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An Attempt to Identify Meaningful Descriptors of Handgrip Strength Using a Novel Prototype: Preliminary Study

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Abstract: Handgrip strength (HGS) is an indicator of muscle condition and general health wellbeing. Usually, instruments measuring handgrip strength only identify its maximum value. This preliminary study is focused on identifying force vs. time parameters which could contribute to better describe individual strength. They were obtained during a Handgrip strength test of 15 s in a sample group of 94 university students. The tests were conducted with a smart multifunction novel prototype dynamometer, named BodyGrip. Mean values of quantities related to the ability to develop and to maintain strength in percentage of maximum handgrip strength, were extracted from the force vs time profile. Contrary to maximum HGS, such quantities were found to be independent of the participant's anthropometric characteristics. Individual comparisons based on those quantities are therefore not affected by the anthropometric characteristics. It was possible to identify individuals, differing on the development of HGS. Results suggest that the functionality of the BodyGrip tool enables a more thorough characterization of the time profile of the Handgrip strength that might influence the knowledge of the muscle functions, such as power development and endurance.

Keywords: handgrip strength-time curve; handgrip dynamometer; force development characteristics; explosive force; sustainability

1. Introduction

There are conditions and diseases that cause loss of muscular strength and wasting, such as undernutrition, sarcopenia, and physical frailty [1–3]. Handgrip strength (HGS) has been reported to be associated with markers of disability and morbidity [2]. In addition, research has shown that HGS value below normal grip strength is related to hospital length of stay [4], low vitamin D status [5] and higher risk of institutionalization and of mortality [6]. These outcomes, among many others, justify the relevance of this clinical marker of wellbeing.

Muscle strength impairment occurs before changes in muscle structure and composition can be detected [7]. Based on this early event in the disease process, isometric HGS has been widely used for screening, for diagnosis and for monitoring all the health events that are strongly related to functional and nutritional impairment [1].

Hand-held dynamometry offers numerous advantages over other nutritional, functional and health status indicators, as it is an inexpensive, easy to use and portable evaluation method. Moreover, HGS measurement are non-invasive, quick to perform, reliable, exhibiting low intra and between observer variability and do not require specialized professionals [8]. Maximum HGS (Fmax) of an individual can be quantified by measuring maximum force value using a simple protocol. Although most of the research focuses on maximum HGS, many others have been considering different force parameters that can be obtained in HGS tests such as the rate of force development (referred as RFD) [9] and sustainability of maximum force [10], using adapted devices for providing the force profile during test time. There is evidence that the explosive force, usually assessed via RFD, is related to mobility [11], is different in young and older people [12] and it is commonly used parameter in sports performance studies considering also other groups of muscles [9,13]. However, the use of distinct adapted devices, the time interval considered to calculate RFD and the protocol adopted are very distinct from study to study, preventing the establishment of general procedures.

Other studies consider parameters defined from the force-time profile such as “time to peak force” [14], the time to reach distinct levels of peak force such as 50%, 70% or 90% [15,16]. The time required to decrease from the peak force to 80%, 70% and 60% of peak force is a parameter reported in [17]. The area under the force–time curve from onset of exertion to a given test time is studied in [14,15] and has been also related to disabilities in rheumatoid hands [18]. There is no common reference test time, as in these research works the test time considered ranges from two seconds [19], to five seconds [14], seven seconds [20], fifteen seconds [21] and up to sixty seconds [18]. Once again, a huge diversity of parameters is found, all related to the development of force during the test time as well as protocols (when referred) and adapted devices.

The present exploratory study, using a sample of young healthy adults, aims at analyzing how HGS changes with time during the handgrip test, including all relevant features that can be explored such us explosive force, peak force and force sustainability. Therefore, an investigation on how these different parameters relate to each other is performed with the purpose of establishing a more in-depth characterization of the HGS force vs. time profile, based on universal parameters related to a typical response of a first order system. The protocol follows the one defined in [22] conveniently amended for obtaining the handgrip force vs. time profile. A novel patented prototype for HGS measurement was used able to register the force vs. time profile that offers good precision and has been validated against the golden standard [21] in which concerns maximum HGS.

Considering the evidence from many different studies that maximum HGS is related to anthropometric data such as height, weight and hand length [21,23] the present study also analyses the relationship of some anthropometric data with the proposed features related to explosive force, peak force and force sustainability.

Therefore, this exploratory study aims at being a contribution to establish a set of HGS reference descriptors that can be universally used by different researchers from different areas in future studies.

2. Materials and Methods

2.1. Procedure

Considering the exploratory research study objectives and the BodyGrip system features, the study protocol adopted to measure force vs. time profile of HGS follows the recommendations described in [22], and was conveniently amended for this new type of test. The participant was previouslyinformed on the system functionality and the test procedure, followed by a demonstration: after triggering the system by the expert, the participant should grip the device and apply strongly all his handgrip force. During the test duration (15 s), he/she would be incited to sustain force as long as possible.

After this step, the participant anthropometric data were collected using the procedures recommended by the International Society of Kinanthropometry (ISAK) [24]. Information on age, physical activity, diseases, previous surgeries, and hand dominance was self-reported. Measures of weight, height, left and right hand lengths were also taken. The handgrip strength test phase started by sitting the participant in a chair with back support and fixed arms, regarding the following circumstances: shoulder adducted and neutrally rotated, elbow closed to the body and flexed at

90 degrees, the forearm and wrist in neutral position and thumbs up supported by the chair fixed arm. The participant wrist should be just over the end of the arm of the chair.

The test is recorded in database during the test duration. The test would be repeated three times, alternately in right and left hands and, according to the referred protocol. The resting time between tests was 1 min.

2.2. Sample

A convenience sample of 99 students (21 males and 78 females), aged between 18 and 38 years old, from the Faculties of Engineering and of Nutrition and Food Sciences, both from the University of Porto was recruited.

Potential participants presenting muscle diseases, chronic blood disorders other diseases or surgeries that could affect muscle performance, were not included. All participants received verbal and written information about the study and signed an informed consent form. The Ethics Committee of "Hospital de São João, Porto, Portugal", approved this investigation. The entire study was conducted in accordance with the recommendations established by the last revision of the Declaration of Helsinki.

The sample characteristics of homogeneity and healthy were requirements to provide a base for the main objective of the study in exploring the parameters of handgrip strength force vs. time.

2.3. The BodyGrip Prototype

The participants' isometric HGS profile during the test time duration was evaluated using a prototype system originally named BodyGrip, integrating a novel dynamometer (Figure 1) which interacts with a software application. The device used in this system was already validated against the gold standard Jamar [25], in which concerns the maximum of the HGS. The system is under international pattern request [26]. The US patent has been very recently granted (end of October 2020) and the University of Porto spin-off named Gripwise Tech (https://www.racius.com/gripwise-tech-lda/), is now producing the first unities of the system with the trademark of Gripwise.

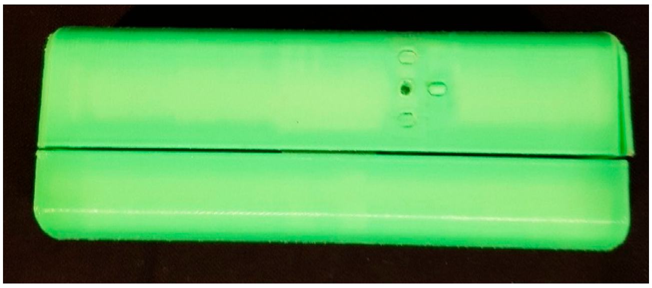


Figure 1. BodyGrip dynamometer prototype.

The system allows the automatic recording of the force vs. time profile during an adjustable time interval in a computer or remote database, and provides a real time graphical representation (only observed by the evaluator who conducts the test protocol).

These characteristics open new possibilities to explore data of the force vs. time profile and to study new features that could be used as new descriptors in future studies. These possibilities together with the novel characteristics of the device and the potential to integrate intelligent algorithms in the software application will bring promising perspectives for the area and for the system.

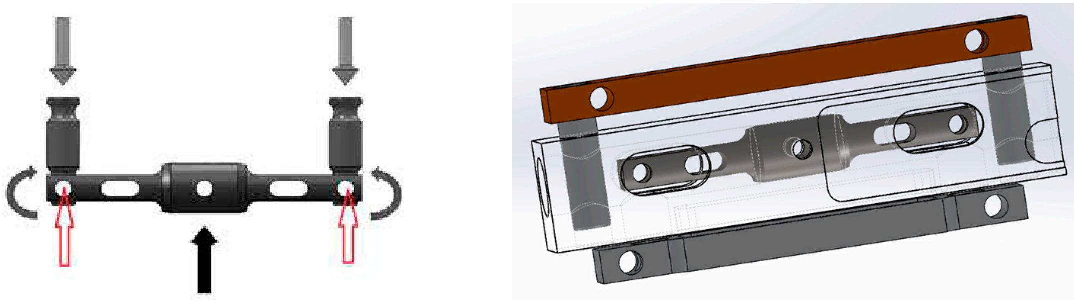
The BodyGrip device allows measuring the compressive or tensile force of a muscle or of a group of muscles by just adapting convenient accessories. It also can provide the energy transferred to the device during the user test (leg, arm, knee, elbow, shoulder or thorax) and, therefore, the estimation of user spent average and/or instantaneously power [27].

Therefore, its usefulness in terms of evaluation of body muscular force also opens the fields of application, not only for evaluating but also for rehabilitation and following up treatment progress.

Its design allows materializing it as a small device, light, easily portable and with a wireless connection to a computer, that runs the software application for data recording, processing and storage of the force vs. time profile.

This light (0.230 kg) and compact (114 mm × 22 mm × 45 mm) solution is capable of measuring forces up to ±980 N, with good sensitivity and resolution (0.098 N), with precision of ±0.098 N making it a potential pocket device for clinical use. The good sensitivity and its light body with small dimensions also make it adequate to be used either in the pediatric or in the geriatric areas.

This device combines primary sensing elements (metallic part) and the secondary sensing elements (resistance strain gauges) resulting in two symmetric strain gauge load cells due to its mechanical centered cantilever system design (Figure 2).



(**a**) (**b**)

Figure 2. Schematic perspectives of the device design: the novel load cell (**a**) and device housing (**b**).

The system has a software application for personal computers that can be easily adapted for a mobile device. The application allows recording the user data, set the test time and, force-time recording. The force vs. time profile is presented in the user interface graphical window, in real time (10 ms sampling). Any additional algorithm for post processing is possible to be programmed in the prototype electronics, easily.

2.4. Data Analysis

In the following analysis, the force vs. time profiles of the dominant hand of 99 participants, 78 females and 21 males, were considered. Due to some incomplete HGS data, the analysis covers only 73 females, resulting in 94 subjects.

Figure 3 shows a typical behavior of HGS as function of time for the 15 s long trial. The descriptors taken from the force vs. time curves, and signaled in Figure 3, are:

(1) The maximum force attained in the 15 s test—F_{max}.
(2) The time it takes to reach the maximum force—t_{Fmax}.
(3) Handgrip strength at 63.2% of its maximum value—$F_{63.2}$. This choice stems from the fact that the force profile follows a typical response of a first order system.
(4) The time it takes to reach $F_{63.2}$—$t_{F63.2}$
(5) HGS at the end of the 15 s test—F_{final}.
(6) The arithmetic average of the HGS points in the 15 s test—F_{av}.

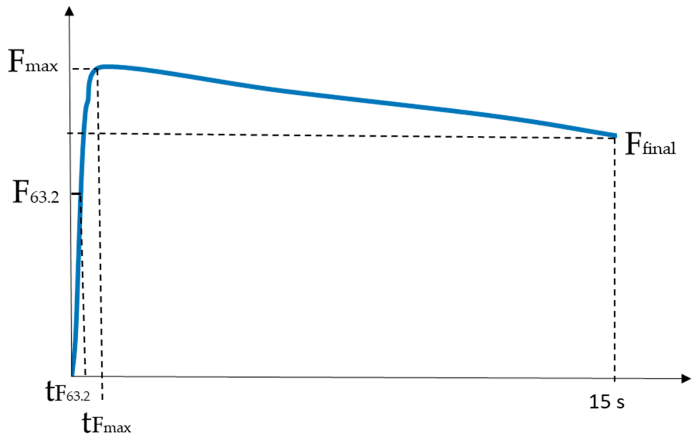


Figure 3. Proposed descriptors in a typical handgrip strength (HGS) vs. time curve.

The quantities (a) to (d) defined below are introduced to quantify the different rates of change of HGS along the 15 s test. They are normalized to the maximum force.

(a) pF_{av}—average force during 15 s test expressed in percentage of Fmax.
(b) pRate1 = (F63.2/tF63.2)/Fmax—rate of change of force up to tF63.2 expressed in percentage of Fmax.
(c) pRate2 = (Fmax − F63.2)/(Fmax ∗ (tFmax − tF63.2))—the rate of change of force from tF63.2 to tFmax, expressed in percentage of Fmax.
(d) pRate3 = (Ffinal − Fmax)/(F_{max} ∗ (15 − tF_{max}))—the rate of change of force from the time of maximum force until the end of the test, in percentage of F_{max}.

These normalized variables are related to the ability to develop and to maintain HGS (during the 15 s test time).

Data analysis comprised the following steps:

- Friedman non-parametric statistical test to detect differences in descriptors' means across the multiple time trials. This test revealed no statistical significant differences (for instance, the tests yields $\chi^2(2) = 0.391$, $p = 0.822$ for F_{max}). Therefore, averaged values (of the three trials) were considered for each individual;
- Gender comparisons of the anthropometric data and of the descriptors;
- Spearman two tailed correlations calculated between:
  - Anthropometric data;
  - Anthropometric data and the descriptors;
  - Referred descriptors of the HGS vs. time curve.
- Relevant relationships were further analyzed via linear regression.

Finally, the sample was divided in two categories of pF_{av} and comparisons across those categories were conducted.

The Statistical Package for Social Sciences for Windows, (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. IBM Corp., Armonk, NY, USA) was used in these analyses.

3. Results

Anthropometric characteristics of the participants are shown in Table 1, together with the results of gender comparison tests. The two tailed Spearman correlations between weight, height and dominant hand length (L_{DH}) are all statistically significant as denoted by the bold values, with $p < 0.001$ level, the strongest occurring between height and L_{DH} (r = 0.741). The relationship between these variables is expressed by the regression equation $L_{DH} = 12.19 * \text{Height} - 2.05$ ($R^2 = 0.668$, $p < 0.001$).

Table 1. Anthropometric characteristics.

	Gender		**Significance**
	Female N = 73 (76.7%)	**Male N = 21 (22.3%)**	***p***
Median Age (Min − Max)	20 (19–37)	22 (19–38)	0.009
Weight (kg) Mean ± SD	61.1 ± 11.8	72.5 ± 11.8	**<0.001**
Height (m) Mean ± SD	1.64 ± 0.07	1.74 ± 0.10	**<0.0001**
Length_{DH} (cm) Mean ± SD	17.9 ± 0.07	19.3 ± 1.7	**<0.0001**

Table 2 indicates the means and standard deviations of the previously defined descriptors, as well as the significance of the non-parametric Mann–Whitney U gender comparison test Significant differences are denoted by the bold values.

Table 2. Means, standard deviations and gender comparisons of the descriptors.

Descriptor (Unit) Mean ± SD	**Gender**		**Significance**
	Female N = 73 (76.7%)	**Male N = 21 (22.3%)**	***p***
F_{max} [N]	201 ± 61	368 ± 120	**<0.001**
tF_{max} [s]	1.89 ± 0.84	1.96 ± 1.08	0.765
$F_{63.2}$ [N]	125 ± 38	227 ± 75	**<0.001**
$tF_{63.2}$ [s]	0.67 ± 0.40	0.75 ± 0.42	0.452
F_{final} [N]	139 ± 51	255 ± 97	**<0.001**
F_{av} [N]	154 ± 52	287 ± 101	**<0.001**
pF_{av}	77 ± 6.7	77 ± 6.9	0.582
$pRate_1$ [1/s]	60 ± 7	63 ± 14	0.789
$pRate_2$ [1/s]	42 ± 25	51 ± 42	0.207
$pRate_3$ [1/s]	−2.42 ± 0.72	−2.36 ± 0.92	0.763

Furthermore, there are no significant differences between the mean value of times to reach 63.2% of maximum force and the mean value of time to reach maximum force. In addition, no significant gender differences exist in the quantities expressed as percentage of F_{max} (pF_{av}, $pRate_1$, $pRate_2$, $pRate_3$).

Table 3 shows the two-tailed Spearman correlation coefficients between the descriptors and the anthropometric data, with the bold values indicating statistically significant correlations.

Table 3. Two tailed correlation coefficients.

Spearman Correlation Coefficients between Descriptors and Anthropometric Data			
Descriptor	**Weight**	**Height**	L_{DH}
F_{max}	**0.531** **	**0.462** **	**0.537** **
tF_{max}	−0.027	0.134	**0.260** *
$F_{63.2}$	**0.523** **	**0.462** **	**0.546** **
$tF_{63.2}$	0.059	0.138	0.201
F_{final}	**0.424** **	**0.408****	**0.519****
F_{av}	**0.486** **	**0.427** **	**0.513** **
pF_{av}	−0.014	−0.037	0.076
$pRate_1$	−0.018	−0.107	−0.161
$pRate_2$	0.0148	−0.110	**−0.206** *
$pRate_3$	−0.085	−0.069	0.074

* Significant at the 0.05 level, ** significant at the 0.01 level.

F_{max} correlates with weight, height and length of dominant hand. The stronger relationship is with L_{DH} as indicated by the regression equation F_{max} = 53,44 * L_{DH} − 735 (R^2 = 0.416, $p < 0.001$) with F_{max} in N and L_{DH} in cm.

tF_{max} correlates with length of dominant hand L_{DH}. However, the linear relationship between them is non-significant (R^2 = 0.018, $p > 0.05$).

It is relevant to note from Table 3 that the quantities expressed in percentage of the F_{max} have no significant correlation with the anthropometric characteristic of the participants.

Two tailed non-parametric correlations between all descriptors are shown in Table 4 (statistically significant correlations are signaled by the bold values). As expected, F_{max} relates strongly with $F_{63.2}$ and F_{final}. However, it does not correlate with tF_{max} or tF_{63}. Although the correlation between F_{max} and pF_{av} is significant (0.316, $p < 0.01$), the regression analysis indicates non-significant linear relationship between them (pF_{av} = 0.0174 * F_{max} + 72.31, R^2 = 0.07). On the other hand, pF_{av} is significantly related to the value of F_{final}. (pF_{av} = 0.042 * F_{final} + 69.62, R^2 = 0.237, $p < 0.001$).

Table 4. Two tailed Spearman correlation coefficients.

Spearman Correlation Coefficients between Descriptors										
	F_{max}	tF_{max}	$F_{63.2}$	$tF_{63.2}$	F_{final}	F_{av}	pF_{av}	$pRate_1$	$pRate_2$	$pRate_3$
F_{max}	1.000									
tF_{max}	0.191	1.000								
$F_{63.2}$	**0.996 ****	0.130	1.000							
$tF_{63.2}$	0.109	**0.518 ****	0.130	1.000						
F_{final}	**0.922 ****	**0.312 ***	**0.927 ****	0.195	1.000					
F_{av}	**0.975 ****	**0.248 ***	**0.974 ****	0.096	**0.965 ****	1.000				
pF_{av}	**0.316 ***	**0.291 ***	**0.330 ****	0.018	**0.566 ****	0.032	1.000			
$pRate_1$	−0.07	**−0.513 ****	−0.078	**−0.962 ****	−0.156	−0.055	0.032	1.000		
$pRate_2$	−0.181	**−0.915 ****	−0.200	**−0.236 ***	**−0.293 ***	**−0.256 ***	**0.361 ****	**0.203 ***	1.000	
$pRate_3$	0.200	**0.207 ***	**0.216 ***	0.172	**−0.516 ****	**0.347 ****	**0.815 ****	−0.138	−0.188	1.000

* Significant at the 0.05 level, ** significant at the 0.01 level.

The quantities $pRate_1$, $pRate_2$ and $pRate_3$ are the mean rates of change, in percentage of F_{max}, occurring in three different stages of HGS course. The quantity $pRate_1$ is considerably bigger than $pRate_2$, suggesting that until $tF_{63.2}$, the force rises steeply and once reached that value its rise slows down until F_{max} is reached. The quantity $pRate_3$ is a direct measure of the ability to maintain the force, in percentage of F_{max}. The correlation between the quantities $pRate_1$, $pRate_2$ and $pRate_3$ are non-significant.

To understand better their relationship with pF_{av}, a multiple linear regression was calculated to predict pF_{av} based on $pRate_1$, $pRate_2$ and $pRate_3$. The regression equation found $pF_{av} = 0.027 * pRate_1 - 0.069 * pRate_2 + 6.773 * pRate_3$ is significant ($F(3,90) = 84.42$, ($p < 0.001$) with $R^2 = 0.738$). The independent variables, measured in 1/s, are all significant predictors of pF_{av} ($p < 0.001$).

The results for the standardized regressions coefficients indicate that $pRate_3$ is the strongest predictor of pF_{av} and $pRate_1$ the weakest.

To investigate how to distinguish HGS time development between individuals, independently of their maximum handgrip strength, the sample was split into two equal sized pF_{av} categories (average pF_{av} = 76.5 ± 6.9; median = 76.6). Using the non-parametric independent Mann–Whitney U test, significant differences were found in $pRate_2$ and $pRate_3$ across the two categories, Cat 1 and Cat 2, as shown in Table 5.

Table 5. Significant differences between two categories of pHGS_mean.

Descriptor (Unit) Mean ± SD	**Cat 1 (N = 47)**	**Cat 2 (N = 47)**	p
pF_{av}	70.8 ± 4.2	82.1 ± 3.7	<0.001
$pRate_2$ (1/s)	51.7 ± 33.7	38.5 ± 23.6	0.003
$pRate_3$ (1/s)	−2.93 ± 0.49	−1.88 ± 0.61	<0.001

Figure 4 shows a sketch of the different phases of HGS time development, normalized to Fmax for the two categories of pF_{av}. Both groups of pF_{av} have a similar rate of change from the beginning of the test until 63.2% of F_{max}. The participants of Cat 2 exhibit a lower force development rate since $F_{63.2}$ until F_{max}, and a lower decreasing force after reaching F_{max} when compared with participants of Cat 1, presenting a better endurance.

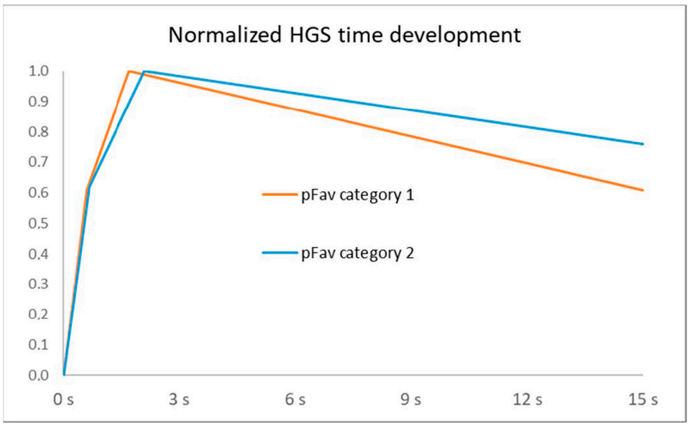


Figure 4. Sketch of HGS vs. time for the two groups of participants.

4. Discussion

This exploratory study proposes the use of several meaningful descriptors of handgrip strength using a novel prototype that provides HGS vs. time data. The force vs. time profiles of the dominant hand of 94 young adults (73 females and 21 males) were obtained in an isometric handgrip test, during 15 s. A trained researcher collected the data according to a strict protocol. The used device, named BodyGrip, is small and light, has good sensitivity and it is validated against Jamar, the golden standard.

From the force vs. time profile, five descriptors were taken and other quantities, defined in percentage of F_{max}, were calculated. They are the average value of force and three different rates of changes of force during a test of 15 s, in percentage of F_{max}.

The present findings suggest that there are three stages of force development. It was found that the average time to reach $F_{63.2}$ is approximately 0.69 s, and 1.9 s to reach F_{max}, with no differences between genders. In the future, it will be interesting to investigate whether these times are similar or different for other group ages.

The definition of the rates from zero to 63.2% of maximum force and from 62.3% of maximum force to maximum force might be an easier way to assess explosive force, since it can be replicated universally.

The relationships of maximum handgrip strength with the anthropometric characteristics, in particular with L_{DH} are in agreement with what is already known from other studies. In the future, further studies could investigate if a possible software correction would avoid adapting the device to the user's hand length.

Other descriptors proposed are not correlated with weight, height or L_{DH}. Two of them, $pRate_1$ and $pRate_2$, can be regarded as measures of explosive force. The other $pRate_3$ as a measure of the ability to maintain pF_{av}. The quantity pF_{av} expressed in percentage of F_{max}, contains information how HGS changes during the 15 s test.

All the participants have shown a similar ability to increase force up to 63.2% of F_{max}. However, those with bigger pF_{av}, have a slower rate of change decreasing force after reaching F_{max}, exhibiting a better endurance. With this study, it was possible to analyze different aspects of the force vs. time curve related to explosiveness and sustainability and to compare those characteristics within two groups differing in normalized average handgrip force. That comparison is not often seen in the literature.

The biggest limitations of this exploratory study are the small number of participants, and the uneven number of participants from both sexes. However, findings of many other studies were confirmed, in particular in what concerns the existing relationship between F_{max} and anthropometric data.

The results clearly suggest that other quantities obtained from analyzing force vs. time development might be also very important in characterizing HGS. In particular, they might give further insight on the relationship between explosive and endurance capabilities of individuals.

The proposed parameters can serve as set of HGS reference descriptors that can be universally used by different researchers, from different areas, in future studies.

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References

1. Cruz-Jentoft, A.J.; Bahat, G.; Bauer, J.; Boirie, Y.; Bruyere, O.; Cederholm, T.; Cooper, C.; Landi, F.; Rolland, Y.; Sayer, A.A.; et al. Sarcopenia: Revised European consensus on definition and diagnosis. *Age Ageing* **2019**, *48*, 601. [CrossRef] [PubMed]
2. Rantanen, T.; Volpato, S.; Ferrucci, L.; Heikkinen, E.; Fried, L.P.; Guralnik, J.M. Handgrip strength and cause-specific and total mortality in older disabled women: Exploring the mechanism. *J. Am. Geriatr. Soc.* **2003**, *51*, 636–641. [CrossRef] [PubMed]
3. Bohannon, R.W. Grip Strength: An indispensable biomarker for older adults. *Clin. Interv. Aging* **2019**, *14*, 1681–1691. [CrossRef] [PubMed]
4. Guerra, R.S.; Fonseca, I.; Pichel, F.; Restivo, M.T.; Amaral, T.F. Handgrip strength and associated factors in hospitalized patients. *JPEN J. Parenter. Enter. Nutr.* **2015**, *39*, 322–330. [CrossRef]
5. Mendes, J.; Santos, A.; Borges, N.; Afonso, C.; Moreira, P.; Padrao, P.; Negrao, R.; Amaral, T.F. Vitamin D status and functional parameters: A cross-sectional study in an older population. *PLoS ONE* **2018**, *13*, e0201840. [CrossRef]
6. McGrath, R.; Vincent, B.M.; Peterson, M.D.; Jurivich, D.A.; Dahl, L.J.; Hackney, K.J.; Clark, B.C. Weakness may have a causal association with early mortality in older Americans: A matched cohort analysis. *J. Am. Med. Dir. Assoc.* **2020**, *21*, 621–626. [CrossRef]
7. Lopes, J.; Russell, D.M.; Whitwell, J.; Jeejeebhoy, K.N. Skeletal muscle function in malnutrition. *Am. J. Clin. Nutr.* **1982**, *36*, 602–610. [CrossRef]
8. Bohannon, R.W. Parallel comparison of grip strength measures obtained with a MicroFET 4 and a Jamar dynamometer. *Percept. Mot. Ski.* **2005**, *100*, 795–798. [CrossRef]
9. Aagaard, P.; Simonsen, E.B.; Andersen, J.L.; Magnusson, P.; Dyhre-Poulsen, P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J. Appl. Physiol.* **2002**, *93*, 1318–1326. [CrossRef]
10. Stock, R.; Thrane, G.; Askim, T.; Anke, A.; Mork, P.J. Development of grip strength during the first year after stroke. *J. Rehabil. Med.* **2019**, *51*, 248–256. [CrossRef]
11. Hester, G.M.; Ha, P.L.; Dalton, B.E.; VanDusseldorp, T.A.; Olmos, A.A.; Stratton, M.T.; Bailly, A.R.; Vroman, T.M. Rate of force development as a predictor of mobility in older adults. *J. Geriatr. Phys.* **2020**, *2001*. [CrossRef]
12. Watanabe, K.; Tsubota, S.; Chin, G.; Aoki, M. Differences in parameters of the explosive grip force test between young and older women. *J. Gerontol. A Biol.* **2011**, *66*, 554–558. [CrossRef] [PubMed]

13. Haff, G.G.; Carlock, J.M.; Hartman, M.J.; Kilgore, J.L.; Kawamori, N.; Jackson, J.R.; Morris, R.T.; Sands, W.A.; Stone, M.H. Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. *J. Strength Cond. Res.* **2005**, *19*, 741–748. [CrossRef]
14. Nakada, M.; Demura, S. The characteristics of laterality of explosive force exertion of hand grip and toe grip. *Adv. Phys. Educ.* **2014**, *4*, 6. [CrossRef]
15. Demura, S.; Yamaji, S.; Nagasawa, Y.; Minami, M.; Kita, I. Examination of force-production properties during static explosive grip based on force-time curve parameters. *Percept. Mot. Ski.* **2000**, *91*, 1209–1220. [CrossRef] [PubMed]
16. Ikemoto, Y.; Demura, S.; Yamaji, S.; Minami, M.; Nakada, M.; Uchyiama, M. Force-time parameters during explosive isometric grip correlate with muscle power. *Sport Sci. Health* **2007**, *2*, 64–70. [CrossRef]
17. Yamaji, S.; Demura, S.; Nagasawa, Y.; Nakada, M.; Kitabayashi, T. The effect of measurement time when evaluating static muscle endurance during sustained static maximal gripping. *J. Physiol. Anthr. Appl. Hum. Sci.* **2002**, *21*, 151–158. [CrossRef]
18. Dias, J.J.; Singh, H.P.; Taub, N.; Thompson, J. Grip strength characteristics using force-time curves in rheumatoid hands. *J. Hand Surg. Eur. Vol.* **2013**, *38*, 170–177. [CrossRef]
19. Borges, L.S.; Fernandes, M.H.; Schettino, L.; da Coqueiro, R.S.; Pereira, R. Handgrip explosive force is correlated with mobility in the elderly women. *Acta Bioeng. Biomech.* **2015**, *17*, 145–149.
20. Househam, E.; McAuley, J.; Charles, T.; Lightfoot, T.; Swash, M. Analysis of force profile during a maximum voluntary isometric contraction task. *Muscle Nerve* **2004**, *29*, 401–408. [CrossRef]
21. Leyk, D.; Gorges, W.; Ridder, D.; Wunderlich, M.; Rüther, T.; Sievert, A.; Essfeld, D. Hand-grip strength of young men, women and highly trained female athletes. *Eur. J. Appl. Physiol.* **2007**, *99*, 415–421. [CrossRef] [PubMed]
22. Roberts, H.C.; Denison, H.J.; Martin, H.J.; Patel, H.P.; Syddall, H.; Cooper, C.; Sayer, A.A. A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardised approach. *Age Ageing* **2011**, *40*, 423–429. [CrossRef] [PubMed]
23. Zaccagni, L.; Toselli, S.; Bramanti, B.; Gualdi-Russo, E.; Mongillo, J.; Rinaldo, N. Handgrip strength in young adults: Association with anthropometric variables and laterality. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4273. [CrossRef] [PubMed]
24. Stewart, A.; Marfell-Jones, M.; Olds, T.; Ridder, H. *International Standards for Anthropometric Assessment*, 2011th ed.; International Society for the Advancement of Kinanthropometry: Lower Hutt, New Zealand, 2011.
25. Guerra, R.S.; Amaral, T.F.; Sousa, A.S.; Fonseca, I.; Pichel, F.; Restivo, M.T. Comparison of Jamar and bodygrip dynamometers for handgrip strength measurement. *J. Strength Cond. Res.* **2017**, *31*, 1931–1940. [CrossRef] [PubMed]
26. Restivo, M.T.; Quintas, M.; da Silva, C.; Andrade, T.; Santos, B. Device for Measuring Strength and Energy, Application 15759.939. U.S. Patent 10856795, 8 December 2020.
27. Vardasca, R.; Abreu, P.; Mendes, J.; Restivo, M.T. Handgrip Evaluation: Endurance and Handedness Dominance. In *Smart Industry & Smart Education, REV 2018, Lecture Notes in Networks and Systems*; Auer, M., Langmann, R., Eds.; Springer: Cham, Switzerland, 2019; Volume 47, pp. 507–516.