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MAXIMAL AND EXPLOSIVE STRENGTH NORMATIVE DATA FOR HANDGRIP TEST ACCORDING TO GENDER: INTERNATIONAL STANDARDIZATION APPROACH

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ABSTRACT
Purpose. In daily living, hands are the basic organs for manipulative tasks of the human body, and they are specialized for various motor tasks with different physical object contact situations. Insufficient strength during aging constitutes a key component of sarcopenia and is associated with subsequent disability and mortality. The simplest and very valid test for assessing general strength is the handgrip test, and the need for international standards for grip strength seems very essential. The study aimed to set normative data for different handgrip strength dimensions in an international healthy adult community.
Methods. The maximal muscle force and maximal explosive muscle force for dominant and non-dominant hand were examined across 838 subjects from 11 countries. The result values were compared with the internationally published findings for external validation.
Results. The mean value for both hands maximal strength in an adult male was 997 ± 176 N for the absolute and 11.78 ± 1.95 N/kg for the relative measure; in females, the respective values equalled 550 ± 110 N and 8.49 ± 1.79 N/kg. The mean value for maximal explosive strength in an adult male was 6473 ± 1420 N/s for the absolute and 76.47 ± 16.22 N/s/kg for the relative measure; in adult females, the respective values equalled 3506 ± 915 N/s and 54.13 ± 14.38 N/s/kg.
Conclusions. The normative reference values provided in this study may serve as an international guide for interpreting maximal and explosive handgrip strength measurements obtained from healthy adult individuals of both genders.
Key words: handgrip, maximal strength, explosive strength, international standards, normative values

Introduction

The human hand is one of the most distinctive organs of humankind in terms of interaction with the environment. Also, it plays a primary role in the successful evolution of humans [1]. In daily life, hands are the basic organs for manipulative tasks of the human body, and they are specialized for various motor skills to interact with physical objects [2]. This is the biological reason why the handgrip movement and achieved strength dimensions are recognized as a limiting factor in all the manipulative activities by the upper part of the body, regardless of whether this refers to daily activities, work and the professional environment, or sports [3–5].

The hand uses a mechanism to grab handles and large heavy tools with the power grip, whereby all fingers are flexed around objects [2]. The power grip is

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the most primitive but also the most powerful grasping movement, which makes it a very convenient position for testing, especially for arms and cranial parts of the body. Because of that, the handgrip strength is a well-known test which can be easy to use for different population samples [3, 4, 6–9]. Besides that, handgrip strength dimensions have been recognized as valuable biomarkers of general health status, and they have been recommended as valid indicators of overall muscle body strength, independent of age and gender [10–16].

The following 2 dimensions of isometric muscle strength are considered as the most representative mechanical contractile characteristics: maximal isometric muscle force (F_{max}) and maximal isometric rate of force development (RFD_{max}) [5, 17, 18]. Both of them are enumerated among the most important muscle contractile dimensions considering measurements of physical abilities, regardless of whether referring to healthy people, people with certain health risk, or athletes [4, 7, 8, 12, 14, 16].

The mentioned mechanical contractile characteristics can be easily evaluated by applying the maximum handgrip test, as a highly reliable, valid, easy to administer, and widely utilized useful testing tool in the general adult population, as a robust marker of aging and general health status [12, 19, 20].

Given all the previously mentioned advantages, and with a very simple measurement procedure, the handgrip test is mostly applied in population studies, especially in population-based cross-sectional studies, to describe muscular fitness during aging, using age-group standards and normative values [21–24].

However, all population studies already published have defined normative standards with internal validation of data, i.e. only with the national population. The second concept of the mentioned studies involved only one muscular dimension, i.e. maximal strength (F_{max}). Unfortunately, maximal explosiveness (RFD_{max}), for which there are scientific facts considering health and life well-being effects, has no defined standards yet [7, 25]. Also, the following benefits associated with RFD_{max} can be recognized as important functional consequences as the characteristic determines the force that can be generated in the early phase of muscle contraction (0–200 ms). According to the recently published research, it seems that RFD is better related to performance in sports-specific and daily task functioning and more sensitive than F_{max} to detect chronic and acute changes in neuromuscular function, which can be essential for a researcher in sports sciences and human exercise physiology, as well as for practice in the field of rehabilitation, health, aging, and physical training [7, 18].

Besides, it is very important for sports performance because it has been used to evaluate the capacity to rapidly generate muscular force, and it is a determinant of the neural factor of muscle contraction [17].

Since it is known that lack of optimal strength is a key component of sarcopenia and is associated with subsequent disability and mortality, the need for international specific standards for handgrip strength dimensions from a health prevention diagnostics point of view seems to be very essential. For these reasons, the study aimed to set normative data for different handgrip strength dimensions (F_{max} and RFD_{max}) for healthy adults of both genders on the international level of standards.

Material and methods

Study design

The research was conducted via a multicentre retrospective cohort study while applying laboratory and field testing procedures. The direct measurement was used with an isometric testing protocol [4, 5, 8]. All measurements were made with the same equipment by the same researchers and under the same testing procedures during the period of 2016–2020. The research followed the Declaration of Helsinki [26].

Subject sample

In this research, we analysed the results of a handgrip test conducted in a sample of 838 subjects from 11 countries (Croatia: n = 27, Cyprus: n = 18, Germany: n = 21, Hungary: n = 29, Italy: n = 15, Lebanon: n = 19, Lithuania: n = 54, Russia: n = 219, Serbia: n = 326, Slovenia: n = 96, Spain: n = 14). The general descriptive data of the sample were as follows. For males (n = 444): age: 37.0 ± 14.0 years, body height: 182.0 ± 7.0 cm, body mass: 85.5 ± 13.0 kg, body mass index: 26.0 ± 4.0 kg/m^2. For females (n = 394): age: 37.0 ± 13.0 years, body height: 168.0 ± 7.0 cm, body mass: 66 ± 12.0 kg, body mass index: 23.0 ± 4.0 kg/m^2.

All respondents were healthy adult individuals from the general population. They were informed about the purpose of the study and voluntarily accepted to be involved in the study. Participants were excluded if they were suffering from an injury at the time of handgrip assessment, had undergone any arm or hand injury within the previous 6 months, or had undergone surgery of either hand or wrist in the previous year. Also, non-communicable diseases and hormonal disorders were among the exclusion criteria.

Testing procedure

The handgrip isometric test protocol was carried out with standardized procedures and equipment, i.e. a handgrip device (Figure 1) with a fixed strain gauge (Sports Medical Solutions, All4gym d.o.o., Serbia) was used to measure the mechanical characteristics of isometric handgrip strength [20]. During the test, the subjects were sitting upright in the middle of a chair with an extended arm and holding the measuring device in the tested hand, in accordance with the procedure explained in previously published literature [4, 5, 7, 20, 27]. The earlier published results have shown that the applied handgrip test is highly reliable, with the intraclass correlation coefficient ranging 0.938–0.977 for F_{max} and 0.903–0.971 for RFD_{max} [27].

Before the handgrip testing procedures, verbal explanation was given; each examinee performed 2 pretrial familiarization measurements, alternating the hands randomly, at a moderate effort. After a 2-minute rest, the handgrip test was carried out. The power grip, as the strongest grip, was used. The subjects were asked to exert the strongest and quickest possible pressure on the device on the researcher's sign, holding the grip for a minimum of 2 seconds, while the verbal encouragement was provided [5, 20, 27]. The handgrip test of the dominant and non-dominant hand was conducted twice (in a randomized order), with a 1-minute interval between the trials. During the testing, the participants were instructed to keep their arms by their side, and the tested arm was placed in the slightly abducted position (approximately 5–10 cm), without touching the body or the chair.

F_{max} and RFD_{max} were recorded from each trial using a laptop computer. The maximal force was assessed through the maximum of the achieved muscle force level (F_{max}), and RFD_{max} was calculated as the maximal slope of the force-time curve (over the first derivative of the force-time curve) with regard to the force onset [5, 28]. The onset of the contraction was defined as the point in time when the first derivative of the force-time curve exceeded the baseline by 3% of its maximal value. The strain gauge used in the handgrip test was connected to a force reader with the precision of ± 0.1 N. The force-time signal was sampled at 500 Hz (i.e. 500 samples per second) and low-pass filtered (10 Hz) with a fourth-order (zero-phase lag) Butterworth filter, and RFD_{max} was calculated with the method of the instantaneous slope of force-time relation considering the measurement time interval [5, 28].

A software-hardware system specially designed for isometric measurement (Sports Medical Solutions Isometrics, ver. 3.4.0) was used for data collection and processing. All test results for variables were recorded

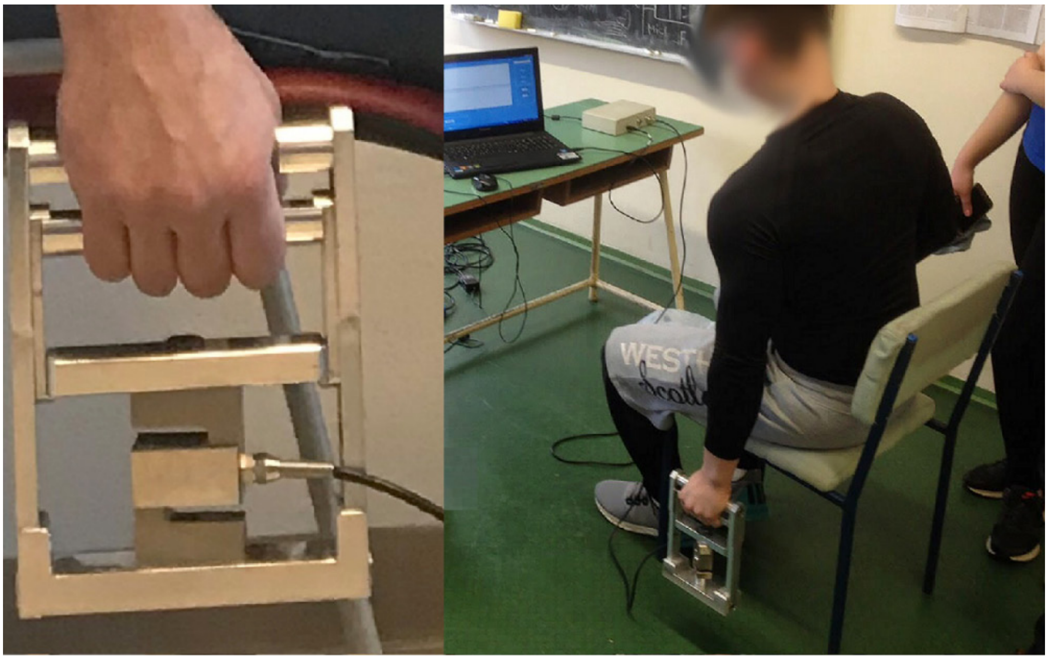


Figure 1. Sports Medical Solutions handgrip device with a fixed strain gauge

in a specialized database, and the better result was used for data processing and statistical analysis.

Variables

As most representative handgrip variables, we used the following, expressed in absolute and relative aspects.

Variables for maximal mechanical force dimensions, considering the absolute aspect, were:

1. F_{max}_D, F_{max}_ND, and F_{max}_SUM: maximal muscle force for the dominant (D) and non-dominant (ND) hand, and summarized (SUM) value of maximal muscle force for the D and ND hand, expressed in newtons (N).

2. RFD_{max}_D, RFD_{max}_ND, and RFD_{max}_SUM: maximal explosive muscle force for the D and ND hand, and summarized (SUM) value of maximal explosive muscle force for the D and ND hand, expressed in newtons per second (N/s).

Variables for maximal mechanical force dimensions, considering the relative aspect, were:

3. F_{rel}_D, F_{rel}_ND, and F_{rel}_SUM: relative aspects of maximal muscle force for the D and ND hand, and summarized (SUM) value for the D and ND hand, expressed in newtons per kilogram of body mass (N/kg).

4. RFD_{rel}_D, RFD_{rel}_ND, and RFD_{rel}_SUM: relative aspects of maximal explosive muscle force for the D and ND hand, and summarized (SUM) value for the D and ND hand, expressed in newtons per second per kilogram of body mass (N/s/kg).

Statistical procedures

For all variables, basic descriptive statistics were calculated: mean value, standard deviation, and coefficient of variation, as central tendency measures and dispersion of raw data. For the real range of data, minimal and maximal values are shown, while for defining critical ranges for the observed data, the 95% confidence interval for mean with lower and upper bound reference line was calculated. Because of the multicentre nature of the study, the accuracy of overall measurement procedures was calculated with the absolute value of the standard error of the mean. For normative values, 2 different metrological procedures were used: calculation 7D metrological procedures and percentile distribution standards [29, 30]. All statistical analyses were carried out with the SPSS Win Statistics 23.0 software package, with the probability level of 95% and a *p*-value of 0.05 [31].

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethical Committee of the Faculty of Sport and Physical Education, University of Belgrade, under the number of 484–2.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

In Table 1, descriptive data are shown for the explored variables, depending on gender. Table 2 presents the calculated international handgrip standards for the observed variables for each gender. Figures 2 and 3 depict the boxplot distribution for the absolute and relative values, respectively, of maximal muscle force and maximal explosive muscle force for male and female subjects. Table 3 presents the percentile standards for handgrip muscle force by gender. In Figures 4–7, external validation data for F_{max}_SUM and RFD_{max}_SUM for male and female subjects are shown for comparison of the actual results with those of other published studies that used the same method of measurement.

Discussion

The study demonstrated (Table 1) that the mean value for maximal handgrip strength for an adult male was 997 ± 176 N (512.4 and 484.5 for the dominant and non-dominant hand, respectively), considering the absolute measure, and 11.78 ± 1.95 N/kg (6.1 and 5.7 for the dominant and non-dominant hand, respectively) as a relative measure. As for the explosive strength, for an adult male, the mean value for maximal explosive handgrip strength was 6473 ± 1420 N/s (3347.7 and 3124.9 for the dominant and non-dominant hand, respectively) as an absolute and 76.47 ± 16.22 N/s/kg (39.5 and 36.9 for the dominant and non-dominant hand, respectively) as a relative measure. Regarding the female results, the mean value for maximal handgrip strength was 550 ± 110 N (284.1 and 265.8 for the dominant and non-dominant hand, respectively), considering the absolute measure, and 8.49 ± 1.79 N/kg (4.4 and 4.1 for the dominant and non-dominant hand, respectively) as a relative measure. As for the explosive strength, it was observed that the

Table 1. Descriptive data for the explored variables by gender

Variables		Mean	*SD*	CV%	SEM	95% CI lower bound	95% CI upper bound	Min	Max
Males									
F_{max} (N)	D	512.4	95.1	18.6	4.5	503.5	521.2	221.0	859.0
	ND	484.5	86.9	17.9	4.1	476.4	492.6	238.0	821.0
	SUM	997.0	176.0	17.6	8.3	981.0	1013.0	532.0	1680.0
RFD_{max} (N/s)	D	3347.7	757.5	22.6	35.9	3277.1	3418.4	782.0	5572.0
	ND	3124.9	716.9	22.9	34.0	3058.0	3191.7	955.0	5267.0
	SUM	6473.0	1420.0	21.9	67.4	6340.0	6605.0	1737.0	10,645.0
F_{rel} (N/kg)	D	6.1	1.0	16.4	0.1	5.9	6.1	3.0	9.3
	ND	5.7	1.0	17.5	0.1	5.6	5.8	2.8	8.8
	SUM	11.8	1.9	16.5	0.1	11.6	12.0	6.2	17.8
RFD_{rel} (N/s/kg)	D	39.5	8.6	21.8	0.4	38.7	40.3	9.5	63.4
	ND	36.9	8.3	22.5	0.4	36.1	37.7	11.7	60.6
	SUM	76.5	16.2	21.2	0.8	75.0	78.0	21.2	124.0
Females									
F_{max} (N)	D	284.1	57.0	20.1	2.9	278.4	289.7	115.0	530.0
	ND	265.8	57.7	21.7	2.9	260.0	271.4	122.0	491.0
	SUM	550.0	110.0	20.0	5.5	539.0	561.0	259.0	1010.0
RFD_{max} (N/s)	D	1858.3	500.7	26.9	21.6	1776.6	1940.1	488.0	15,016.0
	ND	1681.7	434.5	25.8	23.4	1635.7	1727.7	552.0	3537.0
	SUM	3506.0	915.0	26.1	46.1	341.0	3596.0	1148.0	7790.0
F_{rel} (N/kg)	D	4.4	0.9	20.5	0.1	4.3	4.5	1.7	7.0
	ND	4.1	0.9	21.9	0.1	4.0	4.2	1.4	6.6
	SUM	8.5	1.8	21.1	0.1	8.3	8.7	3.9	13.3
RFD_{rel} (N/s/kg)	D	28.7	7.5	26.1	0.6	27.4	29.6	7.3	50.1
	ND	26.0	7.0	26.9	0.4	25.3	26.7	6.4	48.6
	SUM	54.1	14.4	26.6	0.7	52.7	55.6	17.1	102.9

SD – standard deviation, CV% – coefficient of variation, SEM – standard error of the mean, CI – confidence interval, F_{max} – maximal muscle force, RFD_{max} – maximal explosive muscle force, F_{rel} – relative aspect of maximal muscle force, RFD_{rel} – relative aspect of maximal explosive muscle force, D – dominant hand, ND – non-dominant hand, SUM – summarized for both hands

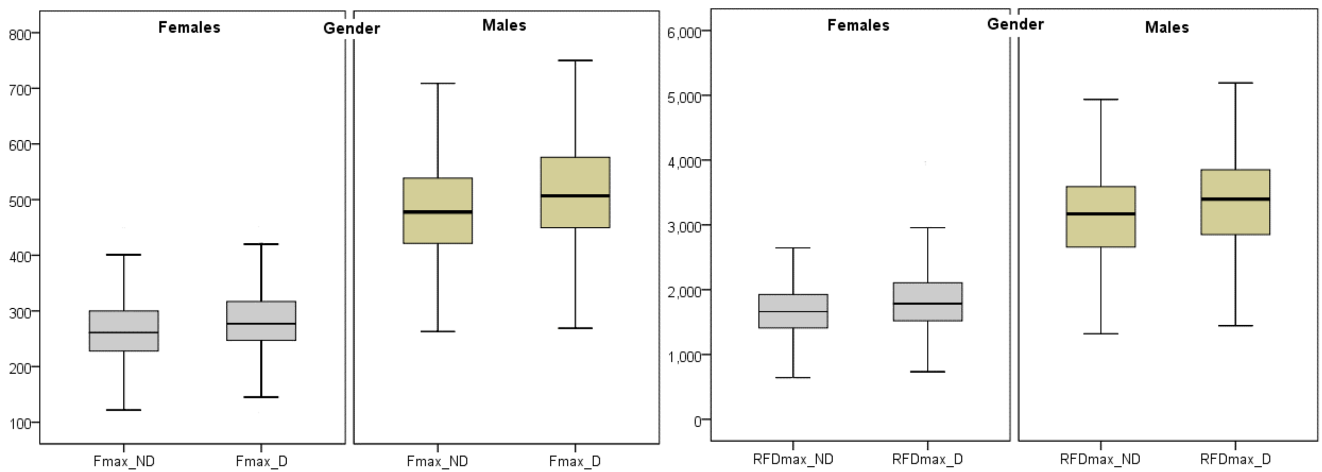


Figure 2. Boxplot distribution for maximal muscle force (F_{max}) and maximal explosive muscle force (RFD_{max}) for the dominant (D) and non-dominant (ND) hand among male and female subjects

Table 2. Handgrip muscle strength normative standards for the observed variables by gender

Variables		Superior	Excellent	Above standard	Standard values	Below standard	Poor	Very poor
Males								
F_{max} (N)	D	≥ 703	702–607	606–560	559–465	464–417	416–322	≤ 321
	ND	≥ 658	657–571	570–528	527–441	440–398	397–311	≤ 310
	SUM	≥ 1349	1173–1348	1085–1172	910–1084	821–909	646–820	≤ 645
RFD_{max} (N/s)	D	≥ 4863	4862–4105	4104–3726	3725–2969	2968–2590	2589–1833	≤ 1832
	ND	≥ 4559	4558–3842	3841–3483	3482–2766	2765–2408	2407–1691	≤ 1690
	SUM	≥ 9314	7894–9313	7183–7893	5763–7182	5053–5762	3632–5052	≤ 3631
F_{rel} (N/kg)	D	≥ 8.1	8.1–7.1	7.1–6.6	6.6–5.5	5.5–5.0	5.0–4.0	≤ 4.0
	ND	≥ 7.7	7.7–6.7	6.7–6.2	6.2–5.2	5.2–4.7	4.7–3.7	≤ 3.7
	SUM	≥ 15.7	13.7–15.7	12.8–13.7	10.8–12.8	9.8–10.8	7.9–9.8	≤ 7.9
RFD_{rel} (N/s/kg)	D	≥ 56.7	56.7–48.1	48.1–43.8	43.8–35.2	35.2–30.9	30.9–22.3	≤ 22.3
	ND	≥ 53.5	53.5–45.2	45.2–41.1	41.1–32.8	32.8–28.7	28.7–20.4	≤ 20.4
	SUM	≥ 108.9	92.7–108.9	84.6–92.7	68.4–84.6	60.3–68.4	44.0–60.3	≤ 44.0
Females								
F_{max} (N)	D	≥ 398	397–341	340–312	311–255	254–227	226–170	≤ 169
	ND	≥ 381	380–323	322–295	294–237	236–208	207–150	≤ 149
	SUM	≥ 770.0	769–660	659–605	604–495	494–440	439–330	≤ 329
RFD_{max} (N/s)	D	≥ 2805	2804–2314	2313–2069	2068–1579	1578–1334	1333–843	≤ 842
	ND	≥ 2611	2610–2146	2145–1914	1913–1449	1448–1217	1216–753	≤ 752
	SUM	≥ 5336	5335–4421	4420–3964	3963–3048	3047–2591	2590–1676	≤ 1675
F_{rel} (N/kg)	D	≥ 6.2	6.2–5.3	5.3–4.8	4.8–3.9	3.9–3.5	3.5–2.5	≤ 2.5
	ND	≥ 6.0	6.0–5.0	5.0–4.6	4.6–3.6	3.6–3.2	3.2–2.2	≤ 2.2
	SUM	≥ 12.1	12.1–10.3	9.4–10.3	7.6–9.4	6.7–7.6	4.9–6.7	≤ 4.9
RFD_{rel} (N/s/kg)	D	≥ 43.6	43.6–35.9	35.9–32.0	32.0–24.3	24.3–20.5	20.5–12.8	≤ 12.8
	ND	≥ 40.5	40.5–33.2	33.2–29.6	29.6–22.3	22.3–18.7	18.7–11.4	≤ 11.4
	SUM	≥ 82.9	68.5–82.9	61.3–68.5	46.9–61.3	39.8–46.9	25.4–39.7	≤ 25.4

F_{max} – maximal muscle force, RFD_{max} – maximal explosive muscle force, F_{rel} – relative aspect of maximal muscle force, RFD_{rel} – relative aspect of maximal explosive muscle force, D – dominant hand, ND – non-dominant hand, SUM – summarized for both hands

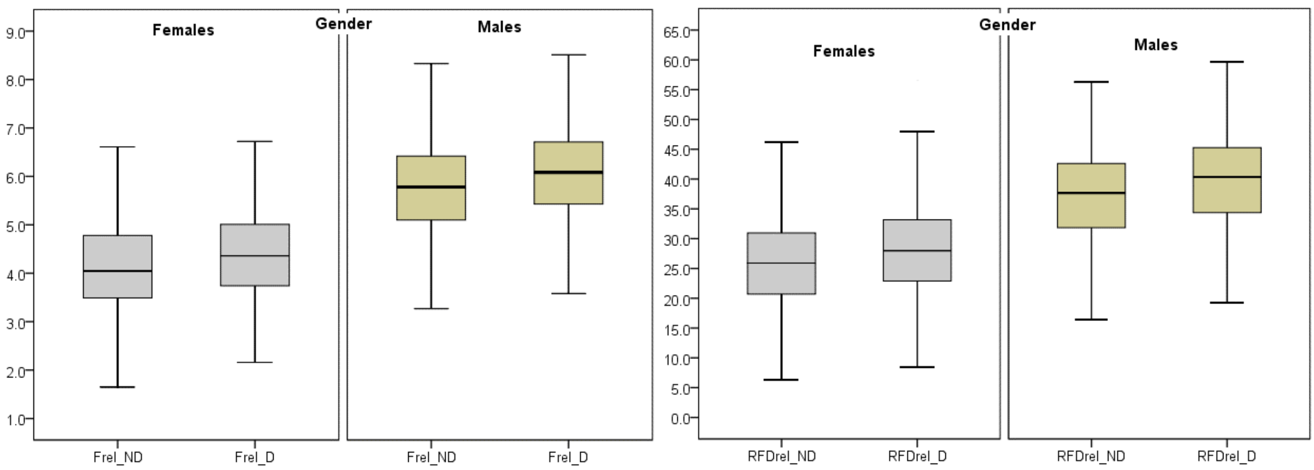
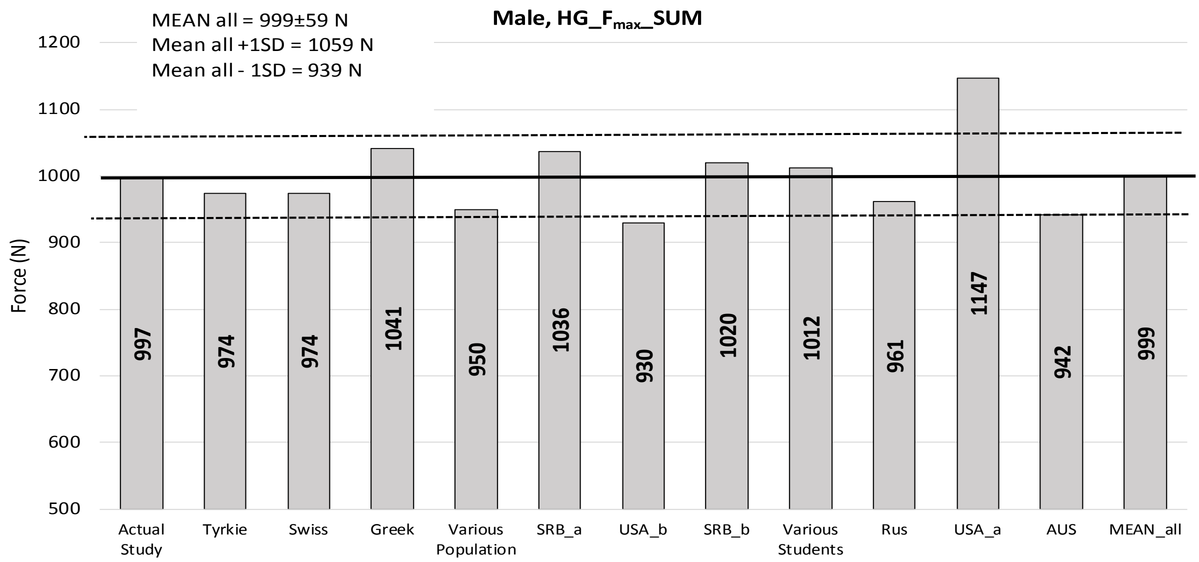


Figure 3. Boxplot distribution for the relative aspects of maximal muscle force (F_{rel}) and maximal explosive muscle force (RFD_{rel}) for the dominant (D) and non-dominant (ND) hand among male and female subjects

Table 3. Handgrip muscle force percentile standards for the observed variables by gender

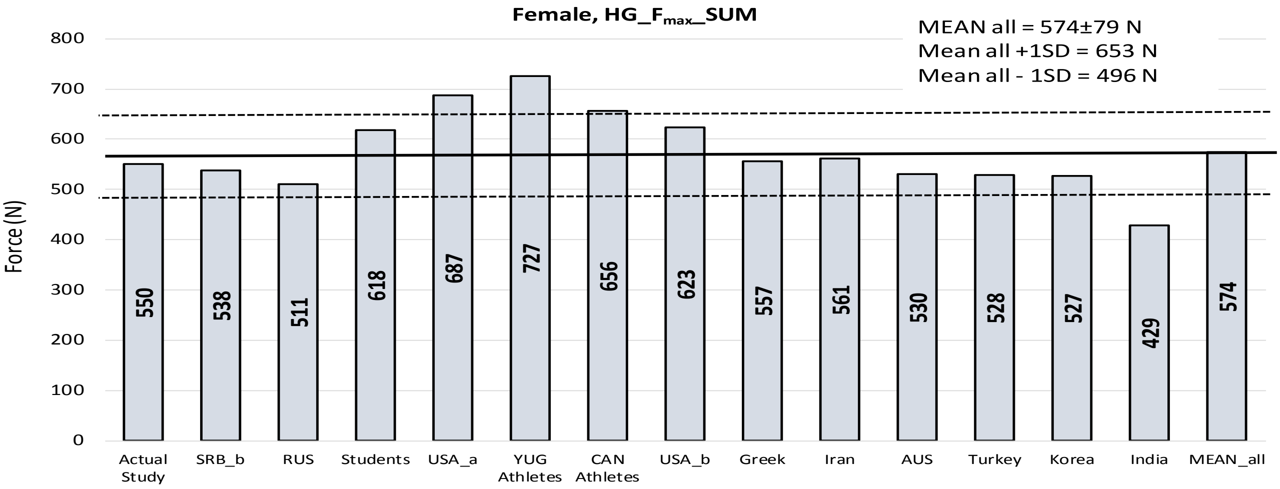
Percentiles		F_{max}_D	F_{max}_ND	F_{max}_SUM	RFD_{max}_D	RFD_{max}_ND	RFD_{max}_SUM	F_{rel}_D	F_{rel}_ND	F_{rel}_SUM	RFD_{rel}_D	RFD_{rel}_ND	RFD_{rel}_SUM
Males (*n* = 444)	2.5	335	323	686	1672	1642	3527	4.0	3.7	8.1	20.8	18.4	40.3
	5	367	350	722	2040	1852	3860	4.3	4.1	8.4	22.8	22.3	45.2
	10	400	378	775	2314	2157	4482	4.8	4.3	9.2	28.4	26.4	54.5
	30	466	441	915	3024	2751	5810	5.5	5.2	10.8	35.5	33.4	69.1
	50	507	478	980	3395	3172	6603	6.1	5.8	11.9	40.4	37.7	78.6
	70	562	522	1077	3746	3516	7229	6.5	6.3	12.8	44.2	41.6	85.1
	90	631	599	1214	4219	3936	8029	7.3	6.9	14.1	49.4	47.1	95.0
	95	676	636	1300	4560	4354	8701	7.6	7.2	14.6	51.9	49.7	100.0
	97.5	719	659	1406	4946	4601	9605	8.2	7.7	16.0	56.0	52.8	106.8
Females (*n* = 394)	2.5	191	165	367	929	821	1879	2.6	2.3	5.2	13.4	11.7	25.8
	5	201	180	389	1079	930	2119	2.9	2.6	5.6	15.8	15.0	31.8
	10	222	198	419	1246	1099	2378	3.2	2.9	6.2	18.3	16.9	36.2
	30	252	233	490	1577	1452	3060	3.9	3.6	7.5	24.2	21.7	46.1
	50	277	261	539	1787	1661	3463	4.4	4.0	8.4	28.1	25.9	53.6
	70	310	292	595	2030	1857	3866	4.8	4.7	9.4	31.8	30.1	61.2
	90	352	330	682	2423	2234	4587	5.7	5.3	10.9	38.1	35.9	72.9
	95	381	358	738	2707	2397	4993	5.9	5.6	11.5	40.2	37.7	76.7
	97.5	430	399	819	2962	2905	5826	6.3	5.9	11.9	43.9	40.6	81.4

F_{max} – maximal muscle force, RFD_{max} – maximal explosive muscle force, F_{rel} – relative aspect of maximal muscle force, RFD_{rel} – relative aspect of maximal explosive muscle force, D – dominant hand, ND – non-dominant hand, SUM – summarized for both hands



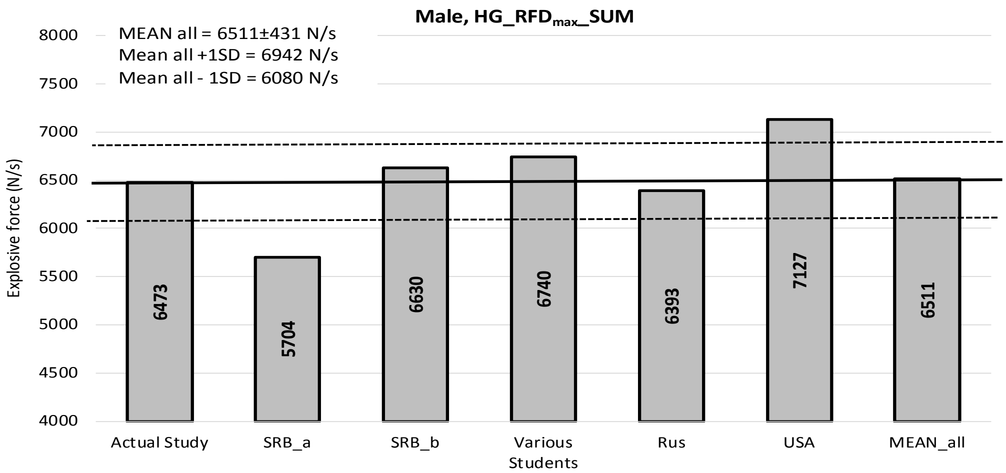
Data adopted from: Werle et al. [32], Mitsionis et al. [33], Hogrel [34], Eksioglu [35], Perna et al. [6], Marković et al. [27], Wang et al. [24], Dopsaj et al. [5], Wang et al. [36], Marković et al. [20].

Figure 4. External validation data for handgrip (HG) summarized maximal muscle force (F_{max}_SUM) for male subjects



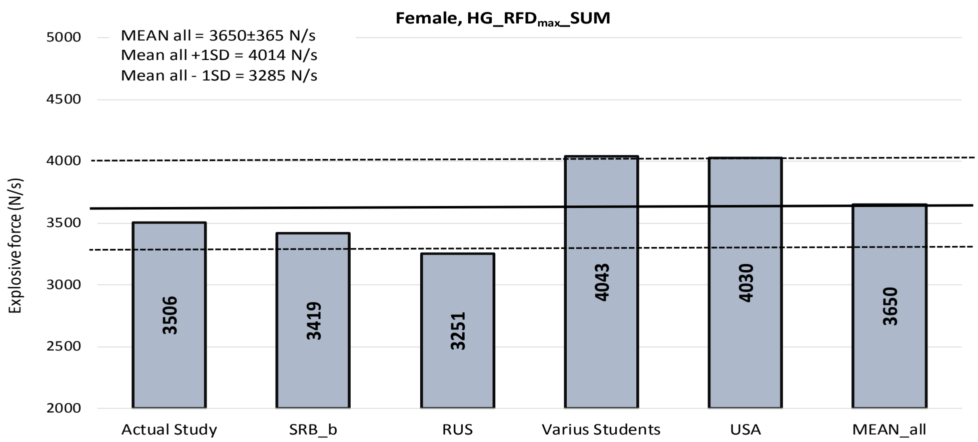
Data adopted from: Keogh et al. [37], Koley et al. [38], Mitsionis et al. [33], Ivanović and Dopsaj [39], Mohammadian et al. [40], Hogrel [34], Eksioglu [35], Perna et al. [6], Wang et al. [24], Zaric et al. [4], Dopsaj et al. [5], Wang et al. [36].

Figure 5. External validation data for handgrip (HG) summarized maximal muscle force (F_{max}_SUM) for female subjects



Data adopted from: Hogrel [34], Perna et al. [6], Dopsaj et al. [8], Marković et al. [27], Wang et al. [24], Dopsaj et al. [5], Wang et al. [36].

Figure 6. External validation data for handgrip (HG) summarized maximal explosive muscle force (RFD_{max}_SUM) for male subjects



Data adopted from: Perna et al. [6], Wang et al. [24], Zaric et al. [4], Dopsaj et al. [5], Wang et al. [36].

Figure 7. External validation data for handgrip (HG) summarized maximal explosive muscle force (RFD_{max}_SUM) for female subjects

mean value for maximal explosive handgrip strength for an adult female was 3506 ± 915 N/s (1858.3 and 1681.7 for the dominant and non-dominant hand, respectively) as an absolute and 54.13 ± 14.38 N/s/kg (28.7 and 26.0 for the dominant and non-dominant hand, respectively) as a relative measure.

With reference to the parameters of homogeneity and accuracy of measurement, it can be concluded that the data can be accepted as homogeneous (because the coefficient of variation was between 16.4% and 26.9%) (Table 1).

In the general Australian population, Egger et al. [41] suggest that the average sum for male handgrip strength was 96 kg (942 N), while the average sum for females was 54 kg (530 N). Wang et al. [24, 36] found that the handgrip isometric strength obtained from dominant and non-dominant hands of male and female participants equalled 93.8 kg (919.8 N) and 59 kg (578.5 N), respectively. Both studies indicated scores below the present results, but still in line with the normal standard range of normative handgrip data.

Comparing with the results of other studies [3, 5, 6, 9, 10, 24, 25, 27, 32–34, 36–41] which were performed with the same measurement method, genders, and ages, it can be confirmed that the external validity of our results is acceptable because the average values for the variables of F_{max}_SUM and RFD_{max}_SUM are in the range of one standard deviation from the previously published findings (Figures 4–7). Still, there are no suitable studies which would investigate the observed handgrip strength contractile characteristics in the relative aspect (dependent on body mass), so, unfortunately, the current data cannot be externally validated.

However, considering the values of the index of gender dimorphism (Figures 2 and 3) as the ratio of measured variables between sexes [42], it can be stated that the results for the variables of F_{max}_SUM, RFD_{max}_SUM, F_{rel}_SUM, and RFD_{rel}_SUM in females were at the level of 0.552 (55.2%), 0.542 (54.2%), 0.721 (72.1%), and 0.708 (70.8%) as compared with men, respectively. In other words, men were absolutely and relatively stronger and more explosive than women at the ratio of 1.81, 1.85, 1.39, and 1.41, respectively.

Overall, considering the handgrip normative data for the general population of healthy adults, it can be concluded that we can accept the following standard (average) values of maximal and explosive strength: F_{max}_SUM of 910–1084 N and 495–604 N, as well as RFD_{max}_SUM of 5763–7182 N/s and 3048–3963 N/s for males and females, respectively (Table 1). As for the relative handgrip strength aspect, the following standard values can be accepted: F_{rel}_SUM of 10.8–12.75 N/kg and 7.60–9.38 N/kg, as well as RFD_{rel}_SUM of 68.37–84.58 N/s/kg and 46.94–61.32 N/s/kg for males and females, respectively (Table 2).

Also, the results imply that the relative values of measurement errors, expressed as the average for the dominant and non-dominant hand and calculated as (standard error of the mean / mean) × 100, for the strength characteristics determined in the handgrip test by using a measuring instrument, were very small. They equalled 0.86% and 1.08% in the male sample and 1.06% and 1.28% in the female sample for F_{max} and RFD_{max}, respectively (Table 1). This proves that the accuracy of the applied measurement method and instrument is very high, which allows the conclusion that the obtained data are valid for scientific interpretation.

Thus, we can infer that humans, who can be characterized as extremely handgrip strong individuals (Table 2), can achieve an F_{max}_SUM and RFD_{max}_SUM greater than 1349 N ((≥ 703 N for the dominant and (≥ 658 N for the non-dominant hand) and greater than 9314 N/s (≥ 4863 N/s for the dominant and ≥ 4559 N/s for the non-dominant hand) in males, and greater than 770 N (≥ 398 N for the dominant and ≥ 381 N for the non-dominant hand) and greater than 5336 N/s (≥ 2805 N/s for the dominant and ≥ 2611 N/s for the non-dominant hand) in females. However, if a person cannot produce more than 7.9 or 4.9 N/kg of relative strength value or more than 44.0 or 25.4 N/s/kg of relative explosive strength value as a sum of left and right handgrip results, according to the actual normative data, they can be classified as a very weak handgrip individual (male or female, respectively; Table 2).

The analogue normative scale, expressed in percentile distribution standards (Table 3), showed very similar cut-off zones, which implies that both types of data can be used, depending on the chosen classification methodology.

Conclusions

On the basis of the parameters of homogeneity and accuracy of measurement, it can be concluded that the data can be recognized as homogeneous and as accurate, which means that the suggested nominal normative values can be accepted with a high level of internal validity, regardless of gender. When comparing the findings with the results of other studies which were performed with the same measurement method, genders, and ages, it can be confirmed that the external validity of our results is highly acceptable because the average values for the variables of F_{max}_SUM and

RFD_{max}_SUM are in the range of one standard deviation from the previously published, i.e. scientifically validated findings.

A study of this type presents the permanently valid level of interest of the scientific research to increase the fundamentals of knowledge and to perfect the testing procedures in health diagnostics, therapy, rehabilitation, and sports. The normative reference values provided in this study may serve as an international guide for interpreting grip strength measurements obtained from tested individuals.

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Disclosure statement

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Conflict of interest

The authors state no conflict of interest.

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