MEASUREMENT SCIENCE REVIEW, **24**, (2024), No. 5, 193-199

sciendo

ISSN 1335-8871

MEASUREMENT SCIENCE REVIEW

Journal homepage: https://content.sciendo.com

Metric Stability of One Month Handgrip Maximal and Explosive Isometric Strength Measured by Classic and Impulse Contractions

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Abstract: The aim of this study is to determine the metric stability of the one-month handgrip test (HGT) in order to define the contractile characteristics of the biological variation of maximal isometric strength (F_{max}) and maximal isometric rate of force development (RFD_{max}) of the handgrip in two different testing regimes (classic and impulse). The study was conducted with a total of 16 participants (11 men and 5 women). Testing was performed using an isometric handgrip probe with a standardized test protocol and equipment sports medical solutions (SMS). The results of F_{max} showed a low relative standard error of the mean (RS = 1.33 %), a high value of inter-class correlation (ICC = 0.996), and no statistically significant change in trend ($p > 0.05$) during the testing period. Therefore, can conclude that the HGT procedure in classic mode can be used as a stable parameter in a human subject sample. However, the RFD_{max} results showed a low RS (2.13 %) and a high ICC value (0.996), but a statistically significant change of trend ($p < 0.05$) during the measurement period. The regression constant (RCO) trend was 42.629 N/s, which can be attributed to learning or to the adaptive effects of the test procedure, which triggered similar adaptation processes as the training. In general, it can be concluded that the handgrip can be used to sensitively measure the effects of different long-term health improvements, or the effects of different medical/health exercises, rehabilitation programs, effects of medication applications, or dietary supplements for F_{max}. However, further research should be conducted for the RFD_{max} considering the metric stability parameters.

Keywords: Reliability, strength, dynamometer, health.

1. Introduction

The hands are specialized manipulation organs of the human body that can perform different tasks with different physical objects and apply different muscle forces depending on the type and intensity of the load [1]. Maximum muscle strength can be measured with different types of dynamometers in different contraction modes, including the most commonly used isometric mode as well as concentric and eccentric modes [2].

The handgrip dynamometer serves as a diagnostic tool for measuring handgrip strength (HGS). It is valuable for assessing congenital or acquired abnormalities of the hand and objectively tracking and evaluating the healing progress of hand or upper limb injuries. This non-invasive and rapid test is used in clinical settings and research studies that rely predominantly on mechanical dynamometers to provide data related solely to maximum HGS [3].

The handgrip test (HGT) is one of the tests that can be used to assess the general muscle strength potential of the body [1] and provides information on nutritional status and muscle mass, physical function, health status [4], and overall body strength [5]. The test helps in the assessment of hand injuries, work capacity, and conditions such as arthritis, chronic fatigue syndrome, and muscular dystrophy. It is also used to evaluate the effectiveness of treatments for various disabilities [6]. The HGT is the gold standard for the assessment of mechanical muscle characteristics, including maximal muscle strength (F_{max}) and maximal isometric rate of force development (RFD_{max}) [7]. Explosive muscle strength is typically assessed by measuring RFD_{max} [8]. RFD_{max} has important functional consequences as it determines the force that can be generated in the early phase of muscle contraction (0 – 200 ms). For isolated muscle preparations, the contractile RFD_{max} is determined from the slope of the force-time curve (Δforce/Δtime), while for joint movements, the RFD_{max} is calculated as the slope of the moment-time curve (Δmoment/Δtime). For the elbow flexors and knee extensors, the time required to reach the maximum RFD_{max} is approximately 300 ms [10]. Muscle strength is defined as the magnitude of torque exerted by one or more muscles during a single maximum isometric contraction of

DOI: 10.2478/msr-2024-0026

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unlimited duration [9]. The strength of a muscle is often compared to muscular power and can be described as the ability of a single muscle or a group of muscles to generate force when contracting against an external resistance [10]. Factors such as the size, number and type of muscle fibers as well as the type of contraction and degree of activation determine muscle force production independent of joint angles [11]. When measuring F_{max} during classic contraction, the mechanical component of the muscle is defined. Parameters related to the neural component, the effective synchronization of the motor units and the plasticity of the central nervous system can be determined by measuring RFD_{max} [10], [8].

For a test to be used to measure certain abilities, it must first be validated and reliable. The HGS is used, for example, in sport [12], rehabilitation [13] and clinical assessments [14]. Variability in strength is most commonly measured using the coefficient of variation (*CV*), which is calculated by dividing the standard deviation (*SD*) of a series of strength values by the mean of the same series [15]. A high-reliability instrument has been statistically validated to ensure consistent measurement across sessions, examiners, and instruments. Reliability is usually assessed using correlation coefficients and standard error of measurement [16].

According to the initial findings of a group of authors [17], it is crucial to adapt the established methodology to the specific needs and objectives of each sport. For objective values of explosive strength, the use of an impulse model for isometric testing is recommended. For the assessment of maximal strength, however, the use of a traditional test model is recommended. This approach allows a more precise, targeted and sensitive assessment of muscle mechanical properties in terms of their maximal and explosive strength. The use of the sports medical solution (SMS) handgrip (HG) dynamometer is also found in other studies and is considered a highly accurate measurement tool for the assessment of maximal and explosive HGS [18], [19]. Recent studies have shown that the HG dynamometer system is very reliable for measuring F_{max} [20].

One study [21] investigated the factors affecting the reliability of HGS measurements in middle-aged and older adults over 1-4 months. The results of the study showed a high reliability of HGS measurements. However, in clinical setting, testing and retesting may occur over different time periods, including on the same day or after an extended interval, such as the completion of a rehabilitation program, which may result in gaps of several weeks or months between tests [22], [23]. In this context, the aim of this study is to determine the reliability of the tests at one month to define the long-term biological variation of HGS contractile characteristics, as well as F_{max} and RFD_{max} in two different test regimes (classic and impulse). This is important for scientific and methodological reasons for the definition of all metrological characteristics of the HGT, as it is a regular, long-term and metrologically sensitive and specific instrument. On the other hand, it is necessary to define quantitative methodological indicators of the test as an applied measurement method, in terms of determining the longitudinal test procedure, the longitudinal biological variations and the circadian variations, both for the classic F_{max} and for the impulse RFD_{max} measurement method.

2. SUBJECTS & METHODS

Research sample

The study was conducted on a total of 16 healthy and physically active adults. The participants were members of the Faculty of Sport and Physical Education, with an average age of 31.1 ± 0.5 years. The sample comprised 11 men (Age = 33.7 ± 12.4 yrs.) and 5 women (Age = 26.2 ± 2.7 yrs.). At the end of the study, the total number of participants was 30, of which 14 had less than 5 test days and were therefore excluded from the study due to the low number of test days.

All participants took part in the study voluntarily and had no neuromuscular disorders, musculoskeletal dysfunctions, injuries or previous operations on the hand or arm. The study was conducted in accordance with the principles of the Declaration of Helsinki and with the approval of the Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade (484-2).

Equipment

The data were recorded with the isometric handgrip probe (Fig. 1). Signals from a force transducer (CZL302: Dongguan City, China) were acquired using the commercially available software SMS, Belgrade, Serbia – Isometrics Ver. 3.4.0 with a sampling rate of 1000 Hz. The signals were filtered with a low pass (5 Hz), second-order Butterworth filter. The software automatically calculated the F_{max} (peak value on the force-time trace after reaching the plateau) and RFD_{max} (peak value of the first derivative of the force-time signal) [11], [16]. The signals are shown in Fig. 2 and Fig. 3. The sensor calibration was performed using laboratory weights.

Fig. 1. SMS handgrip device with a fixed strain gauge.

Fig. 2 and Fig. 3 show the F_{max} and RFD_{max} signals obtained from the HGS measurements with the SMS software. The red line represents the RFD_{max} curve, while the blue line represents the F_{max} curve. In addition, the values for F_{max} and RFD_{max} during classic and impulsive contraction are displayed next to the signals. In addition to the results for strength and explosiveness, you can also see the time frame for reaching maximum strength and maximum explosiveness. The time for F_{max} during the classic contraction is greater than 300 ms, while the time for F_{max} during the impulsive contraction is up to 300 ms [10].

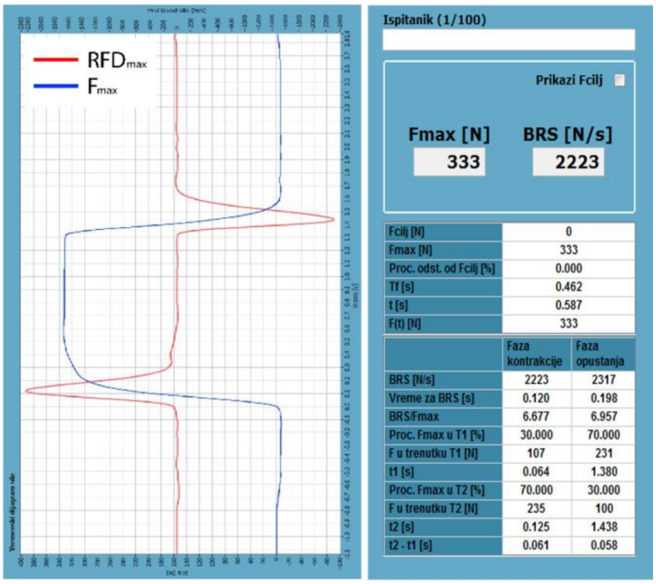

Fig. 2. Signals of F_{max} in classic contraction collected using the SMS software.

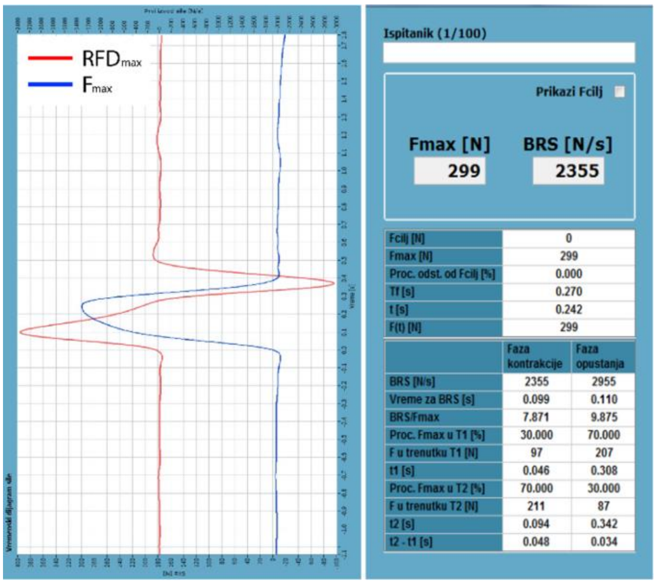

Fig. 3. Signals of RFD_{max} in impulse contraction collected using the SMS software.

Measurement methods

The measurements took place in the Methodological Research Laboratory (MRL) at the Faculty of Sport and Physical Education in Belgrade, between 10:00 and 14:00. Before the measurement, each participant already had experience in using an isometric probe and was thoroughly familiarized with the procedures for the HG test. Accordingly, they performed two grip tests at submaximal intensity. The participants were subjected to the test asynchronously, i.e. not daily, under real-life conditions to ensure that the measurements were spontaneous, natural and free from any influence or protocol. During the HGT, on average of 11 measurements measurement frequency (*MF*) were taken over 30 days *(D)* with an average interval of 3 days *MF* between each measurement. Alternatively, participants were measured randomly at intervals of 2 to 5 days.

MF was determined using the following formula:

$$MF = \frac{D}{MD}$$

where *D* – duration of the test in days and *MD* – measurement days.

Single day tests were randomized from trial to trial, with a 2 minute break between each trial. Since the participants already had experience with HG measurements, they performed two trials for each test and each measurement mode [19], with the better result being selected for statistical analysis. In the first trial, subjects performed classic contractions, while in the second trial they performed impulse contractions. The HGS (F_{max} and RFD_{max}) was tested using standardized test procedures and protocols [8], [17], [20].

In the classic protocol, the instruction was to contract as strongly and quickly as possible and to maintain the maximal contraction for ~2 s. In the impulse protocol, the instruction was to produce as strong and short a contraction as possible, but without jerk. The measurement was performed in a sitting position (knee joint angle at 90°; normal anatomical position of the arm) with both arms being measured alternately (Fig. 1).

Variables

To assess the overall upper body strength, the following variables were defined separately for each participant over 30 days:

1. Maximal isometric strength, summarized for the right and left hand ($F_{maxHGsum}$) expressed in Newtons (N), was measured using classic contractions [18].
2. Maximal isometric rate of force development, summarized for the right and left hand ($RFD_{maxHGsum}$) expressed in Newtons per second (N/s), was measured with impulse contractions [18].

Statistical analysis

The results of the male and female participants were statistically analyzed together to demonstrate a new methodology with a human phenomenon at a general level. Descriptive statistics was used to calculate – the mean, a measure of dispersion – the standard deviation (*SD*) and the coefficient of variation (*CV*). The reliability of the tests was assessed by the inter-class correlation coefficient (*ICC*), whose values were defined as low $ICC < 0.5$, moderate $ICC = 0.5 – 0.75$ and excellent reliability $ICC > 0.9$ [17]. The precision of the measurement (measurement error) was assessed using the relative (*RS*) and absolute (*AS*) standard errors of the mean [18]. Linear regression was performed to determine the dynamics of the trend change during the HGT period. Based on the results obtained, variables such as the regression coefficient (*RCC*), regression constant (*RCO*), slope of *y*, R-squared (R^2), *F*-value and *p*-value were analyzed. All statistical tests were performed using the software package MS Excel 2013, IBM SPSS v23.0.

Results

The initial results for each participant are shown in Tables 1, 2, 3 and 4 further in the text. Table 1 and Table 2 show the descriptive indicators for $F_{maxHGsum}$ classic and $RFD_{maxHGsum}$ impulse. The results show that all variables are homogeneous, as the *CV* is 4.12 % in $F_{maxHGsum}$ and 6.60 % in $RFD_{maxHGsum}$. *RS* has a value of 1.33 % in $F_{maxHGsum}$ and 2.13 % in $RFD_{maxHGsum}$.

Table 1. Descriptive statistics of $F_{maxHGsum}$, respectively for all subject samples.

ID	*M*	*SD*	*CV*	*AS*	*RS*	*D*	*MD*	*MF*
1	969	40.99	4.23	15.49	1.60	36	7	5
2	1357	44.70	3.29	11.17	0.82	30	16	2
3	1075	34.45	3.20	8.36	0.78	34	17	2
4	874	31.17	3.57	7.56	0.86	30	17	2
5	676	16.97	2.51	6.93	1.02	32	6	5
6	575	33.69	5.85	7.73	1.34	30	19	2
7	1130	19.43	1.72	5.61	0.50	28	13	2
8	892	29.34	3.29	9.78	1.10	35	9	4
9	843	67.61	8.01	27.60	3.27	24	6	4
10	600	69.79	11.62	21.04	3.50	29	11	3
11	578	25.03	4.33	8.34	1.44	26	9	3
12	1103	54.71	4.96	18.24	1.65	30	9	3
13	1051	35.44	3.37	14.47	1.38	28	6	5
14	1213	33.81	2.79	9.76	0.80	31	12	3
15	1200	27.95	2.33	7.75	0.65	30	13	2
16	1147	18.68	1.63	7.06	0.62	25	7	4
AVG	956	36.48	4.12	11.68	1.33	30	11	3

Note: *M* (mean); *SD* (standard deviation); *CV* (coefficient of variation); *AS* (absolute standard error of the mean); *RS* (relative standard error of the mean); *D* (duration of the test in days); *MD* (measure days); *MF* (measure frequency); *AVG* (average values).

Table 2. Descriptive statistics of $RFD_{maxHGsum}$, respectively for all subject samples.

ID	*M*	*SD*	*CV*	*AS*	*RS*	*D*	*MD*	*MF*
1	6040	383.72	6.35	145.03	2.40	36	7	5
2	8647	594.23	6.87	148.56	1.72	30	16	2
3	7638	522.60	6.84	126.75	1.66	34	17	2
4	6966	430.33	6.18	104.37	1.50	30	17	2
5	4803	314.53	6.55	128.41	2.67	32	6	5
6	4151	407.23	9.81	93.43	2.25	30	19	2
7	7540	364.56	4.83	105.24	1.40	28	13	2
8	6040	303.31	5.02	101.10	1.67	35	9	4
9	5764	822.77	14.27	335.89	5.83	24	6	4
10	4187	435.42	10.40	131.29	3.13	29	11	3
11	3684	240.54	6.53	80.18	2.18	26	9	3
12	8008	394.19	4.92	131.40	1.64	30	9	3
13	7422	494.61	6.66	201.92	2.72	28	6	5
14	8326	251.26	3.02	72.53	0.87	31	12	3
15	8103	284.44	3.51	78.89	0.97	30	13	2
16	8082	306.52	3.79	115.85	1.43	25	7	4
AVG	6588	409.39	6.60	131.30	2.13	30	11	3

Note: *M* (mean); *SD* (standard deviation); *CV* (coefficient of variation); *AS* (absolute standard error of the mean); *RS* (relative standard error of the mean); *D* (duration of the test in days); *MD* (measure days); *MF* (measure frequency); *AVG* (average value).

The results of the regression analysis to determine the relationship between $F_{maxHGsum}$ and $RFD_{maxHGsum}$ as a function of the measurement days are shown in Table 3 and Table 4. In addition, the *p*-value is greater than 0.05, indicating that there are no statistically significant changes in the HGS measurements between the different measurement days.

Table 3. Regression model of $F_{maxHGsum}$, respectively for all subject samples.

ID	*RCO*	*RCC*	*Slope*	R^2	*F*	*p*
1	3.59	954.81	0.38	0.04	0.18	0.68
2	2.03	1339.90	0.15	0.05	0.72	0.41
3	1.99	1057.50	0.19	0.08	1.41	0.26
4	-1.53	887.93	-0.17	0.07	1.26	0.28
5	1.43	671.67	0.21	0.01	0.14	0.91
6	0.35	571.88	0.06	0.01	0.14	0.72
7	1.89	1118.50	0.17	0.15	1.83	0.21
8	4.75	868.36	0.55	0.22	1.99	0.20
9	6.11	822.20	0.74	0.02	0.09	0.78
10	-10.67	664.76	-1.61	0.31	3.96	0.08
11	3.69	559.67	0.66	0.25	2.37	0.17
12	-4.97	1127.80	-0.44	0.02	0.15	0.71
13	9.49	1017.80	0.93	0.21	1.03	0.37
14	3.27	1191.90	0.27	0.16	1.88	0.21
15	-2.84	1220.30	-0.23	0.15	1.96	0.19
16	2.75	1136.69	0.24	0.06	0.32	0.59
AVG	1.33	950.69	0.13	0.12	1.22	0.42

Note: *RCO* (regression constant); *RCC* (regression coefficient); *Slope* (Slope of Y); R^2 (squared value); *F*-value; *p*-value; *AVG* (average value).

Table 4. Regression model of $RFD_{maxHGsum}$, respectively for all subject samples.

ID	*RCO*	*RCC*	*Slope*	R^2	*F*	*p*
1	-84.30	6377.40	-1.32	0.17	1.09	0.34
2	101.15	7788.00	1.29	0.63	23.53	0.00
3	36.94	7306.30	0.51	0.16	2.91	0.11
4	47.19	6541.80	0.72	0.32	6.86	0.02
5	111.57	4412.70	2.53	0.56	5.05	0.08
6	24.82	3902.90	0.64	0.11	2.04	0.17
7	49.27	7220.40	0.68	0.22	2.73	0.13
8	0.33	6038.70	0.01	0.01	0.02	0.89
9	-109.54	6147.80	-1.78	0.06	0.24	0.65
10	-47.58	4473.30	-1.06	0.38	5.55	0.04
11	22.59	3571.20	0.63	0.13	1.03	0.34
12	-16.50	8090.50	-0.21	0.01	0.03	0.87
13	142.14	6925.30	2.05	0.31	1.74	0.24
14	22.07	8182.90	0.27	0.12	1.32	0.28
15	-38.04	8369.70	-0.45	0.24	3.65	0.08
16	49.72	7883.30	0.63	0.07	0.37	0.57
AVG	19.49	6452.01	0.32	0.22	3.64	0.31

Note: *RCO* (regression constant); *RCC* (regression coefficient); *Slope* (Slope of Y); R^2 (squared value); *F*-value; *p*-value; *AVG* (average value).

Table 5 shows *ICC* values that are close to 1, indicating high consistency or reliability between measurements. This indicates that most of the variability is due to actual differences between subjects and not due to random or systematic measurement error. The *F*-value is greater than 0.05, which shows that there are no statistically significant differences between the groups. This could indicate that there are no systematic measurement errors.

Table 5. *ICC* of $F_{maxHGsum}$ and $RFD_{maxHGsum}$, for all subject samples.

	ICC	95 % Conf. Int.		F	p
		Lower bound	Upper bound		
$F_{maxHGsum}$	0.996	0.996	1.000	1.147	0.358
$RFD_{maxHGsum}$	0.996	0.986	1.000	1.289	0.263

Fig. 4 and Fig. 5 show graphically the basic descriptive statistics (mean with standard deviation) and regression line with the model ($F = 0.392$; $F = 7.096$) and ($p = 0.547$; $p = 0.029$) of the summarized results of all participants in the longitudinal section by test day. Fig. 4 and Fig. 5 show the results of 11 measurements over 30 days. For the first day, the average values for $F_{maxHGsum}$ and $RFD_{maxHGsum}$ were determined for all participants, as well as for the other measurements.

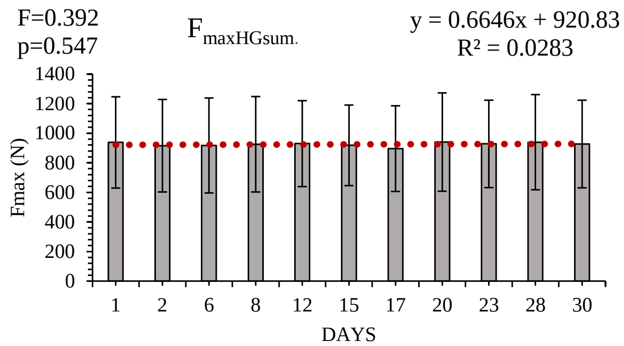

Fig. 4. Summary of the results of all participants per testing day for the variable $F_{maxHGsum}$.

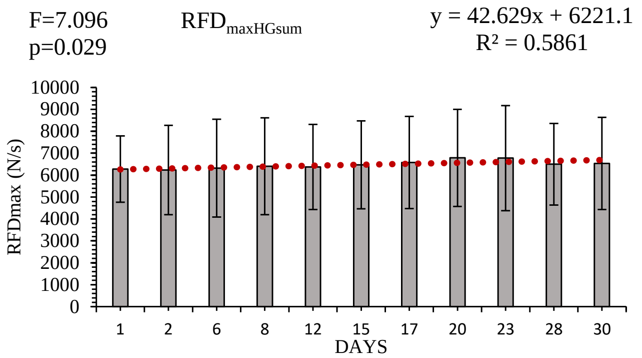

Fig. 5. Summary of the results of all participants per testing day for the variable $RFD_{maxHGsum}$.

5. Discussion

This study provides results indicating high reliability, high homogeneity of data, absence of errors in repeated measurements, and no significant changes in HGS measurements over a month of randomized test days. The combined results of $F_{maxHGsum}$ and $RFD_{maxHGsum}$ for the left and right hand may represent the overall strength of the upper body. The average values from our study for $F_{maxHGsum}$ and $RFD_{maxHGsum}$ are similar to the results of the study by [19], which presented normative handgrip data in the general population of healthy adults, namely $F_{maxHGsum}$ of 910 – 084 N and 495 – 604 N and $RFD_{maxHGsum}$ of 5763 – 7182 N/s and 3048 – 3963 for men and women, respectively. The results of the *CV* (Table 1 and Table 2) for the variable $F_{maxHGsum}$ show a 4.12 % variability and $RFD_{maxHGsum}$ a 6.60 % variability. Since the value is below 10 % of variability, this indicates a high homogeneity value of the data compared to the mean [24]. In other words, this is crucial for all subsequent repeated longitudinal studies using the long-term measurements of the HGT. The *AS* value of 12 N for the $F_{maxHGsum}$ and 132 N/s for the $RFD_{maxHGsum}$ indicates minimal error in repeated measurements, suggesting that the measurements are accurate and reliable. The *RS* values of 1.33 % for $F_{maxHGsum}$ and 2.13 % for $RFD_{maxHGsum}$ are low, there is no significant difference between day-by-day consecutive trials measured with the HGS [25]. Based on the results in Table 5, it can be concluded that the measurement is consistent and reproducible [26]. For the variable $F_{maxHGsum}$ the *ICC* has a value of 0.996 and for the variable $RFD_{maxHGsum}$ a value of 0.996, which means that the measurement is reliable. When measuring maximum voluntary isometric contraction (*MVIC*), all participants achieved a reliability coefficient between 0.996 and 1.000 for both variables, which is considered a near-perfect degree of reliability. The study [21] investigated factors influencing the reliability of HGS measurements in middle-aged and older adults over 1 – 4 months. The results showed high reliability ($ICC = 0.95$), but also sensitivity to the influence of different examiners, especially when measuring the non-dominant hand. This could be a limiting factor in longitudinal studies. Measurements of HGS with the Jamar dynamometer conducted over 12 weeks are reliable with an *ICC* of 0.954 for the left hand and 0.912 for the right hand [26]. In a study conducted by [20], the SMS HG dynamometric system was also found to have a high degree of inter-reliability $ICC \geq 0.971$ for the measurement (maximum isometric force – F_{max}) for both the dominant and non-dominant hand.

The results in Table 3 and Table 4 show that the number of days is not a key factor in explaining the variation in the HGS, as shown by the very low value. This means that the model with the number of days as an independent variable explains only a small part of the variation in the HGS. In addition, the *p*-value ($p > 0.05$) indicates that the changes in HGS from day to day are not statistically significant. The *RCO* (1.33 N; 19.49 N/s) indicates that the changes in HGS between days are relatively small. Although the results suggest that the number of days does not play a significant role in the variations in HGS, it is important to note that the HGS test results are generally reproducible and consistent. This means that the HGS measurements are stable and consistent for the same subjects during testing, which could indicate the metric stability of HGS. Fig. 4 shows the summarized results of the handgrip measurements per test days with a trend dynamics change constant of 0.664 N. $F = 0.392$ and $p = 0.547$ also indicate that the $F_{maxHGsum}$ does not change over the measurement period. In other words, the strength is measured in the same way every time, regardless of the day or circadian rhythm. Based on the constant of the regression line and the observed changes in the F_{max} contractile characteristics, it can be concluded that the applied test and measurement are reproducible and consistent in the applied modality of the classic method.

On the other hand, Fig. 5 shows an increasing trend dynamics change constant of 42.629N/s in $RFD_{maxHGsum}$. The results of the regression analysis show that there is a significant change in the variable $RFD_{maxHGsum}$ over the measurement period. The values $F = 7.096$ and $p = 0.029$ indicate that $RFD_{maxHGsum}$ has indeed changed over time. Statistically significant changes and an increase in the constant trend of change over time could be due to specific adaptations to the long-term test protocol or to specific motor learning as a side effect of the one-month procedure used. Since the participants have not previously used the movement pattern that occurs during the impulse contraction, the body recognizes it as a new stimulus, leading to an increase in the value of RFD_{max} over time. The mechanisms of neuronal adaptation are crucial to the increase in RFD_{max}, including changes in muscle morphology, increased firing frequency of motoneurons, decreased presynaptic inhibition and inhibitory neuronal pathways [27]. A study by [8] also found that the early phase (50 ms) of voluntary activation and force production during explosive contractions is highly variable at the individual level, regardless of the measurement methods used. Consequently, explosive force production is reliable when measured from 100 ms onwards. If an assessment of longitudinal changes is made retrospectively (e.g., after an intervention), the results should be interpreted with caution [28]. As the results presented in this study are among the first, there may be limitations in terms of the number of participants, the representativeness of the sample and the age of the participants. This study may serve as a starting point for future research where similar tests can be used to determine if there are differences in strength and explosiveness between patients following limb injury or surgery and healthy participants.

6. Conclusion

The reliable use of the HGT was confirmed both in the classic mode for F_{max} and in the impulse mode for RFD_{max}. The F_{max} results show that the test can be used as a stable parameter in human subjects. The test can be used to study the long-term effects of various health interventions such as exercise, medication or dietary supplements.

A significant trend change was observed in RFD_{max} measured in pulse mode, possibly due to specific motor learning or side effects of the test procedure. Further research is needed to understand how the impulse expression of force is affected, how much time is needed for adaptation, and the effects of training or learning. These aspects should be clarified before the test is used in long-term sports science or clinical studies.

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Received April 02, 2024
Accepted September 17, 2024