

Sustained Grasp Strength Characteristics What Changes with Skeletal Muscle Injuries

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ABSTRACT

Background: Grasping is present in most of the activities of daily living. The estimated total use of the hands in activities of daily living is more than five hours a day, not counting work and sports activities. The hand grasp strength peak is only relevant for short durations of applied forces, in the activities. The sustained strength gives a more realistic assessment of strength capabilities, during daily tasks.

Objective: To characterize the sustained grasp strength over 5 seconds, in different grasps configurations, and identify changes in these when a musculoskeletal injury is present.

Patients: Thirty right-handed participants, fifteen healthy (Control Group), and fifteen injured (Experimental Group) with musculoskeletal hand conditions, on the right side, 18 men and 12 women, were integrated into this study. In both groups, there were 9 men and 6 women.

Methods: The Biometrics E-link[®] Dynamometer G200, was used, being kilograms as the measurement unit. The test position, to assess the hand grasp sustained strength, was recommended by the American Society of Hand Therapists. The strength was collected for 5 seconds, in the right hand, on eight grasp configurations, which can be performed on the dynamometer.

Results: Men have more sustained strength than women, in all the grasp configurations assessed. The Experimental Group has inferior results regarding the peak strength, and the behavior of the strength is less stable. The man obtains the maximum endurance, and it is always over zero. The Inferior Pincer and the Parallel Extension are the grasp configurations that require less strength, being both precision grasps. The Medium Wrap is the grasp configuration that requires more strength, and it is also the one that has more differences between groups, regarding the strength and the peak strength. The three strongest grasps have the same configuration being the difference in the diameter of the grabbed object.

Conclusion: The strength behavior for 5 seconds is similar between participants, with or without musculoskeletal conditions, being less high, less regular, and decreasing faster when there is an injury.

Keywords: Activities of daily living, Endurance, Hand, Sustained grasp strength.

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1. INTRODUCTION

Musculoskeletal disorders are a major concern as injury rates, related to work, happen frequently. Many of these injuries happen in the hands and wrists since those are the most involved structures in work activities. To increase the understanding of the tolerance of the hand to withstand work without injury, different efforts have been made [1].

The hand is an overly complex system, a functional limb that includes more than 20 joints and 30 muscles, that

together allow us to perform different types of activities, using several objects with a high level of precision [2]. Repetitive hand movements and force full exertion associated with the force power grasp can contribute to hand traumas [3].

In several manual tasks, including manufacturing tasks, the fingers are often very used to pull, push, and manipulate objects of varied sizes. Few data exist to indicate the



capacity of the fingers, two or more, to manipulate objects, during the activities [1].

Both the intrinsic and extrinsic musculature of the hand and forearm contributes to grasp exertions. The positions of the joints of the hand and fingers, and the size of the object being grabbed, affect mechanical advantage. The type of grasp or pinch, as well as its width, may be conditioning the action of intrinsic and extrinsic flexors during grasp exertions, where grasp width depends on the size of the grabbed object [4].

Grasping is present in most of the activities of daily living [5]. The estimated total of use of the hands in activities of daily living, during the day, is more than five hours, not counting work and sports activities [6].

The influence of gender, dominance, hand size, and grasp type has been investigated previously, however, the effect of this on sustained strength has not been studied. To help define the performance of quality human movement, one of the most important characteristics is the mechanical contractile muscle capability to develop as much strength as possible during the activity over time [7].

Investigating the force exerted by the hand is very important to understand the effect of handle characteristics on the grasp, not only as a single measurement but also related to the grasp configuration, object diameter, weight, and parts of the hand involved (number of fingers, type of contact, thumb position, etc.) [5]. Peak strength is only relevant for short durations of applied forces, in the activities, whereas a more realistic assessment of strength capabilities is given by sustained strength [4]. Hand grasp strength endurance is essential to perform activities of daily living that require repetitive grasping movements for a sustained period [8]. There are studies related to endurance and fatigue, on hand grasp strength, however, none of them analyses different anatomical positions [9].

The isokinetic assessment of dynamic force production requires the use of a dynamometer and involves the measurement of the force applied in a constant motion of angular velocity. It is widely used in sports, injury prevention, strength prediction, and in training or rehabilitation programs [10]. Biometrics E-link® Dynamometer is validated to do it [11] and equated to Jamar®, the most widely used and recommended dynamometer [12].

There are several studies made, using the hand grasp strength and endurance, relying on tests with several repetitions of tasks to measure the endurance. The Dynamometer D200, from the Biometrics E-Link®, is an electronic device that measures the strength in a moment or within a period and automatically registers the strength, the average, the peak of strength, the time to peak, and the endurance.

When a hand injury happens is predicted that the sustained hand grasp strength decreases, as it is known that the hand grasp strength decreases [13]. However, there are no studies describing these changes, and the sustained grasp strength behavior, in these cases.

Investigating the characteristics and the changes in sustained hand grasp strength when a musculoskeletal hand condition is present, will be extremely helpful for clinicians and rehabilitators.

This study intends to characterize the sustained grasp strength behavior, for 5 seconds (s) in eight different grasp configurations and identify changes in the sustained strength when a musculoskeletal injury is present. By using eight different grasp configurations, most of them using five fingers (five strength vectors), we will have a more realistic understanding of the strength behavior during the daily tasks since the tasks, performed by each type of grasp configuration, are already identified [14].

2. MATERIALS AND METHODS

2.1. Study Design

This cross-sectional descriptive exploratory study aims to make the methodology for assessing hand grasp strength more comprehensive, and realistic. It compares two independent groups, one without hand pathology, the control group, and the other with hand pathology, the study group [15].

2.2. Study Population

Portuguese, age ≥ 20 and ≤ 65 years. With this age range, we aim to have an active adult population.

2.3. Exclusion Criteria for the Control Group

As exclusion criteria from the control group, the existence of diagnosed pathology of the upper limbs, of neurological, degenerative, musculoskeletal, or vascular origin, was considered. The measurement of hand grasp strength in pregnant women, with the use of maximum applied strength, can cause the expulsion of the fetus in the terminal stages of pregnancy and because it is a transient condition can influence the grasp strength of the hand [16], so it was considered an exclusion criterion.

2.4. Inclusion Criteria for the Experimental Group

The inclusion criteria were, for the experimental group, to have a musculoskeletal or traumatological health condition that directly affects the hand.

2.5. Exclusion Criteria for the Experimental Group

The exclusion criteria of the experimental group were the existence of comorbidity of hand health conditions, degenerative diseases of the central nervous system, strokes, and traumatic brain injuries. To homogenise the experimental group sample, it was considered functionality. To do so, the International Classification of Functioning, Disability, and Health was used. The considered parameters were the “Body Functions,” “Body Structures” and “Activities and Participation.” The participants could not have less than “2” (moderate problem) or higher than “3” (severe problem) in the qualifiers. The selection of these values for the qualifiers, to integrate the experimental group, is related to the fact that the “0” has no problem, the “1” is a mild problem that would not give significantly different data from the control group, the “4” because it is a complete problem, and the participants would probably not be able to perform the assessment protocol. Pregnancy was also an exclusion criterion.

TABLE I: MEDIAN, MAXIMUM, AND MINIMUM AGE, BODY MASS INDEX, HAND LENGTH AND WIDTH, PER GROUP

Group		Age	BMI	Hand length (cm)	Hand width (cm)
CG	Md	36	23.52	18.1	10.5
	Min	22	20.72	16.4	9.0
	Max	59	27.47	20.9	12.2
EG	Md	36	22.10	18.8	10.4
	Min	24	19.80	16.5	9.0
	Max	60	31.60	20.3	12.1

Note: CG–Control Group; EG–Experimental Group; Md–Median; Min–Minimum; Max–Maximum; BMI–Body Mass Index.

2.6. Sample

Fifteen healthy participants were integrated into the control group and fifteen injured participants with musculoskeletal hand conditions, on the right hand, were integrated into the experimental group. The 30 participants were right-handed and regarding gender, 18 were men and 12 were women. In both the control and experimental groups there were 9 men and 6 women. The age median was 36 years, and the Body Mass Index was 23.52 for the control group and 22.1 for the experimental group. Regarding the hand measures, the median hand length was 18.1 cm, and the hand width was 10.5 cm for the control group. In the experimental group, the hand length was 18.8 cm and the hand width was 10.4 cm (Table I).

2.7. Ethical Clearance

All the participants were volunteers, fully informed of the procedures, advantages, and minor constraints, and gave their written consent. This research has complied with all relevant national and institutional regulations and has the approval of the Ethics Committee of the Faculty of Human Motricity of the University of Lisbon.

2.8. Data Collection Tool

The Dynamometer G200, from the Biometrics E-Link®, with kilograms as a measuring unit, was used to assess the hand grasp sustained strength.

2.9. Data Collection Procedure

The test position, to assess the hand grasp sustained strength, was recommended by the American Society of Hand Therapists assessment protocol: in a seated position on a back chair without arms, feet on the floor, knees, and hip at 90° flexion, back in touch with the chair, harm along the trunk, elbow at 90° flexion, forearm in a middle position and wrist between 0° and 30° [17], [18], [12].

The strength was collected for the right hands, for 5 seconds, giving 100 values of strength along this time. The time to peak, the peak force, and the endurance were also automatically identified for which grasp. There was collected strength from eight grasp configurations, which can be performed with the dynamometer [13]. These configurations are the Index Finger Extension, Parallel Extension, Small Diameter, Fixed Hook, Medium Wrap, Inferior Pincer, Ring, and Large Diameter, from the Feix Grasp Taxonomy [13], [19].

2.10. Data Processing and Analysis

Quantitative data analysis was performed by using the Statistical Package for the Social Sciences® 27th edition

and the MatLab® software. There were discrete variables such as age and continuous such as hand grasp strength, peak strength, and time to peak. Gender and hand dominance are nominal variables. Since there are two groups with fifteen participants each and no normal distribution, was used the Mann Whitney test to compare the groups. There will be presented the median, maximum, and minimum values for the variables sustained hand grasp strength, peak strength, and time to peak.

To analyse the strength behavior along the 5 s and 100 measurements, there were made graphics with these values by using the differential percentage from the maximal force (Figs. 1 and 2).

3. RESULTS

For all the subjects, the graphics show the sustained grasp strength behavior, during the five seconds. In Fig. 1, the strength raises and then maintains the level for the rest of the time, as can be seen in the red line on the top, representing the percentage of sustained maximum strength. The lines on the bottom are the average differences, from the mean values, during the five-second test. In all the configurations the strength starts above zero and rises to the peak. The peak is considered as the maximum strength before starts to descend, even if it rises again.

Comparing the two groups (Figs. 1 and 2), the strength is lower in the experimental group, for all the grasps configurations, and the decrease in strength, along the time, is also higher in the experimental group. The strength characteristics, in the control group are more stable than in the experimental group where it can be seen the oscillations on the bottom in the blue line. In the grey stain, there are registers of the minimum and maximum variations along the time, considering the median values. The strength behavior is more variable in the experimental group.

Regarding the median values of the sustained grasp strength, for each one of the analysed grasps configurations, there are significant differences between the control group and the experimental group, (sig. < 0.05). The minimum registered value is 1.9 kg, in the experimental group, on the Parallel Extension configuration, and the maximum registered value is 68.2 kg, in the control group, on the Medium Wrap (Table II).

The grasp configuration that allows to apply more strength is the Medium Wrap and less strength is the Inferior Pincer. The Medium Wrap uses 5 finger strength vectors, five fingers, and the Inferior Pincer uses only 2 fingers, 2 strength vectors, the index, and the thumb.

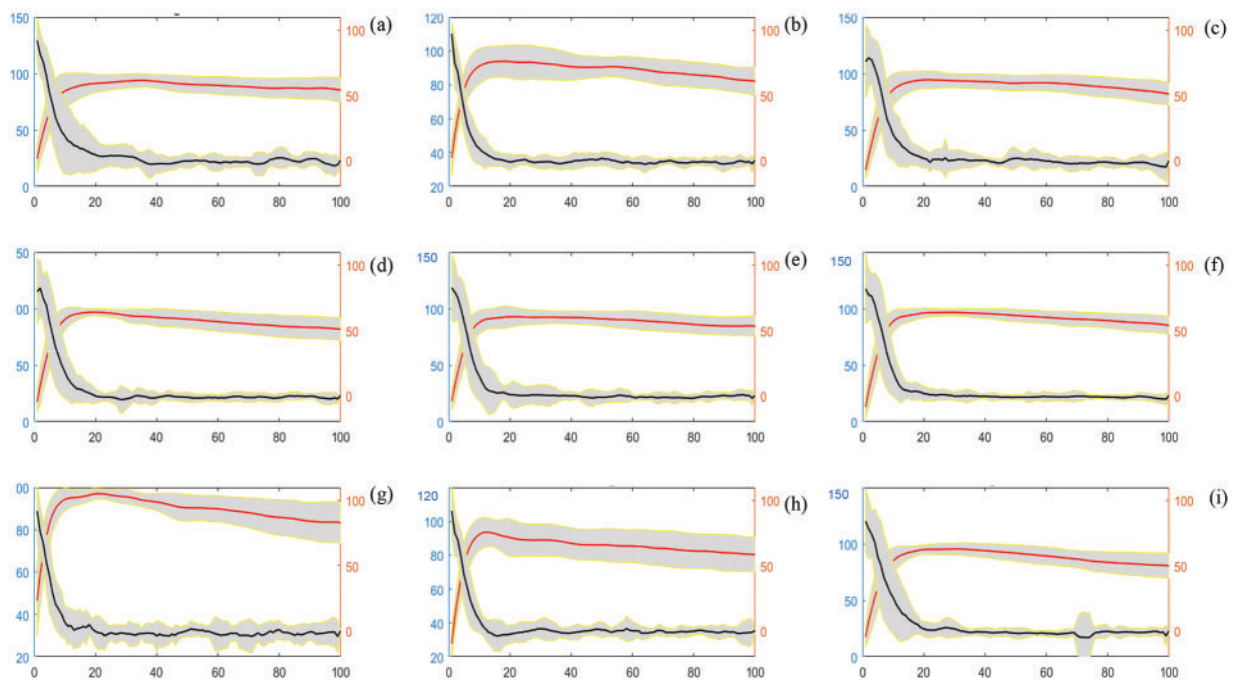


Fig. 1. Behavior of the control group strength for each grasp configuration during 5 seconds. Numbers in blue are the maximal sustained strength, in red the differential to maximal sustained strength and in black the time, in percentages: (a) Index finger extension, (b) Parallel extension, (c) Small diameter, (d) Abducted thumb, (e) Fixed hook, (f) Medium wrap, (g) Inferior pincer, (h) Ring, (i) Large diameter.

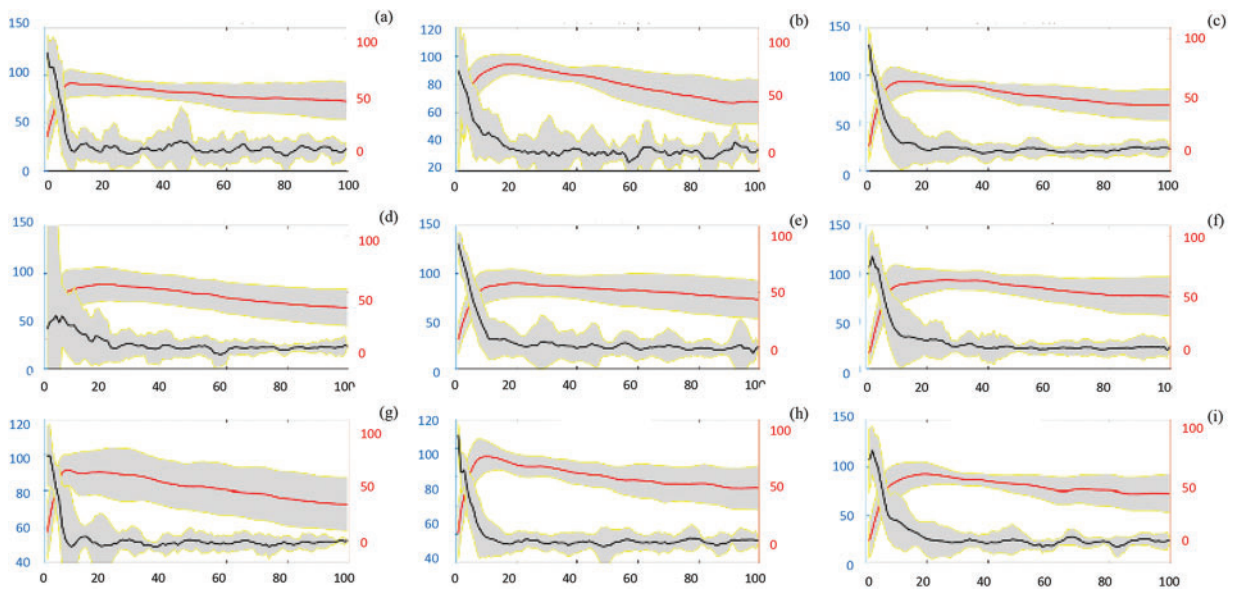


Fig. 2. Behavior of the experimental group strength for each grasp configuration, during 5 s. Numbers in blue are the maximal sustained strength, in red the differential to maximal sustained strength and in black the time, in percentages: (a) Index finger extension, (b) Parallel extension, (c) Small diameter, (d) Abducted thumb, (e) Fixed hook, (f) Medium wrap, (g) Inferior pincer, (h) Ring, (i) Large diameter.

TABLE II: MEDIAN, MAXIMUM, AND MINIMUM OF THE STRENGTH VALUES, PER GROUP, FOR EACH ASSESSED GRASP CONFIGURATION

Group		Index finger extension	Parallel extension	Small diameter	Fixed hook	Medium wrap	Inferior pincer	Ring	Large diameter
									
CG	Md	11.60	10.20	29.10	23.40	38.00	7.00	14.20	30.90
	Max	34.1	15.4	51.1	41.0	68.2	15.7	22.2	61.8
	Min	6.4	6.2	14.9	11.0	20.2	3.3	7.4	14.7
EG	Md	7.60	5.80	15.20	13.30	25.20	4.40	6.40	15.80
	Max	22.3	9.2	27.1	23.8	38.6	5.7	14.5	28.8
	Mi.	2.2	1.9	3.1	3.5	5.2	2.3	3.1	4.0

Note: Min–Minimum; Max–Maximum.

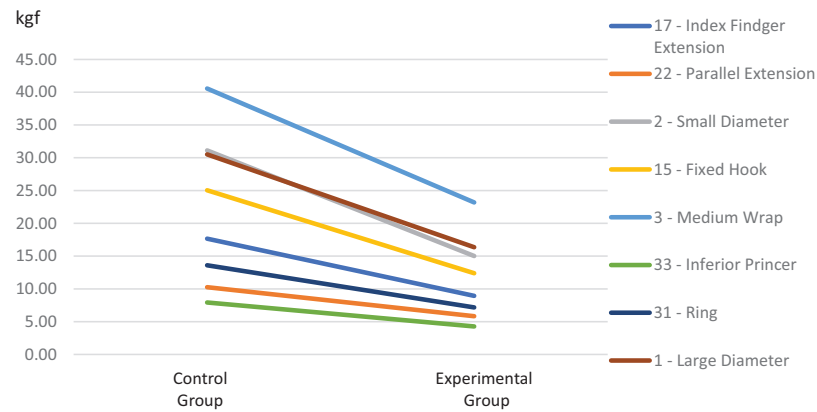


Fig. 3. Comparing values of grasp strength of control and experimental groups.

TABLE III: MEDIAN, MINIMUM, AND MAXIMUM OF TIME TO PEAK, PER GROUP, FOR EACH GRASP CONFIGURATION

Group		Index finger extension	Parallel extension	Small diameter	Fixed hook	Medium wrap	Inferior pincer	Ring	Large diameter
									
CG	Md	0.60	0.60	0.90	0.90	0.80	0.60	0.60	1.00
	Min	0.3	0.3	0.4	0.3	0.5	0.2	0.3	0.3
	Max	3.2	2.8	2.2	2.5	2.2	1.4	1.6	2.3
EG	Md	0.40	0.50	0.60	0.50	00.90	0.40	0.50	0.90
	Min	0.1	0.1	0.4	0.2	0.4	0.2	0.3	0.2
	Max	2.5	1.3	3.2	2.0	4.0	1.6	1.4	2.8

Note: CG–Control Group; EG–Experimental Group; Md–Median; Min–Minimum; Max–Maximum.

TABLE IV : MEDIAN, MINIMUM, AND MAXIMUM OF THE PEAK STRENGTH VALUE, PER GROUP, FOR EACH GRASP CONFIGURATION

Group		Index finger extension	Parallel extension	Small diameter	Fixed hook	Medium wrap	Inferior pincer	Ring	Large diameter
									
CG	Md	12.20	9.70	31.60	24.50	39.50	7.20	14.40	30.90
	Min	9.5	5.4	12.5	11.2	24.7	3.1	7.2	16.0
	Max	36.4	15.9	50.7	40.3	67.6	16.6	21.4	56.1
EG	Md	8.40	5.80	15.30	11.70	25.30	4.50	7.10	15.80
	Min	2.4	2.3	3.3	3.7	5.8	2.6	3.0	4.4
	Max	22.7	9.3	27.9	23.5	39.1	5.8	14.9	29.8

Note: CG–Control Group; EG–Experimental Group; M–Median; Min–Minimum; Max–Maximum.

When comparing values of strength between groups, there is a decrease in strength, in the experimental group (Fig. 3). The Inferior Pincer and the Parallel Extension are the grasp configurations that require less strength, and they are both precision grasps configurations, using the pads of the fingers to establish contact with the grasped object. The Medium Wrap is the grasp configuration that requires more strength and has also more strength difference between the control and experimental groups (17 kg). The three strongest grasps have the same configuration being the difference in the diameter of the grabbed object and in the assessment position of the dynamometer handle. These are the Medium Wrap (ø4.8 cm), the Large Diameter (ø8.7 cm), and the Small Diameter (ø3.5 cm). These grasp configurations must be assessed with the dynamometer handle positioning according to their diameter: the Medium Wrap in the second position, the Large Diameter

in the fifth position, and the Small Diameter in the first position [13].

The Time to Peak represents the time that takes to reach the higher value before it decreases. The Time to Peak (Table III), varies between 0.1 and 4 seconds in the experimental group, and 0.2 to 3.2 seconds in the control group.

The experimental group reaches the strength peak quicker (0.1 seconds) than the control group (0.7 seconds). This is related to the fact that strength values are lower in the experimental group. The peak strength is always higher, in the median, minimum, and maximum values, in the control group. The lower value is 2.3 kg in the Parallel Extension, in the experimental group. The highest value is 67.6 kg in the Medium Wrap, in the control group. From both groups, the three highest values of peak strength were obtained in the Small Diameter, Medium Wrap, and Large

TABLE V: MEDIAN, MINIMUM, AND MAXIMUM OF THE PEAK STRENGTH VALUE, PER GROUP, FOR EACH GRASP CONFIGURATION

Group		Index finger extension 	Parallel extension 	Small diameter 	Fixed hook 	Medium wrap 	Inferior pincer 	Ring 	Large diameter 
Women	Md	8.60	6.20	16.40	13.65	22.80	3.950	7.35	15.10
	Min	2.2	1.9	3.1	3.5	5.2	2.3	3.1	4.0
	Max	12.3	8.2	21.2	20.8	28.7	5.6	9.4	18.0
Man	Md	12.00	9.00	27.70	23.40	37.60	6.25	13.7	29.55
	Min	2.8	5.2	9.9	6.6	13.7	3.5	3.2	9.5
	Max	34.1	15.4	51.1	41.0	68.2	15.7	22.2	61.8

Note: Md–Median; Min–Minimum; Max–Maximum.

TABLE VI: MEDIAN, MINIMUM, AND MAXIMUM OF ENDURANCE VALUE PER GENDER FOR EACH GRASP CONFIGURATION

Group		Index finger extension 	Parallel extension 	Small diameter 	Fixed hook 	Medium wrap 	Inferior pincer 	Ring 	Large diameter 
Women	Md	−0.45	−0.35	−1.05	−0.95	−1.35	−0.25	−0.35	−1.00
	Min	−1.0	−0.8	−2.0	−1.7	−2.7	−0.4	−0.9	−2.3
	Max	0.0	0.0	0.1	0.4	−0.3	−0.1	0.0	−0.2
Man	Md	−0.55	−0.45	−0.90	−1.00	−1.35	−0.30	−0.85	−1.35
	Min	−2.6	−0.9	−2.4	−1.8	−5.4	−0.7	−1.8	−4.0
	Max	0.5	0.3	0.4	1.0	1.1	0.1	0.4	0.3

Note: Md–Median; Min–Minimum; Max–Maximum.

Diameter grasp configurations. The grasp configuration with a higher peak strength is the Medium Wrap and less peak strength is the Inferior Pincer (Table IV).

When comparing genders, the grasping strength is higher in men in all the groups and grasp's configurations. The minimum value obtained by women is 1.9 kg, in the Parallel Extension, and by men is 2.8 kg in the Index Finger Extension. The highest value obtained was for the Medium Wrap women 28.7 kg, and men 68.2 kg (Table V).

Regarding endurance, the Biometrics E-Link[®] analyses the stability of the strength during the 5 seconds. When comparing gender, the man has the maximum values of endurance, being always positive, but also the minimum values, in all the grasps configurations, except for the Small Diameter (Table VI).

4. DISCUSSION

There are not many studies referring the sustained hand grasp strength, and also there are not many instruments that assess this variable, and the ones that do are expensive. The peak strength, and time to peak, during a sustained strength, are other variables that we could not find analysed in the literature frequently.

Endurance is analysed in several articles in the literature however, always related to the capability to perform different tasks or carry objects, during a period of time. In this study, using an instrument that measures and calculates this parameter, automatically is an advantage. The accurate register of the data is a warranty by the automatic register of the Biometrics E-Link[®] system. In this way, there are no biases in the data register in this study.

The sustained grasp strength is lower in women than in men, being this characteristic similar to the grasp strength values described by Massy-Westropp *et al.* [20]. When there is a musculoskeletal injury, the grasp behaves similarly but the values of the strength, and peak strength decrease significantly. This is also found in the grasp strength in several health conditions namely in musculoskeletal impairments that often express functionally as a loss of strength [21]. The time to peak, as the strength, is lower when there is a hand injury, it is similar to or faster than in normal situations. Man obtains the maximum endurance, and there are no significant differences between genders. These results are similar to the ones of Massy-westropp *et al.* [20]. However, when the mean is the focus, most of the time women have more endurance than men, being only in the Small Diameter configuration the other way around. Similar results were found in other studies, with different instruments and analysing a specific muscle [22].

The sustained strength is a work strength. It rises until a first peak strength, within the first two seconds, independently of the grasp configuration, and then decreases.

The strength behavior is more regular in the control group than in the experimental group where is more irregular along the 5 seconds.

The Inferior Pincer and the Parallel Extension are the grasp configurations that require less strength, being both precision grasps, using the pads to establish contact with the grabbed object. The Medium Wrap is the grasp configuration that requires more strength, and it is also the one that has more differences between groups, regarding the strength, the time to peak, and the peak strength. The

three strongest grasps have the same configuration being the difference in the diameter of the grabbed object. These are the Small Diameter, the Medium Wrap, and the Large Diameter.

5. CONCLUSION

It could be interesting to make this type of analysis with a larger number of participants, or in specific health conditions, and even collect the normative data for the sustained strength, being this a relevant work strength measurement. It also would be interesting to compare the sustained hand grasp strength behavior, during the 5, 10, 15, 20, and 30 seconds time tests.

The lack of information related to the characteristics of the sustained grasp strength makes this study interesting to the scientific and clinical areas, to better understand the sustained strength behavior and the capabilities for work-related tasks.

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

REFERENCES

- [1] Cort JA, Potvin JR. Maximum isometric finger pull forces. *Int J Ind Ergon*. 2011;41:91–5. doi: 10.1016/j.ergon.2010.12.008.
- [2] Jarque-Bou NJ, Atzori M, Müller H. A large calibrated database of hand movements and grasps kinematics. *Sci Data*. 2020;7(1):1–10. doi: 10.1038/s41597-019-0349-2.
- [3] Shiri R, Viikari-Juntura E, Varonen H, Heliovaara M. Prevalence and determinants of lateral and medial epicondylitis. *Ame J of Epi*. 2006;164:1065–74.
- [4] Dempsey PG, Ayoub MM. The influence of gender, grasp type, pinch width and wrist position on sustained pinch strength. *Int J Ind Ergon*. 1996;17:259–73.
- [5] Rossi J, Berton E, Grélot L, Barla C, Vigouroux L. Characterisation of forces exerted by the entire hand during the power grip: effect of the handle diameter. *Ergon*. 2012;55(6):682–92.
- [6] Vergara M, Sancho-Bru JL, Gracia-Ibáñez V, Pérez-González A. An introductory study of common grasps used by adults during performance of activities of daily living. *J Hand Ther*. 2014;27(3):225–34. doi: 10.1016/j.jht.2014.04.002.
- [7] Dopsaj MM, Ivanovic J, Koropanovski N, Studies P, Vuckovic G. Basic and specific characteristics of the hand grip explosive force and time parameters in different strength trained population. *Brazilian J Biomotricity*. 2009;3(2):177–93.
- [8] Karatrantou K. Dynamic handgrip strength endurance: a reliable measurement in older women. *J Geriatr Phys Ther*. 2019;42(3):E51–6.
- [9] Alkurdi ZD, Dweiri YM. A biomechanical assessment of isometric handgrip force and fatigue at different anatomical positions. *J Appl Biomech*. 2010;26(2):123–33.
- [10] Valamatos MJ, Mil-Homens P, Pinto R. Avaliação Isocinética da Força. Correia PP, Mil-Homens P, Vilhena de Mendonça G, editors. In *Treino Da Força-Avaliação, Planeamento e Aplicações. [Strength Training-Assessment. Planning and Applications]*. vol. 2. Lisboa, Portuguese: Edições FMH, 2017, pp. 39.
- [11] Tomás MT, Fernandes MB. Grip strength-agreement analysis between two dynamometers: JAMAR vs. E-Link. *Saúde e Tecnol*. 2012;7:39–43. doi: 10.25758/set.484. Portuguese.
- [12] Mathiowetz V, Wiemer DM, Federman SM. Grip and pinch strength: norms for 6- to 19-year-olds. *Am J Occup Ther*. 1986;40(10):705–11. doi: 10.5014/ajot.40.10.705.
- [13] Roldão E, Gil Pascoal A. Is it possible to assess more grasps configurations? A new assessment approach on hand strength. *Acta Sci Orthop*. 2023;6(4):13–20.
- [14] Roldão E, Gil Pascoal A. Grasps in daily tasks. *J Heal Sci Nurs*. 2021;6(4):1–7.
- [15] Cleber P, de Freitas EC. Método Científico. In *Metodologia do Trabalho Científico: Métodos e Técnicas da Pesquisa e do Trabalho Acadêmico. [Methodology of Scientific Work: Research and Work Methods and Academic Techniques]*. 2a. Rio Grande do Sul, Feevale E, Ed. Brasil, Portuguese, 2013, pp. 37.
- [16] Eksioglu M. Normative static grip strength of population of Turkey, effects of various factors and a comparison with international norms. *Appl Ergon*. 2016;52:8–17.
- [17] Fess EE, Moran CA. Grip and Pinch. In: American Society of Hand Therapists, editor. Clinical Assessment Recommendations [Internet]. 1st ed. United States of America: American Society of Hand Therapists; 1981. pp. 6–8.
- [18] Larson CC, Ye Z. Development of an updated normative data table for hand grip and pinch strength: a pilot study. *Comput Biol Med*. 2017;86(January):40–6. doi: 10.1016/j.compbimed.2017.01.021.
- [19] Feix T, Romero J, Schmiedmayer HB, Dollar AM, Kragic D. The grasp taxonomy of human grasp types. *IEEE Trans Human-Mach Syst*. 2016;22:66–77. doi: 10.1109/THMS.2015.2470657.
- [20] Massy-westropp NM, Gill TK, Taylor AW, Bohannon RW, Hill CL. Hand Grip Strength: age and gender stratified normative data in a population-based study. *BMC Res Notes*. 2011;4(127):1–5. Available from: <http://www.biomedcentral.com/1756-0500/4/127>.
- [21] Wolf LD, Matheson LN, Ford DD, Kwak AL. Relationships among grip strength, work capacity, and recovery. *J Occup Rehabil*. 1996;6(1):57–70.
- [22] Fulco CS, Rock PB, Muza SR, Lammi E, Cymerman A, Butterfield G, et al. Slower fatigue and faster recovery of the adductor pollicis muscle in women matched for strength with men. *Acta Physiol Scand*. 1999;167(3):233–9.