CONSIDERATIONS OF PHYSIOLOGICAL DESIGN PARAMETERS FOR DYNAMOMETERS

[1]MATTHEW D. KING, [2]CHARLOTTE FLAGHERTY, [3]JING LIN

[1,2]Department of Engineering Construction and Living Sciences, Otago Polytechnic, Dunedin, New Zealand.
[3]Department of Civil Engineering, Dalian Ocean University, Dalian. China
E-mail: [1]mking@op.ac.nz, [2] flahecc1@student.op.ac.nz, [3]sutezjl@126.com,

Abstract –
Purpose: This paper considers the relevance of grip strength in everyday life and why and how it is measured to establish a baseline of physiological design parameters which will allow the development of a standardised test protocol for the handgrip dynamometer which generates consistent and accurate results.
Methods: Relevant publications were reviewed and evaluated to glean insight into the effects of various device and test parameters on the test outcomes.
Results: A number of physiological parameters were consistently reported as having a negative effect on the reliability of the test results. These parameters include variations in the: Choice of test Device, Anthropometrics, Test Protocols, Body Position, Instructions, Device Feedback, in addition to a range of Physical parameters which will be discussed in a subsequent review.
Conclusions: Even though Jamar controls a majority of the hand grip testing market, there are a range of results as well as a range of Jamar products available on the market which give a variety of test results. These test results, in combination with inconsistencies identified in the above listed test parameters, revealed inconsistent medical examination outcomes. It is possible to develop a standardized testing protocol and to incorporate appropriate physiological considerations to generate a more standardised outcome from hand grip tests.Many devices have been made available on the market with widely varying applications due, in part, to an inconsistency in understanding of physics and the inconsistent selection of design parameters.
Grip strength is important for everyday activities in and out of the work environment. The assessment of explosive and sustained grip strength is used as an indicator of overall strength and health as well as to measure the impact of injuries to the hand and wrist.
A reliable device is required to run grip strength tests. The device must be of a design appropriate for use by normal healthy individuals as well as patients with hand deformity, tissue sensitivity and reduced ability who can only deliver low levels of force. It must also be able to deliver results that are both accurate and reproducible.

Keywords: Dynamometer, Grip Strength, Jamar, Test protocol, Hand Grip Strength Testing

BACKGROUND

Grip strength is the ability of the forearm and the hand to exert a force squeezing the hand or individual fingers (Moreira D, 2003). It is important for everyday activities in and out of the work environment.
The assessment of grip strength is often used in the clinical scenario as an indicator of overall physical strength and health (Massy-Westropp N, 2004) as well as for assessment of specific hand and wrist injury impact (Ashton L, 2003).Measuring grip strength identifies potential strength deficits and tracks improvement through rehabilitation after injury. It can also be used to establish realistic treatment goals for hand and wrist injuries. (Moreira D, 2003). Grip strength is either explosive/dynamic (e.g. catching, grabbing), or sustained/static (e.g. carrying a shopping bag, operating a lever). (Williamson T L, Sept 2003) Because testing of handgrip strength in clinical settings is carried out on patients presenting with a wide range of grip abilitysuch a device should consider design parameters that promote ease of use from the point of view of the patient as well as the clinical practitioner.
There are several different types of dynamometer in use: Pneumatic, Hydraulic, Electronic/Strain. Any device that allows for the varying of the surface area over which pressure is applied leads to variable results (i.e. larger hand size leads to artificially lower results than smaller hand size) They do not all have the same physical grip profile.
An evaluation of a variety of test devices revealed that material choices could be at odds with best practices for consistent test results. Good quality, rigid devices made of metal give consistent results but tend to be heavy and unforgiving, which can lead to test fatigue and poor performance due to unsuitability for some hand sizes. In contrast, lightweight plastic devices are easier to use, can be used for longer test sessions and flexure of the device provides a more comfortable grip; but the ability to flex can also cause inconsistent results when comparing the grip strength between test subjects.

INTERPRETATION OF RESULTS FROM PREVIOUS STUDIES:

Overview:
Many daily functions, such as carrying, require the use of the flexor musculature of the forearms and hands, and these are the muscles that are involved in gripping strength. (Hui Lin Ong, Aug 2017)

Handgrip has two functions: a static grip pattern used to hold or handle objects and a dynamic grip pattern which exerts explosive force to assist the functions of the lower limbs or trunk, for instance when grabbing a support to help in getting up from a chair or to climb stairs. (Kayoko Watanabe, 1 May 2011)
Grasping an object with the five digits is complicated. Each digit exerts a six-dimensional wrench on the object. The five digits have in all 30 force/moment degrees of freedom, which must satisfy six constraints of statics (force and moment balance in the three-dimensional space). (Ambike S, Apr 2014)
In order to initiate a grasping motion both the extrinsic and intrinsic tendons of the hand must work together to produce a coordinated effort. (Diaz-Garcia, 2016).
Being able to measure the strength and monitor the improvement of the hand grip is considered an important parameter in rehabilitation. This paper looks into the inconstancies in the results of the test and identifies physiological parameters that influence those results.

Anthropometric requirements

Consideration should be given to age, sex and impairment state of the individual. The author of a European study from 2014 that looked at the effect of body position (supine, standing, sitting) on grip strength concluded "Age is one of the important determinants of the hand grip evaluation, particularly when standing position is used." (El-Sais & Mohammad, Dec 2014)
For those with no injury or disease of the upper extremities, Ke Li et al (2010) and Jean-Yves Hogrel (Hogrel, 2015) found that hand circumference had the largest correlation with maximum grip strength, while Wichelhaus (2018) found length of hand had a significant influence on the hand strength. However, a longitudinal German study concluded that the person's height was a significant factor in grip strength (Steiber, 2016).
A study in 2010 (Ke Li, Dec 2010) considered a set of anthropomorphic factors including hand and palm length, the subject's height; weight; hand, wrist and forearm circumference, while in 2018 researchers looked at gender, hand length and work-related grip activity (Wichelhaus A, Feb 2018). Ke Li concluded that hand circumference can be used to predict maximum grip strength for both men and women and for dominant and non-dominant hands. (Ke Li, Dec 2010). In 1956 the California Medical Association examined factors impacting grip strength in detail and identified four factors that impacted ability to grip:

1. Grip loss resulting from amputation. The image below shows percentage of grip loss due to amputation. For partial loss of any digit at the middle joint the value is 75% of that for finger. For partial loss of any digit at the top joint the value is 20% that of finger. Grip loss would be increased in all cases by pain, limited motion, tender stump, scars, incoordination and muscle weakness.
2. Grip loss resulting from limited hand motion,

The California Medical Associationconsidered the difficulty of estimating the percentage of grip loss resulting from limited hand motion and devised a method of estimation which considered the distance the finger tips missed the palm during flexion. (Kirkpatrick, 1956)

Fingers	Misses mid palm more than 5 cm	Misses mid palm 5 cm	Misses mid palm 2.5 cm
Index	30%	25%	20%
Middle	35%	30%	20%
Ring	25%	20%	10%
Little	10%	10%	5%

Table 2: Table shows distance finger misses mid-palm (in closing) and its percentage impact on grip strength. (after Kirkpatrick, 1956, units updated)

3. Grip loss resulting from pain in the hand, wrist, elbow or shoulder,
4. Grip loss resulting from muscular weakness.

It was also noted that with certain limitations of motion a person may have a normal grip for large objects and yet a complete loss of grip for small objects. (Kirkpatrick, 1956)
In order to compare an individual's grip strength consistently with published expectations for an individual of comparable physiology, the device, or the technician, should be able to account for these researched and understood variations so that the test results can be normed and give meaningful reflection under a wide range of circumstances and medical conditions. This implication favours digital devices that can be programmed and give both raw data and adjusted outputs based on a patient's medical profile. The device would therefore need to be a design based on a microprocessor.

Test Protocols from Previous studies:

In order to standardise handgrip strength tests, consideration must be given to the type of instruction given, the amount and quality of verbal encouragement and whether visual feedback on static strength is given. Myung-Chul Young et al tested a group of males and found all three factors had positive effects on static and peak grip strength and time to reach maximal strength. (Myung-Chul Jung, Nov 2004)

Body Position

It is considered that consistency of test administration is a key factor in the quality of information garnered from handgrip strength tests. (Lorie Gage Richards, Mar 1995)although (Spjkerman D C M, 1991) concluded that, although standardisation of protocol was important, protocols with stricter conditions did not enhance reliability.

The American Society of Hand Therapists' protocol for strength-grip testing recommends a standard position as follows: seated with straight back on chair with backrest; feet flat on floor, shoulder adducted and neutrally rotated, elbow at 90 degrees, forearm supported in the neutral position.

The American Society of Hand Therapists (ASHTs) describe specific guidelines for the measurement of grip strength using the Jamar (TM) dynamometer. (Weinstock-Zlotnick, Bear-Lehman, & Yu, 2011)

Positioning of the arm, wrist and hand are important for grip strength testing as is whether the test subject is standing or sitting.

The position of the body, arm, wrist and hand, the choice of test device and the number and duration of trails are important to consider. (Lorie Richards, 1996)

The effect of testing posture and elbow position on grip strength has been studied. Balogun et al found there was a significant ($p < .05$) difference between the grip strength measured in subjects sitting with the elbow in 90°flexion and standing with the elbow in full extension. The findings suggest the need for clinicians to maintain standard testing conditions while measuring grip strength. (Balogun J, 1991). Mathiowetz found a sample of 29 women displayed a significantly stronger grip strength measurement in the 90° elbow flexed position than in the fully extended position (Mathiowetz Virgil, 1985)

James Pryce investigated the effect of wrist position on grip strength by testing subjects grasping an adjustable isometric handle in nine wrist positions between neutral and ulnar deviation, fifteen degrees each side of neutral in volar and dorsiflexion. Findings revealed a significant difference between ulnar deviation wrist positions and between volar-dorsiflexion wrist positions, and that there was significant interaction between ulnar deviation and volar-dorsiflexion wrist positions (Pryce, 1980). Pryce used Duncan's Multiple Range Test to show no significance for zero degrees ulnar deviation and 15 degrees dorsiflexion, 15 degrees ulnar deviation and 15 degrees dorsiflexion, 15 degrees ulnar deviation and zero degrees volar-dorsiflexion, and zero degrees ulnar deviation and zero degrees volar-dorsiflexion wrist positions; although he concluded those means were significantly higher than the power grip strength means for the other five wrist positions tested.

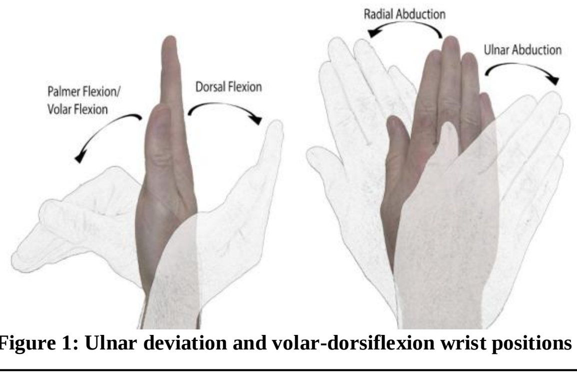

Figure 1: Ulnar deviation and volar-dorsiflexion wrist positions

O'Driscoll et al found that grip strength was significantly reduced when wrist position deviated from the self-selected optimum position which was found to be 35 degrees of extension and 7 degrees of ulnar deviation. Grip strength was significantly less in any position of deviation from this self-selected position, even after accounting for fatigue. (O'Driscoll, 1992)

A study in 2005 concluded that it may be useful to introduce self-selection of the handgrip position in protocols to assess the maximal handgrip strength after finding that both in sitting and in standing, participants were able to self-select the handgrip position on the hand dynamometer with which the maximal handgrip strength could be delivered. (Boadella Juliette M., 2005)

It would be easier for a clinician to instruct the patient to self-select the handgrip position, but could that still be considered consistent? If the measurement being sought is maximum grip strength, and research has shown that patients consistently self-select the position that produces the maximum grip strength, then perhaps a less rigid testing protocol will produce better and more consistent results in some respects. The research appears to indicate that tests should be consistently performed with the patient either standing or sitting while the arm is bent at 90 degrees and the device is oriented at the self-selected optimum handgrip position which will most likely be at 35 degrees of extension and 7 degrees of ulnar deviation.

INSTRUCTION AND ENCOURAGEMENT:

Muscle strength measurement is influenced by instruction (Williamson T L, Sept 2003)

Most research studies clearly describe the instructions given to the participants at the time the research is being performed. However, these instruction are not consistent.

A standardized set of instructions should be developed and uniformly issued to produce consistent results. This produces obvious challenges and the only way to guarantee the consistency is to prerecord the encouragement and ensure that it is offered at the same intensity and with the same timing for every test. This can also only be accomplished with the use of a microprocessor which is monitoring the test results for consistency in timing.

FEEDBACK

The ASHT guidelines do not provide guidance for the position of a digital or computer screen display during grip strength testing.It is known that during reliability or validity studies the patient is not allowed to see a feedback screen, it is not known whether patients in a clinical setting are able to view the digital or computer display during testing. (Weinstock-Zlotnick, Bear-Lehman, & Yu, 2011)

The question arises as to whether providing visual feedback of their effort to the patient is important. In normal test conditions the patient cannot see the screen with the Jamar handheld dynamometer.

"It has been known that the force produced in isometric conditions drops if no visual force feedback is provided, even when subjects try to maintain its magnitude (Slifkin et al. 2000; Vaillancourt and Russell 2002; Baweja et al. 2009)." (Ambike S, Apr 2014)

"Sincerity of maximum voluntary effort is a factor in grip strength measurement as this has relevance to monetary payment in worker's compensation, motor vehicle accident and medical insurance claims." (Ashton L, 2003)

In 1991 Spijkerman et al found that a challenging stimulus to exceed a previous maximal effort (in the form of a real-time graph of effort) created a significant learning effort in patients (Spjkerman D C M, 1991) while in 2011, Weinstock-Zlotnick found participants achieved a small, yet statistically significant, 1.74lb (0.789 kg) stronger grip score when they had visual feedback ($p<0.002$).

DISCUSSION

The author of a recent German study considered that "handgrip strength is an important biomarker of healthy ageing and a powerful predictor of future morbidity and mortality both in younger and older populations." (Steiber, 2016)

We know also that strength of grip is crucial to everyday functioning in the workplace and for domestic and recreational activities.

There are two types of grip: explosive grip, as in grabbing a handrail or catching a frisbee, and sustained grip, as in carrying shopping bags.In the workplace there is commonly a form of sustained grip which involves holding a cylindrical-shaped lever.

The Jamar hand-held dynamometer is the clinical instrument most frequentlyused to measure grip strength. It measures sustained grip using a curved plastic or metal grip that the patient holds and squeezes. Numerous studies have used the Jamar dynamometer to demonstrate the reliability and validity of grip strength testing, to establish grip strength norms (data that characterizes what is usual in a defined population at a specific point or time period (O'Connor, July 1990)) in adults in the United States. (Hanten WP, 1999) However, a 2015 comparison of the Jamar and Myogrip dynamometers found "the reliability of the MyoGrip device was excellent but the Jamar tended to overestimate maximal grip strength by about 14 % across populations." (Hogrel, 2015)

Wichelahus (2018) found a partial reason for the influence of hand length on grip strength in the case of the Jamar dynamometer was that the finger tips do not touch the Jamar dynamometer during grip and therefore do not take part in load transmission. Wichelhaus concluded that the Jamar dynamometer in comparison with a new cylindrical measuring system (Manugraphy system) yielded similar results, while the cylindrical system gave the added benefit of being able to "enable more precise comparisons of isolated hand regions applying dynamic measurements."

If the results of the grip strength tests are not interchangeable for different devices, then either the devices are not measuring the same thing consistently or clinicians are not using consistent methodology to collect the data. A need for a more standardized method and approach is indicated. This standardized method will need to be independent of the clinician proffering the test and specifically responsive to the test being performed in real time. Therefore, the testing device should be computerized and interactive in nature with pre-recorded instructions, encouragement and response that will be consistent globally.

REFERENCES

[1] Ambike S, F. P. (Apr 2014). Factors affecting grip force: anatomy, mechanics, and referent configurations. Experimental Brain Research, Volume 232, Issue 4, 1219-31. DOI:10.1007/s00221-014-3838-8.

[2] Ashton L, S. M. (2003). Serial Grip Strength Testing- Its Role In Assessment Of Wrist And Hand Disability. The Internet Journal of Surgery, Vol 5, No 2.

[3] Balogun J, A. C. (1991). Grip strength: Effects of testing posture and elbow position. Physical Medicine and Rehabilitation, Volume 72, Issue 5, Pages 280–283.

[4] Boadella Juliette M., K. P.-D. (2005). Effect of self-selected handgrip position on maximal handgrip strength. Archives of Physical Medicine and Rehabilitation, Volume 86, Issue 2, Pages 328-331.

[5] Caldwell L S, C. D.-D. (1974). Proposed Standard Procedure for Static Muscle Strength Testing. American Industrial Hygiene Association, Vol 35, 201 206.

[6] Diaz-Garcia, R. J. (2016). A Comprehensive Guide on Restoring Grasp Using Tendon Transfer Procedures for Ulnar Nerve Palsy. Hand Clinics, Volume 32, Issue 3, 361 - 368.

[7] El-Sais, W., & Mohammad, W. (Dec 2014). INFLUENCE OF DIFFERENT TESTING POSTURES ON HAND GRIP STRENGTH. European Scientific Journal, , Vol.10(36).

[8] Hanten WP, C. W. (1999). Maximum grip strength in normal subjects from 20 to 64 years of age . Journal of Hand Therapy, 12, 193-200.

[9] Hogrel, J.-Y. (2015). Grip strength measured by high precision dynamometry in healthy subjects from 5 to 80 years. BMC Musculoskeletal Disorders, 16(1):139.

[10] Hui Lin Ong, E. A. (Aug 2017). Hand-grip strength among older adults in Singapore: a comparison with international norms and associative factors. BMC Geriatrics, https://doi.org/10.1186/s12877-017-0565-6.

[11] Jung MC, H. M. (1999). The effects of instruction, verbal encouragement, and visual feedback on static handgrip strength. Proceedings of the Human Factors and Ergonomics Society 43Rd Annual Meeting, (pp. pg. 703-7).

[12] Kayoko Watanabe, S. T. (1 May 2011). Differences in Parameters of the Explosive Grip Force Test Between Young and Older Women. Journals of Gerontology: Series A, Volume 66A, Issue 5, , Pages 554–558, https://doi.org/1.

[13] Ke Li, D. J.-Y. (Dec 2010). Predicting maximal grip strength using hand circumference. Manual Therapy, Volume 15,

Issue 6, Pages 579-585 https://doi.org/10.1016/j.math.2010.06.010.

[14] Kirkpatrick, J. E. (1956). EVALUATION OF GRIP LOSS—A Factor of Permanent Partial Disability in California: Summation and Conclusions of the Subcommittee for Study of Grasping Power of the Committee on Industrial Health and Rehabilitation of the California Medical Association. California Medicine, 85(5): 314–320.

[15] Lorie Gage Richards, B. O.-T. (Mar 1995). How Forearm Position Affects Grip Strength. The American Journal of Occupational Therapy, https://s3.amazonaws.com/academia.edu.documents/35096602/133.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1552798932&Signature=Glr9E%2F2uYyGZwoGwOpBDrSiaq8I%3D&response-content-disposition=inline%3B%20filename%3DHow_Forearm_Position_Affects_Grip_Streng.

[16] Lorie Richards, P. P.-T. (1996). Grip Strength Measurement: A Critical Review of Tools, Methods, and Clinical Utility. Critical Reviews in Physical and Rehabilitation Medicine, Vol 8, Issue 1-2, pages 87-109.

[17] Massy-Westropp N, R. W. (2004). Measuring grip strength in normal adults: reference ranges and a comparison of electronic and hydraulic instruments. The Journal of Hand Surgery, 29(3):514-9.

[18] Mathiowetz Virgil, C. R. (1985). Effect of elbow position on grip and key pinch strength. The Journal of Hand Surgery, Volume 10, Issue 5, Pages 694-697.

[19] Moreira D, Á. R. (2003). Abordagem sobre preensão palmar utilizando o dinamômetro JAMAR®: uma revisão de literatura. Revista brasileira de ciência & movimento , 11(2):95-9.

[20] Myung-Chul Jung, M. H. (Nov 2004). Quantification of the effects of instruction type, verbal encouragement, and visual feedback on static and peak handgrip strength. International Journal of Industrial Ergonomics, Volume 34, Issue 5, Pages 367-374 https://doi.org/10.1016/j.ergon.2004.03.008.

[21] O'Connor, P. J. (July 1990). Normative data: Their definition, interpretation, and importance for primary care physicians. Family Medicine, 22(4):307-11.

[22] O'Driscoll, S. W.-N. (1992). The relationship between wrist position, grasp size, and grip strength. Journal of Hand Surgery, Volume 17 , Issue 1 , 169 - 177.

[23] Pryce, J. C. (1980). The wrist position between neutral and ulnar deviation that facilitates the maximum power grip strength. Journal of Biomechanics, Vol 13, Issue 6, Pages 505-507, 509-511.

[24] Spijkerman D C M, S. C. (1991). Standardisation of grip strength measurements: Effects on repeatability and peak force. Scandanavian Journal of Rehabilitative Medicine, 23, 203-206 https://www.researchgate.net/profile/Dorien_Spijkerman/publication/21370834_Standardization_of_grip_strength_measurements_Effects_on_repeatability_and_peak_force/links/554743200cf24107d3982789/Standardization-of-grip-strength-measurements-Effe.

[25] Steiber, N. (2016). Strong or Weak Handgrip? Normative Reference Values for the German Population across the Life Course Stratified by Sex, Age, and Body Height. PLoS One, Oct 4, 2016, 11(10): e0163917.

[26] Weinstock-Zlotnick, G., Bear-Lehman, J., & Yu, T.-Y. (2011). A Test Case: Does the Availability of Visual Feedback Impact Grip Strength Scores When Using a Digital Dynamometer? Journal of Hand Therapy, Vol. 24, Iss. 3: 266-75; DOI:10.1016/j.jht.2011.01.004.

[27] Wichelhaus A, C. H.-F. (Feb 2018). Parameters influencing hand grip strength measured with the manugraphy system. BMC Musculoskeletal Disorders, https://doi.org/10.1186/s12891-018-1971-4.

[28] Williamson T L, V. J. (Sept 2003). Re-evaluation of the Caldwell Regimen: The Effect of Instruction on Handgrip Strength in Men and Women. In S. Kumar, Advances in Industrial Ergonomics and Safety IV (pp. 723-729 https://books.google.co.nz/books?id=y0K_2rkrHZEC&pg=PA723&lpg=PA723&dq=caldwell+regimen&source=bl&ots=nwBT4wTSta&sig=ACfU3U3oXW6-_OSRzDGoXDCHb1oEQvw-HQ&hl=ak&sa=X&ved=2ahUKEwjpoqC2wvjgAhUMeisKHeu_Cg8Q6AEwBXoECAYQAQ#v=onepage&q=caldwell%20regimen). CRC Press.

★★★