[[1]](#footnote-1)

Physical Design Parameters for Handheld Dynamometers

**Matthew D. King1, Charlotte Flaherty2, Jing Lin3†**

 **ECL Otago Polytechnic NZ, ECL Otago Polytechnic NZ,** **CE Dalian Ocean University, China**

**mking@op.ac.nz, flahecc1@student.op.ac.nz, sutezjl@126.com**

*Abstract*

***Purpose: This paper considers why and how grip strength is measured and establishes a baseline of physical design parameters which will allow for the development of a handgrip dynamometer which generates consistent and accurate results.***

***Methods: Relevant publications were reviewed and evaluated to glean insight into the effects of various device design considerations on the test outcomes. Additionally, an investigation into the mechanism which provides grip strength for humans was used to inform appropriate data collection techniques.***

***Results: A variety of Dynamometers have been made available on the market with mixed reviews on the consistency of the results, due in part to a lack of understanding of physics and the inconsistent selection of design parameters. A number of physical parameters were consistently reported as having a negative effect on the reliability of the test results. The following physical aspects were considered to inform the design parameters for handgrip strength dynamometers in this paper: Physical characteristics of chosen test Device, Anthropometrics, Test Protocols, Device feedback, shape of handle, material, dimensions, weight and application.***

***Conclusions: Test results revealed inconsistent medical examination outcomes. Dynamometer design parameters have been clarified to generate a more standardised outcome from hand grip tests. Recommended design parameters and protocols have been specified to guide future dynamometer development.***

***Index Terms— Dynamometer, Grip Strength, Jamar, Test protocol, Hand Grip Strength Testing.***

# INTRODUCTION

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 ability such 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.

PNEUMATIC: Pneumatic instruments, for example the modified sphygmomanometer, rely on compression of an air-filled compartment, and thereby measure grip pressure rather than grip strength (Ashton L, 2003). However, varying 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) (Fess E. , 2002). An example of this kind of dynamometer is the Martin Vigorimeter.

HYDRAULIC: The Smith and Nephew, Memphis, TN and Jamar hydraulic handheld dynamometer (Massy-Westropp N, 2004) are examples of hydraulic dynamometers. A survey of occupational therapy schools and clinics in the United States conducted in the mid-1980s found that almost 80% of recipients used the Jamar dynamometer most commonly for determining grip strength (Smith R O, Aug 1985). The sealed hydraulic system registers hand grip force in pounds per square inch (Hamilton G F, 1992). Information is displayed using either a gauge or digital display. A force dynamometer (such as the Jamar) “typically works by measuring the force applied to a lever or through a cable, and the 'moment of force' is determined by multiplying the perpendicular distance from the force to the axis of the level.” (RehabMart.com, 2019).

STRAIN GAUGE: Manufactured by Myogrip the strain gauge dynamometer is a newer design, specifically designed to measure grip strength for patients who are weak and/or frail and present a lighter grip. It is smaller in size than the Jamar or Martin dynamometers and more sensitive. Because of its higher precision, accuracy and sensitivity it is suitable for patients with various neuromuscular disorders. (RehabMart.com, 2019)

ELECTRONIC: examples include Grippit; AB Detektor, Goteborg, Sweden (Massy-Westropp N, 2004)

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:

• Systems of measurement and units of measurement

Hand grip strength testers measure force, which is pressure divided by area, rather than pressure, which is force per unit area. In 1957, the California Medical Association Committee on Industrial Health and Rehabilitation commissioned a sub committee to study grasping power. They identified that it was impossible to correctly measure grip strength by measuring pressure and that force must be measured instead. The analogy of the same person standing full-footed on the floor as opposed to full-footed on a marble was drawn to illustrate the point. Although the same force is involved in both cases the pressure is vastly larger in the second instance. A similar difference in pressure occurs between a small hand, or one with amputated fingers, grasping a strength tester compared to a large hand having the same useful grip. In the case of the former a large grip pressure would be found, whereas the larger hand would develop a smaller grip pressure as the force was spread over a larger area. The report concluded that an instrument measuring grip must respond to the force of the grip only and must not be influenced by the area of contact between the hand and the instrument. (Kirkpatrick, 1956)

# Parameters:

# In order to standardize handgrip strength tests, consideration must be given to the specific protocols to which the clinician conforms while administering the test.

## Test Protocols from Previous studies

 “Grip is composed of isometric stabilisation of the wrist, particularly the wrist extensors, to counter the finger flexors; and finger flexion, with the thumb involved post stabilization to maintain the object in the hand.” (Buhler, 2019)

The National Institute for Health Research has produced a procedural guideline for measuring hand grip strength using the Jamar Dynamometer (NIHR Southampton Biomedical Research Centre, 2016). They have identified 20 steps which are recommended to be followed to ensure reliable consistent results. This has become the industry standard protocol, but this protocol is often varied slightly, either intentionally (due to injuries) or unintentionally (at the technicians discretion), which leads to inconsistent results. A major issue with this protocol is procedure 16 which requires that technician to encourage the participant to: Use a standard squeezing phrase “Squeeze……harder, harder…and stop squeezing”. This is neither necessary(for a properly prepared participant) nor safe(in the case of injury) and, depending on the intensity and persuasiveness of the technician, will almost certainly lead to inconsistent results.

This protocol does not specify how long the test should run or how much time should elapse between tests, but instead it guides the technician to stop the test when ‘the needle stops rising’ and to record three measurements for each hand, alternating sides. It is common within the industry to continue the test until a noticeable reduction in the measured grip strength has been observed (approximately 20%) which usually happens within a few seconds. Additionally, the time required to take a reading from the opposite hand has been accepted as sufficient rest time for the previously tested muscles to recover sufficient strength to provide a meaningful retest. The American Society of Hand Therapists recommends: “A rest period of at least 15 seconds should be provided between grip repetitions.” (American Society of Hand Therapists, 2015)

Caldwell Regimen (Caldwell L S, 1974) for muscle strength testing: measures sustained exertion, such as carrying a suitcase. Protocol runs over 6 seconds (as described below) and strength score is calculated as the mean of three averaged seconds during which a +/- 10% bandwidth must be maintained by the subject:

* One second –increases grasp to max
* Hold for four seconds
* Release – one second

The Rapid Exchange Grip test Protocol calls for 10 samples from each hand in rapid succession. This protocol ineffectively attempts to minimize the participants ability to cheat, but it also has an observed effect on the performance with a reduction in the maximum strength performance of approximately 23% over the span of the test. (Tredgett & David, 2000)

It has also been shown that, even though the dynamometers generally are capable of being adjusted to better fit different size hands, leaving them set to a particular size (Jamar position 2) results in greater ease of use, and still sufficient accuracy to get meaningful results with this position being the optimal position for 70% of participants and 0.8(+-1.78 kg) from their best performance if different than in position 2. (Trampisch, Franke, Jedamzik, Hinirichs, & Platen, 2012)

Prior research suggests that different dynamometer types and brands produce similar results, i.e., reference values are robust to the dynamometer type used (Steiber N. , 2016) While other studies indicate that the results are not interchangeable. (Massy-Westropp N, 2004) (Svens & Lee, 2005)

Various protocols specifies that the technician uses a single test, the best of 2 or 3 test, the mean of 2 or 3 test, as well as tests that are 3, 5 or 10 seconds long. (Bohannon, Peolsson, Massy-Westropp, Desrosiers, & Bear-Lehman, 2006) Any of the above options are likely to be equally reliable in a symptomatic population and the results depend greatly aggravation of pain symptoms which should be checked using the Numerical Rating Scale (NRS). (King J. , 2019) Performance of participants varies for a range of reasons and some of these protocols catch the maximum performance of some of the participants, but none of them are a best practice to capture the majority of the participants best results with consistency and reliability.

Tests at 6 and 10 seconds have captured the typical performance of a participant and their ability to generate their best results. (Kamimura & Ikuta, 2001) It has been shown that the monotonic increase to peak values are reached between 0.6 and 2.7 seconds and that the maximum effort diminishes in a nearly monotonic fashion from that peak value. Following the peak value, a visible plateau of diminished performance of approximately 10% is reached after approximately 2 seconds. To capture the maximum effort while minimizing the fatigue, it is recommended that the performance of the participant be monitored in real time until the result has reduced to approximately 90-95% of the peak value at which time the participant should be instructed to stop squeezing.

To ensure consistent results, a Coefficient Of Variation (COV) of less than 10% for 3 sequential tests is required and all tests need to have reached a peak value and subsequently decreased. (King J. , 2019) It has been found that the best results for physical performance tests are not achieved until the third or fourth test. It is therefore recommended that the participant perform at least 3 tests with each hand, if possible, prior to evaluating if the COV requirement has been met. If any of the tests fall outside of the required range, then they should be repeated until the COV requirement has been met up to a maximum of 6 tests to ensure that fatigue has not begun to affect the results. (Hopkins, Schabort, & Hawley, 2001)

Symptomatic participants should start with uninvolved or least involved side. Asymptomatic participants can start with either side. Starting with the dominant side gives the participant the best learning/warm-up effect.

## Feedback screen

It is desirable for the patient to exert their maximum effort during the grip test. However, it is more desirable for the patient to be honest to the clinician, and to themselves, about the effort being their maximum effort. The limitations have been discussed previously. (King, Flaherty, & Lin, 2019)

While getting the maximum grip strength reading appears to require the participant to be aware in some way of what their current effort is and how it compares to an established benchmark, it is more important that the effort demonstrated be genuinely their best effort. It is consistent, therefore, with the purpose and expectations of the test to not allow the patient to know the magnitude of their efforts until after the test. At the same time, an analysis of the real time data collected during sequential tests should be monitored to look for inconsistencies which may indicate fraud. This approach required digital data collection with the ability to implement an algorithm capable of detecting patterns.

The American Society of Hand Therapists recommends no “visual or auditory feedback to be used” during testing, thus “the dynamometer’s dial should be turned away from the client so they cannot see the display.” (American Society of Hand Therapists, 2015)

## Size and weight of handgrip

Theodore Becker summed up the practical issue of weight and size of the dynamometer as follows: “A dynamometer which is lightweight and easy to move from various places is almost impossible to find.” (USA Patent No. 5,945,590, 1999)

The Jamar handgrip weighs 0.7kg (Wichelhaus A, Feb 2018). A Dutch study that tested handgrip strength of children noted “Jamar-like dynamometers are larger and heavier instruments and may therefore be more difficult for children to use. The Martin vigorimeter has smaller bulbs specially designed for children.” (H.M. (Ties) Molenaar, 2008), however the author concluded that the Jamar-like dynamometer could more reliably measure the grip strength of children. Reliable measurements are more desirable than focusing on a light weight device, so the Jamar-like style of Dynamometer is still a better choice as long as it can be properly used for testing. Recommendations have previously been made which specify the recommended arm and body position relative to the dynamometer. (King, Flaherty, & Lin, 2019) The technicians protocol for use should therefore address the possible difficulties of the participant to properly position the device even if it is too heavy for the participant to use independently and unaided. This will ensure optimal and consistent readings.

## Anthropometric Design Parameters

### Design Strength

When designing a hand held dynamometer, the expected loading is an important factor when determining the design strength of the device. The Jamar handheld dynamometer is described as “of sturdy aluminium construction.” (Jamar Digital Dynamometer, 2019) Testing has revealed that a maximum strength of 67 kg can be expected from a healthy adult male. (Haidar, Kumar, Bassi, & Deshmukh) (Dodds, et al., 2014)

It has also been observed that many of the dynamometers available commercially have a maximum recommended limit of 100kg or less. A review of several of these devices has revealed that a safety factor of between 2 and 5 has been used to determine dimensions and structural materials. Designing the device for a greater maximum applied load typically means that the device will weigh more and therefore be more difficult to use fr some participants. But if our goal is to maximize reliability and consistency with the technician available to assist with the positioning of the device, as stated above, then minor increases in weight can be tolerated.

### Does the Shape Matter?

Grip strength can be a key factor in the workplace when operating machinery. The current gold standard for grip strength testing is the Jamar dynamometer. However, in the workplace, many machines have cylindrical style handles and the Jamar dynamometer, with its shaped handle, may not be the most appropriate tool to test for these conditions.

The Jamar dynamometer is a variable hand span instrument with five different positions for measurement. Maximal grip strength most commonly occurs in the second or third position and is usually tested at the second position. (Ashton L, 2003).

McDowell (2012) found that the highest grip force components with a cylindrical handle were found at the fingertips (McDowell T, Mar 2012) while Wichelhaus (2018) concluded that “some of the forces exerted when gripping are not recorded, particularly forces that are transmitted through the fingertips or the distal phalanx of the thumb” (Wichelhaus A, Feb 2018)

### Should it be Adjustable?

McDowell’s study of 2012 compared how changes in grip size affected grip strength when measured using a Jamar dynamometer and recent grip dynamometer design and found that the size effect was more obvious when the Jamar dynamometer was being used at its smallest span: “The Jamar grip dynamometer may not adequately reflect the fingertip forces at the low and middle spans because the fingertips are not applied in the force measurement plane of the Jamar handle.” This finding was confirmed by Wichelhaus (2018) who found “the Jamar dynamometer allows a unidirectional force measurement only”.

Conversely, Trampisch et al (2012) while looking at handle position to measure maximal isometric hand grip strength in epidemiological studies found that measurements taken at a single standard handle position with the Jamar Plus+ hand dynamometer were sufficiently accurate to assess grip strengths for all subjects. “We therefore recommend handle position 2 as the standard position for measuring grip strength with the Jamar Plus+ hand dynamometer.” (Trampisch U S, Nov 2012)

## Construction material

Information about construction materials for the various handgrip strength dynamometers is hard to find. The Jamar handheld dynamometer is described as “of sturdy aluminium construction.” (Jamar Digital Dynamometer, 2019) while the Manugraphy system (novel biomechanics laboratory, Munich, Germany) is described as having cylinders that are enclosed in soft elastic pressure recording mats. Any material chosen for the fabrication of a Dynamometer should have a relatively stiff structural component, be easy to clean, and provide suitable strength to support the expected loads safety.

## Measurement Method

Hand grip strength testers can be pneumatic, digital or hydraulic. Many tests have been performed and many papers have been written to document their performances.

Whichelhaus (2018) found that a new Manugraphy system (cylindrical handles) was well suited for clinical research purposes because measurements were as reproducible and valid as the conventional measurement technique while the new tool also enabled more precise comparisons of isolated hand regions applying dynamic measurements. (Wichelhaus A, Feb 2018)

 “The novel® manugraphy system (novel biomechanics laboratory, Munich, Germany) is available with different sized cylinders that are enclosed in soft elastic pressure recording mats. Two calibrated pressure sensors per square centimetre are embedded in the mat. “ (Wichelhaus A, Feb 2018)

An Australian study of 2004 compared electronic (Grippit) and hydraulic (Jamar) dynamometers when measuring grip strength in normal adults and concluded that results from both dynamometers were similar. The Grippit provides information about endurance and fatigue of grip over 10 seconds, showing differences between right- and left-dominant adults.” (Massy-Westropp N, 2004)

The consistency or inconsistency of the performance of the participants is still determined by a single value maximum and the consistent prompting of the same researcher.

Only the Manugraphic system mentioned above attempts to collect data other than a single grip strength value. Physiology and injuries, in both the symptomatic and asymptomatic participants, rarely effect the entire hand in the same way. More information is better than less, especially if it can be demonstrated that the data collected can be directly related to previously collected and well documented data. It may be desirable to collect additional data which provides a greater understanding as to how the hand grip is sustained in such a way that it can be still be directly compared to the existing wealth of data already collected with regarding handgrip strength.

# DISCUSSION

The Jamar hand-held dynamometer is the clinical instrument most frequently used to measure grip strength. It measures the maximum isometric grip strength 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 devices. However, of these studies have found that the results were not interchangeable.

This investigation into how the inconsistent results of the grip strength tests are potentially affected by Physical characteristics of chosen test Device, Anthropometrics, Test Protocols, Device feedback, shape of handle, material, dimensions, weight and application. It has been previously recommended that the testing device should be computerized and interactive in nature with pre-recorded instructions, encouragement and response that will be more consistent. (King, Flaherty, & Lin, 2019) Here we have provided a description of what those real time interactive protocols should be.

While the hand grip shape does affect the results, physical design specifications are also influenced by a range of other considerations which will affect the designers choice of materials, design characteristics and overall weight of the device. We have identified that, so long as it is sufficiently rigid and strong, the mechanical nature of the device is unprescribed. But accommodation should be made for the ability of participants to use the device properly with support from the technician, if necessary.

We have also noted that a device that collects more than just the single value maximum force reading is desirable and may give a more informed clinical result, as long as the result can also be related back to the research data that has already been collected.

# ACKNOWLEDGEMENTS

This paper was funded by the State Key Laboratory of Costal and Offshore Engineering of Dalian University of Technology under Grand No. LP1711 and the Research Fund by Otago Polytechnic.

# References

American Society of Hand Therapists. (2015). *Clinical Assessment Recommendations, 3rd Edition.*

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.

Becker, T. J. (1999). *USA Patent No. 5,945,590.*

Bohannon, R. W., Peolsson, A., Massy-Westropp, N., Desrosiers, J., & Bear-Lehman, J. (2006). Reference values for adult grip strength measured with a Jamardynamometer: a descriptive meta-analysis. *Physiotherapy, 92*, 11-15.

Buhler, M. (2019, April). Doctor. *Hand Physiotherapist Southern District Health Board, NZ*. (C. Flagherty, Interviewer)

Dodds, R. M., Syddall, H. E., Cooper, R., Benzeval, M., Deary, I. J., Dennison, E. M., & et al. (2014). Grip strength across the life course: normative data from twelve British studies. *PLOS ONE, 9*. doi:10.1371/journal.pone.0113637

Fess, E. (2002). Documentation: Essential elements of an upper extremity assessment battery. In E. M. A. L. Osterman, *Rehabilitation of the hand and upper extremity: Surgery and therapy* (pp. 263-284). CV Mosby.

H.M. (Ties) Molenaar, J. M. (2008). Age-Specific Reliability of Two Grip-Strength Dynamometers when used by children. *THE JOURNAL OF BONE AND JOINT SURGERY, INCORPORATED*, 1053-1059.

Haidar, S. G., Kumar, D., Bassi, R. S., & Deshmukh, S. C. (n.d.). Average versus maximum grip strength: which is more consistent? *Journal of Hand Surgery - British, Europe, 2004*(29), 82-84. doi:10.1016/j.jhsb.2003.09.012

Hamilton G F, M. C. (1992). Measurement of Grip Strength: Validity and Reliability of the Sphygmomanometer and Jamar Grip Dynamometer . *Journal of Orthopaedic and Sports Physiotherapy*.

Hopkins, W., Schabort, E., & Hawley, J. (2001). Reliability of Power in Physical Performance Tests. *Sports Medicine, 31*, 211-34. doi:10.2165/00007256-200131030-00005

*Jamar Digital Dynamometer*. (2019). Retrieved from OPC Health: https://www.opchealth.com.au/jamar-digital-dynamometer

Kamimura, T., & Ikuta, Y. (2001, October). Evaluation of grip strength with a sustained maximal isometric contraction for 6 and 10 seconds. *Journal of Rehabilitation Medicine, 33*(5), 225-9. doi:10.1080/165019701750419626

King, J. (2019, October 16). Doctor. (M. King, Interviewer)

King, M. D., Flaherty, C., & Lin, J. (2019, September 7). *Considerations of Physiological Design Parameters for Dynamometers.* Retrieved from worldresearchlibrary.org: http://worldresearchlibrary.org/proceeding.php?pid=3144

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.

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.

McDowell T, B. M. (Mar 2012). Effects of handle size and shape on measured grip strength. *International Journal of Industrial Ergonomics*, Volume 42, Issue 2, Pages 199-205 https://doi.org/10.1016/j.ergon.2012.01.004.

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.

NIHR Southampton Biomedical Research Centre. (2016, May). *Procedure for Measuring HAND GRIP STRENGTH USING THE JAMAR DYNAMOMETER.* Retrieved from https://www.uhs.nhs.uk/Media/Southampton-Clinical-Research/Procedures/BRCProcedures/Procedure-for-measuring-gripstrength-using-the-JAMAR-dynamometer.pdf: https://www.uhs.nhs.uk/Media/Southampton-Clinical-Research/Procedures/BRCProcedures/Procedure-for-measuring-gripstrength-using-the-JAMAR-dynamometer.pdf

RehabMart.com. (2019). *Dynamometers, Pinch Gauges, Hand Grip Test, Pinch Dynamometer, Hand Dynamometer*. Retrieved from RehabMart.com Tools for Living: https://www.rehabmart.com/category/dynamometers/pinch\_gauges.htm#bottom

Smith R O, W. B. (Aug 1985). Pinch and Grasp Strength: Standardisation of Terminology and Protocol. *American Journal of Occupational Therapy*, Vol 39, 531-535 doi:10.5014/ajot.39.8.531.

Steiber, N. (2016). Strong orWeak Handgrip? Normative. *PLoS ONE, 11*(10). doi:10.1371/journal.pone.0163917

Svens, B., & Lee, H. (2005). Intra- and inter-instrument reliability of Grip-Strength Measurements: GripTrackTM and Jamar® hand dynamometers. *The British Journal of Hand Therapy, 10*(2), 47-55. Retrieved from https://doi.org/10.1177/175899830501000202

Trampisch U S, J. F. (Nov 2012). Optimal Jamar Dynamometer Handle Position to Assess Maximal Isometric Hand Grip Strength in Epidemiological Studies. *The Journal of Hand Surgery*, Volume 37, Issue 11, Pages 2368-2373 https://doi.org/10.1016/j.jhsa.2012.08.014.

Trampisch, U. S., Franke, J., Jedamzik, N., Hinirichs, T., & Platen, P. (2012, November). Optimal Jamar dynamometer handle position to assess maximal isometric hand grip strength in epidemiological studies. *The Journal of Hand Surgery, 37*(11), 2368-73. doi:10.1016/j.jhsa.2012.08.014

Tredgett, M. W., & David, T. R. (2000, August). Rapid repeat testing of grip strength for detection of faked hand weakness. 2000 Aug;25(4):372-5. *The Journal of Hand Surgery: British & European Volume, 25*(4), 372-375. doi:10.1054/jhsb.2000.0433

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.

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.

1. **†Corresponding Author:** [↑](#footnote-ref-1)