe II muscle fibres into stronger counterparts[3,11-13,26]. In Power Lifting, as well as in other disciplines which involves great hand grip force (Boxing, Handball, Rock climbing), where the adaptation is in strength or muscle power, it was established that there is a significant correlation between the sport discipline and the differences in strength and/or muscle power output which can be explained by training background as well[11-13,27]. The same phenomenon was established in highly trained female athletes from sports which are known to require significantly strong hand grip strength – Judo and Handball. Those athletes are significantly stronger than their untrained female counterparts[4]. Because of increased demand placed upon the upper body during climbing with increased difficulty, for example,

greater strength and endurance in the arms and shoulders could be advantageous[1].

A comparison with the results of functional dimorphism in students population[10], shows a positive correlation with our results. While comparing the results obtained in our and previous researches[10] which are related to the relations between non-dominant and dominant hand, we can agree that healthy and well-trained female at the age of 18–24 have almost the same values of functional dimorphism. There are no difference in average values of $F_{max}Nd/DoHG_{iso}$. Average value difference of $F_{max}$ $Nd/DoHG_{iso}$ between our and previous research is 0.0153 or 1.69% of deficit in absolute index values and percentage values. Similar results were established in maximal hand grip force in both dominant and non-dominant hands, as well as in mean values of relative hand grip force measured by allometric and clasic method. The difference of mean values were at the level of 0.0153 or 1.69% of deficit for $F_{max}$ $Nd/DoHG_{iso}$ to 5.07 N or 1.34% of suficit for $F_{max}DoHG_{iso}$.

## Conclusion

This work defined functional dimorphism and model characteristics of $F_{max}HG_{iso}$ in top level female athletes. With the obtained results we were able to define the influence of different sports on the observed contractile characteristics on both hands and the level of the specific adaptation in different sports, in relation to normal level of $F_{max}Nd/DoHG_{iso}$.

The average values of $F_{max}HG_{iso}$ for the dominant and non-dominant hand grip for the total sample were 381.87 ±60.28 N and 344.63±55.60 N. In relation to $F_{max}HG_{iso}$ the functional dimorphism was established for the sample tested between the dominant and non-dominant hand at the level of significance F=2.918 p=0.003, in favour of the dominant hand. The $F_{max}Nd/DoHG_{iso}$ in sample tested was established at the index level of 0.9030, in other words, the $F_{max}HG_{iso}$ of the non-dominant hand was at the level of 90.30% of the $F_{max}HG_{iso}$ of the dominant hand. With the obtained index values of $F_{max}Nd/DoHG_{iso}$ in different sports using metrologic procedure for defining sport norms[23], we were able to establish ranges of $F_{max}Nd/DoHG_{iso}$ regarding $F_{max}HG_{iso}$, which we used to classify the examinees from the different sports in following categories: dominant asymmetry of $F_{max}Nd/DoHG_{iso}$ (index value is above 0.8673), asymmetry of the $F_{max}Nd/DoHG_{iso}$ (index value is from 0.8674 to 0.8979), normal/average value of $F_{max}Nd/DoHG_{iso}$ (0.8980 to 0.9287), symmetry of $F_{max}Nd/DoHG_{iso}$ (0.9288 to 0.9594) and dominant symmetry of $F_{max}Nd/DoHG_{iso}$ regarding $F_{max}HG_{iso}$ (index value is higher than 0.9595). The average values of the measured hand grip force by the allometric method for both dominant and non-dominant hand were 24.06±3.50 $N/BM^{0.667}$ and 21.72±3.28 $N/BM^{0.667}$, respectively.The classic method yielded 0.62±0.10 N/BM and 0.56±0.09 N/BM, for the dominant and non-dominant hand, respectively.

The descriptive statistics was done in regard to different sports. The maximal average value of $F_{max}HG_{iso}$ for the dominant hand was measured in Karate (420.34± 71.31 N) and for the non-dominant hand in Skiing (383.33±17.00 N), which is understandable considering the nature of that sport. In relation to the tested sample the minimal average value of $F_{max}HG_{iso}$ for the dominant hand was measured in Table tennis players (304.00± 58.51 N), and for the non-dominant hand in Synchronised swimming (284.17±41.88 N). The maximal average value of $F_{rel}HG_{iso}$ for both dominant and non-dominant hand, defined using classic method, was measured in Karate (0.7078±0.1125, 0.6468±0.0820 N/BM), the minimal average value of $F_{max}HG_{iso}$ for the dominant hand was measured in Table tennis (0.5465±0.0739 N/BM), and for the non-dominant hand in Synchronised swimming (0.4897±0.0851 N/BM). The maximal average value of $F_{rel}HG_{iso}$ for both dominant and non-dominant hand, defined using allometric method, was measured in Karate (26.93±4.35, 24.61±3.03 $N/BM^{0.667}$), the minimal average value of $F_{max}HG_{iso}$ for the dominant hand in Table tennis (20.54±3.02 $N/BM^{0.667}$) and for the non-dominant hand in Synchronised swimming (18.66±2.88 $N/BM^{0.667}$).

Multivariate statistical analysis established statistically significant difference for all tested contractile characteristics at the level of Wilks' Lambda 0.476, F=3.276, p=0.000 between the observed sub-samples. Statistically significant difference was also established in all tested contractile sub-fields regarding the function the observed sub-samples of different sports.

The results obtained will be useful while assessing decision criteria, for diagnostic purposes – standardised tests, for metrological purposes – analytic aspect of the obtained results, and for health purposes – defining level of adaptation, level of normal $F_{max}Nd/DoHG_{iso}$ changes regarding the observed contractile characteristics of hand grip.

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## FUNKCIONALNI DIMORFIZAM I KARAKTERISTIKE MAKSIMALNE SILE STISKA ŠAKE KOD VRHUNSKIH SPORTAŠA ŽENSKOG SPOLA

### S A Ž E T A K

Cilj rada je definiranje funkcionalnog dimorfizma ($F_{max}Nd/DoHG_{iso}$) i modela karakteristika maksimalne izometrijske sile stiska šake obje ruke ($F_{max}HG_{iso}$) kod vrhunskih sportaša ženskog spola. Testirano je 275 vrhunskih sportaša ženskog spola iz: tekvondoa, sinhronog plivanja, lake atletike, odbojke, karatea, skijanja, rukometa, stolnog tenisa, dobro trenirane studentice Kriminalističko-policijske akademije (KPA) i kontrolne skupine. Za procjenu $F_{max}HG_{iso}$ korištena je standardizirana oprema, klizni instrument za mjerenje izometrijske sile pregibača prstiju sa tenziometrijskom sondom unutar nje. Srednje vrijednosti $F_{max}HG_{iso}$, relativne sile definirane alometrijskom metodom i relativne sile primjenom klasične metode stiska dominantne i nedominantne ruke na razini cijelog uzorka bile su: 381,87±60,28, 344,63±55,60 N; 24,06±3,50, 21,72±3,28 $N/BM^{0.667}$; 0,62±0,10, 0,56±0,09 N/BM. Srednja vrijednost $F_{max}Nd/DoHG_{iso}$ bila je na razini od 0,924±0,0752. Generalna statistički značajna razlika svih ispitivanih kontraktilnih karakteristika je na razini Wilks Lambda 0,357, F=3,853, p=0,000. Najveća srednja vrijednost $F_{max}HG_{iso}$ dominantne i nedominantne ruke izmjerene je kod karatea (372,04±46,71, 407,04±71,31 N) a najmanja kod stolnog tenisa (282,00±56,00, 304,00±58,51 N). Kod kontrolne skupine je najizraženiji funkcionalni dimorfizam 0,8771±0,0877. Na temelju napravljene klasifikacija funkcionalnog dimorfizma ispitanici iz različitih sportskih grana su razvstani u 4 skupine: dominantna simetrija (skijanje>0,9595); simetrija (tekvondo i stolni tenis 0,9288 do 0,9594); prosječni, tj. prirodni funkcionalni omjer (karate, odbojka, KPA, laka atletika 0,8980 do 0,9287); asimetrija (kontrolna, sinhrono plivanje, rukomet 0,8674 do 0,8979). Na temelju dobivenih podataka biti će moguće izračunati kriterije odluka, sa aspekta dijagnostičkih procedura, sa metrološkog aspekta, sa normativno-zdravstvenog aspekta.