Modernising the Dynamometer for Grip Assessment: Comparison between GripAble and Jamar

Sharah Abdul Mutalib (sharah@gripable.co)
Imperial College of Science, Technology and Medicine

Michael Mace
GripAble Ltd

Chloe Seager
GripAble Ltd

Etienne Burdet
Imperial College of Science, Technology and Medicine

Virgil Mathiowetz
University of Minnesota

Nicola Goldsmith
GripAble Ltd

Research Article

Keywords: Dynamometer, Maximal grip strength, GripAble, Jamar PLUS+

DOI: https://doi.org/10.21203/rs.3.rs-720982/v1

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Modernising the Dynamometer for Grip Assessment: Comparison between GripAble and Jamar

Sharah Abdul Mutalib¹,², Michael Mace¹, Chloe Seager¹, Etienne Burdet², Virgil Mathiowetz³, Nicola Goldsmith¹,⁴

¹ GripAble Ltd, London, UK
² Bioengineering Department, Imperial College of Science, Technology and Medicine, London, UK
³ Occupational Therapy Program, University of Minnesota, Minneapolis, MN, USA
⁴ Miriam May Occupational Therapy, London, UK

Abstract

Introduction: Maximal grip strength (MGS) is a reliable biomarker of overall health and physiological well-being. Therefore, an accurate and reliable measurement device is vital for ensuring the validity of the MGS assessment. This paper presents GripAble, a mobile handgrip device for the assessment of MGS. GripAble’s performance was evaluated using an inter-instrument reliability test against the widely used Jamar PLUS+ dynamometer.

Methods: The MGS data from sixty-three participants (N = 63) measured using GripAble and Jamar PLUS+ were collected and compared. Intra-class correlation (ICC) was performed to evaluate the inter-device reliability between GripAble and Jamar PLUS+. The influence of gender and hand on MGS were also analysed.

Results: GripAble demonstrates good-to-excellent inter-instrument reliability to the Jamar PLUS+ (ICC³,1=0.906). There were significant differences in the mean MGS between GripAble and Jamar PLUS+ (p <0.001 for both). GripAble’s measurement output is equivalent to 69% ([68 - 71]% of Jamar PLUS+’s measurement output. The average difference in mean MGS between the two devices was 10.84 ± 4.18 kg ([4.77 - 18.54] kg), which increases with higher MGS. There were also significant differences in MGS between male and female and between right and left hands measured using GripAble and Jamar PLUS+ (p <0.001 for all comparisons).

Conclusion: GripAble has good-to-excellent inter-device reliability with Jamar PLUS+, suggesting that it can be used clinically as a dynamometer whilst also providing additional functionalities, such as remote assessment, objective evaluation of compliance to standard protocol and assessing multiple facets of grip strength beyond the standard single maximum grip test. Normative MGS data using GripAble should be collected and integrated into the software for immediate comparison. Further studies, including test-retest and inter-rater reliability of using GripAble, are discussed.
Introduction

Maximum grip strength (MGS) is a ubiquitous objective outcome measure for delineating hand functions, including the severity of upper limb impairment, improvement after hand surgery and functional progress after rehabilitation (or lack thereof). A weak grip is associated with poor health-related quality of life (HRQoL) (Sayer et al. 2006), and individuals with impaired grip strength pose an increased risk of having a heart attack, stroke, and cognitive loss (Leong et al. 2015, Cui et al. 2021).

An accurate and reliable instrument for measuring MGS is crucial for ensuring the accuracy of grip assessment and the validity of the resulting clinical interpretation. MGS is typically measured using a handgrip device equipped with a force or pressure sensor -- a dynamometer. The Jamar hydraulic hand dynamometer (Bechtol, 1954) is the gold standard device recommended by the American Society of Hand Therapists (ASHT) for measuring MGS (MacDermid et al. 2015). Jamar also comes in a digital version, Jamar PLUS+, which uses a load cell force sensor instead of a hydraulic sensor (King 2013). Nevertheless, the hydraulic version remains the gold standard, mainly due to its high prevalence in clinical practice and lower cost. Jamar is used in many studies for quantifying MGS, most notably in the well-known normative grip strength studies on adults and children by Mathiowetz et al. (1985 and 1986, respectively), which remain widely used by clinicians worldwide to compare patients' grip strength.

Although Jamar is accurate, reliable and has good-to-excellent test-retest reliability and excellent interrater reliability, it is also deemed outdated by many clinicians, as it is heavy, has questionable robustness, insensitive for measuring low forces and requires regular recalibration. Therefore, many updated devices emerged that demonstrate good-to-excellent inter-instrument reliability with Jamar. These devices include Baseline (Mathiowetz, Vizenor, and Melander 2000), Rolyan (Mathiowetz 2002), Grippit (Svantesson et al. 2009), MyoGrip (Hogrel 2015) and Bodygrip (Guerra et al. 2017).

Nonetheless, Jamar remains the gold standard, due to the heavy reliance and continued use of the aforementioned 1980s normative grip strength datasets. However, a recent study found that this normative data may no longer be valid, as the grip strength of Americans ages 20 - 34 has weakened dramatically relative to their 1980s counterparts (Fain and Weatherford 2016). This finding suggests that a new normative dataset may be needed to consider the anthropometric and lifestyle changes in the past 40 years that may have altered the general population's grip strength.

With an aim to modernise the current dynamometer, this paper presents the GripAble handgrip device (GRIPABLE Limited, United Kingdom) -- a new digital, accurate, sensitive and robust device for measuring grip strength1. GripAble incorporates dual force sensors and connects wirelessly to a mobile device e.g. tablet, enabling users to perform objective MGS assessment. It also has motion sensors to measure range-of-motion and monitor the user's compliance to a standard protocol, such as hand posture during MGS.

According to Fess (1986), the two most crucial criteria of an assessment device are (1) excellent measurement reliability across multiple sessions, examiners and devices and (2) high validity when compared against existing validated instruments. Fess further recommends (3) administrative instructions, (4) equipment criteria, (5) normative data, (6) instruction for interpretation and (7) a bibliography. This paper aims to address the second point by investigating the inter-instrument reliability of GripAble against Jamar PLUS+. Whilst many previous studies used Jamar hydraulic to benchmark against their grip strength assessment device, concern was raised that Jamar hydraulic might not be best as it tends to overestimate grip force due to the inertial movement of the needle, which jumps slightly

1 www.gripable.co
higher than the actual reading. Additionally, there is potential for significant reader error when using the Jamar hydraulic due to the dial only showing 2 kg increments. Therefore, Jamar PLUS+ Digital was chosen as the reference device in this study to compare against GripAble to ensure the accuracy of grip strength data. We hypothesised that there would be a strong correlation and agreement between Jamar+ and GripAble. Considering the physical differences between the two devices, we also hypothesised that there would be systematic differences in measurement output between the two devices.

Methods

GripAble hand grip device

GripAble is a device that comprises a dual load cell force-sensing mechanism which enables the handgrip to deform elastically when squeezed. GripAble has sensitivity of up to 60 gm and is accurate up to 2 kg of force. It is also equipped with an IMU (accelerometer, gyroscope and magnetometer) for measuring hand movement and orientation (Rinne et.al., 2016). The hand grip plate of GripAble can be switched between two modes -- flexible and rigid -- to enable the measurement of grip strength in isotonic and isometric modes, respectively (Mace et. al., 2017). It connects wirelessly via Bluetooth to an Android device with a custom app, which will read and record data associated with the user's hand grip and movement while using GripAble.

Besides for assessment, GripAble was also developed for upper limb training through specially designed app-based therapy games. These virtual therapy games are designed to be highly motivating, accessible to all ages and levels of cognitive function, and to automatically adapt to the ability of the individual (Rinne et. al., 2016).

Instruments

Two GripAble hand grip devices and two Jamar PLUS+ Digital Hand Dynamometers (referred to as Jamar+ hereafter) (Bechtol 1954) were used for measuring MGS. Table 1 presents the feature comparison between GripAble and Jamar+. All GripAbles and Jamar+s were calibrated within two months from the start of the data collection process and were otherwise unused to ensure a level playing field. The Jamar+s were set on position 2 (second smallest handle position). The GripAbles were used in isometric mode to match Jamar+
### Properties

| Properties                      | GripAble | Jamar PLUS+ Digital |
|--------------------------------|----------|---------------------|
| Weight (g)                     | 240      | 490                 |
| Front-to-back depth (mm)       | 48*      | 49 (position 2)    |
| Side-to-side width (mm)        | 40       | 25                  |
| Circumference (mm)             | 141*     | 128 (position 2)   |
| Measurement units              | kg       | kg or lbs           |
| Measuring modes                | Isotonic and isometric | Isometric only |
| Increments of measurement unit (kg) | 0.1 (0 - 90) | 0.1 (0 - 90) |
| Readings (digital/non digital) | Mobile app integration | Digital readout |
| Calculations                    | Maximum value, mean, standard deviation, left-right ratio | Mean, standard deviation, coefficient of variation |
| Data tracking/recording         | Automatic through app | Not available/manual |

*measured in isometric mode

### Table 1: Properties of GripAble and Jamar+.

### Participants

Sixty-three healthy participants (N = 63) aged between 16 – 80 were recruited for the study. Participants were predominantly self-reported right-handed (N_R = 57; N_L = 6). Each participant was assigned an alphanumeric ID and randomly split into four different experiment groups: GripAble right first (A), GripAble left first (B), Jamar+ right first (C), and Jamar+ left first (D). Table 2 describes the demographic information of the participants. Statistical differences of participants’ age between genders (male vs female), between starting device orders (GripAble first vs Jamar+ first) and between starting hand orders (right first vs left first) were calculated using unpaired t-tests. There was no significant difference in age across all comparisons performed.

Participants were excluded if they had any diagnosed upper limb pathology, pain in the hand, wrist or forearm or history of neurological disorder affecting the upper quadrant. All participants had a good comprehension of English to understand verbal instruction and experimentation documentation.
All participants gave informed consent before the study. The experiment was performed following the ethical standards laid down in the 1964 Declaration of Helsinki and was approved by the Imperial College Research Ethics Committee (ICREC) and Science, Engineering & Technology Research Ethics Committee (SETREC).

| Category          | N  | Age (years) | Statistical difference (p-value) |
|-------------------|----|-------------|---------------------------------|
| All               | 63 | 34.95 ± 15.94 | -                               |
| Gender            |    |             |                                  |
| Male              | 33 | 34.67 ± 16.67 | Not significant (p = 0.88)       |
| Female            | 30 | 35.27 ± 15.11 |                                  |
| Starting device   |    |             |                                  |
| GripAble first    | 32 | 35.90 ± 16.55 | Not significant (p = 0.64)       |
| Jamar+ first      | 31 | 33.97 ± 15.23 |                                  |
| Starting hand     |    |             |                                  |
| Right first       | 31 | 32.61 ± 14.87 | Not significant (p = 0.26)       |
| Left first        | 32 | 37.22 ± 16.60 |                                  |

Table 2: Demographic information of the participants. The last column shows the results from unpaired t-tests to calculate statistical differences in participants’ age between genders, between starting devices and between starting hands.

Procedure

The study took place during the COVID-19 pandemic. Therefore, all experiments were conducted outdoors, with a 2-metre distance between the investigator and the participant strictly followed as per NHS England COVID-19 guidelines. At the start of each session, the subject and investigator washed their hands thoroughly, and both devices were sanitised with isopropyl alcohol (IPA) wipes between participants.

Each participant was positioned upright in a seated position on a chair with no armrests during the experiment. The investigator ensured that each participant maintained similar positioning at all times, which was standardised according to the ASHT recommendations (MacDermid et al. 2015), including legs uncrossed, the bottom of the spine positioned against the back of the chair with hips and knees positioned at approximately 90°, arm adducted, elbow flexed at 90°, forearm in neutral and wrist in comfortable 15° to 30° extension and 0° to 15° of ulnar deviation (Figure 1a). Before starting, the investigator first demonstrated a single maximum grip test protocol. Verbal instruction was given, i.e. “Gradually put on the force. Now squeeze as hard as you can. 3, 2, 1, and relax” by the investigator during each measurement, which is also displayed on the GripAble app screen and only visible to the investigator.

Three MGS measurements were recorded from each hand, using each device (i.e. twelve measurements in total). The hand was alternated between trials (e.g. GripAble R-L-R-L-R-L, followed by Jamar+...
R-L-R-L-R-L). A minimum 15-second rest was enforced between each measurement of the same hand. The measurement from the opposite hand was taken during this rest. Two investigators collected all measurements using the same sets of Jamar+ and GripAble devices throughout the study (i.e. one set for each investigator). All measurements taken using GripAble were calculated automatically by the GripAble app, and results were displayed to the investigator at the end of the test. The screen showing the GripAble app faced the investigators the entire time. Figure 1b and 1c show screenshots of the GripAble app’s test pages showing the test page and result page, respectively.

**Figure 1:** Single maximum grip strength test for measuring MSG: (a) The sitting posture of participants following ASHT recommendations. The screenshots of GripAble’s app pages showing (b) the single maximum grip strength test page and (c) the result page.

**Data Analysis**

The mean of the three trials from each hand and device was used for data analysis. The influence of starting device and starting hand orders on MGS was analysed using two unpaired t-tests, i.e. GripAble first vs Jamar+ first group, and right hand first vs left hand first group. Statistical differences in MGS between genders (male vs female) was calculated using an unpaired t-test, whilst between hands (right vs left) and devices (GripAble vs Jamar+) were calculated using paired t-tests.
The inter-instrument reliability between Jamar+ and GripAble was tested using intraclass correlation (ICC) assuming average fixed raters, i.e. ICC (3,1) (Mathiowetz 2002, Koo 2016). ICC values of less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicate poor, moderate, good and excellent reliability, respectively. The ICC values were calculated for all data collectively, as well as separately for each gender, starting device order and starting hand order, for each device and hand. The correlation between Jamar+’s and GripAble’s measurements across all participants, age and gender was also calculated using Pearson’s correlation.

Statistical significance was calculated at a 95% confidence level (p < 0.05). Results are reported as mean ± standard deviation (2.5th to 97.5th percentiles).
Results

Mean MGS

Figure 2 shows the mean MGS from each device and each hand from the three trials. There were significant differences between the overall mean MGS, as well as right hands’ and left hands’ mean MGS between GripAble and Jamar+ (p < 0.001 for all). An unpaired t-test was performed to analyse the influence of the starting device and hand on MGS. No significant differences in overall mean MGS between participants that started with GripAble first or Jamar+ first (p = 0.55 for GripAble measurements, p = 0.93 for Jamar+), or between participants that started with the right hand first or left hand first (p = 0.28 for GripAble, p = 0.25 for Jamar+), suggesting that the starting device and starting hand orders did not influence the results.

![Graph showing mean MGS for GripAble vs Jamar+ for overall (both hands), right, and left hands.](image)

**Figure 2:** Mean MGS for both hands, right and left hands measured using GripAble vs Jamar+. There were significant differences between MGS measured using GripAble vs Jamar+ for all three comparisons performed (paired t-test; p < 0.001 for all).

The influence of gender and hand on the overall mean MGS was also calculated using unpaired and paired t-tests, respectively. Results are visualised in Figure 3. There were significant differences between males and females (p < 0.001 for both GripAble and Jamar+), as well as between right and left hands (p < 0.001 for both GripAble and Jamar+).
Figure 3: Influence of gender and hand on the overall mean MGS. Boxplots showing the differences in grip strength between (a) male vs female and (b) right hand vs left hand, measured using GripAble (left) and Jamar+ (right). There were significant differences in MGS across all comparisons performed (unpaired t-test for gender comparison, paired t-test for hand comparison; p < 0.001 for all).

Inter-instrument reliability between GripAble and Jamar+

Fig 4a shows the mean MGS for each subject comparing Jamar+ (x-axis) to GripAble (y-axis). The right (square markers) and left (triangular markers) hands are shown as connected points. Age and gender are indicated by the marker size and colour, respectively. A Pearson correlation was calculated between GripAble’s and Jamar+’s measurements across all subjects, age ranges, genders and hands. The Pearson correlation coefficient \( r \) was 0.93 (\( p < 0.001 \)), indicating strong agreement between the two devices. A zero-intercept linear fit using total least squares (TLS) revealed that GripAble’s measurement output is equivalent to 69% \([68 - 71\%]; 95\% \text{ CI}\) of Jamar+’s measurement output.

Fig 4b shows a Bland-Altman plot comparing the difference in measurement output between GripAble and Jamar+, plotted against the mean measurement outputs between these two devices. The even, widespread distribution of data points indicates good coverage across a wide range of grip forces. The
average difference between the two devices is 10.84 ± 4.18 kg ([4.77 - 18.54] kg) for the entire dataset and increases with higher forces.

**Figure 4:** Agreement between GripAble and Jamar+ dynamometers: (a) Scatterplot showing high linearity and strong correlation between the mean grip force measurements across subjects. (b) Bland-Altman plot showing strong agreement across a wide measurement range whilst identifying potential outliers. The upper and lower dashed lines are ±1.96 standard deviation, which is equivalent to the approximate value of the 2.5th to 97.5th percentile of the standard normal distribution.

Inter-instrument reliability was tested using intra-class correlation (ICC) assuming average fixed raters, i.e. ICC (3,1). The overall ICC value was computed across all data collectively, and an overall ICC of 0.909 ([0.87 - 0.94]; 95% CI) indicates a good-to-excellent inter-instrument agreement between the two devices. The ICC was also calculated separately for each gender, starting hand order and starting device order. Full results are shown in Table 4.

| Category | Hand | N    | ICC    | Confidence interval 95% |
|----------|------|------|--------|-------------------------|
| **Overall** |      |      |        |                         |
| Both     | 126  | 0.909| [0.87 - 0.94] |
| Right    | 63   | 0.920| [0.87 - 0.95] |
| Left     | 63   | 0.898| [0.84 - 0.94] |
| **Gender** |      |      |        |                         |
| Male     |      |      |        |                         |
| Right    | 33   | 0.899| [0.81 - 0.95] |
| Left     | 33   | 0.887| [0.78 - 0.94] |
| Female   |      |      |        |                         |
| Right    | 30   | 0.859| [0.72 - 0.93] |
### Table 4: Intraclass correlation coefficient (ICC) analysis between GripAble and Jamar+. There were no significant differences between MGS measured using GripAble and Jamar+. Overall, results show good-to-excellent agreement between GripAble and Jamar.

| Starting device     | Left  | 30   | 0.811 | [0.64 - 0.90] |
|--------------------|-------|------|-------|--------------|
| GripAble first     | Right | 32   | 0.937 | [0.87 - 0.97] |
|                    | Left  | 32   | 0.919 | [0.84 - 0.96] |
| Jamar+ first       | Right | 31   | 0.903 | [0.81 - 0.95] |
|                    | Left  | 31   | 0.878 | [0.76 - 0.94] |

| Starting hand       | Right  | 31   | 0.894 | [0.80 - 0.95] |
|                    | Left   | 31   | 0.899 | [0.81 - 0.95] |
| Left first          | Right  | 32   | 0.951 | [0.90 - 0.98] |
|                    | Left   | 32   | 0.893 | [0.79 - 0.95] |

Discussion

Results from the MGS measurements from sixty-three participants using GripAble and Jamar+ show that GripAble has an overall good-to-excellent inter-instrument reliability with Jamar+, with an overall ICC of 0.909 ([0.87 - 0.94]). Pearson’s correlation revealed that GripAble’s force output is equivalent to 69% ($\rho = 0.93$) of Jamar+’s force output, averaging a difference of 11.7 kg ([2.9 - 20.6] kg) between GripAble and Jamar+. This difference increased with higher MGS, suggesting that the difference was not due to a constant offset, but a systematic, proportionality term between the two devices.

We hypothesised that such a difference might be attributed to several factors, such as physical differences between GripAble and Jamar+, including weight, width and circumference. For instance, the narrower-shaped Jamar+ encourages an intrinsic minus grip with the proximal interphalangeal joints predominantly active whilst GripAble promotes a grip that recruits more flexion at the metacarpophalangeal joint. Moreover, GripAble is also nearly half the weight of Jamar+, which may have further contributed to the difference.

Psychological factors could also play a part. Jamar+ is made of metal and plastic, whereas GripAble is made entirely of plastic. The material difference and the lower weight of GripAble may have given the impression of it being fragile, causing the participants to be more reserved from exerting maximal grip force on the device. Therefore, verbal reinforcement may be needed for future grip assessment studies to encourage the user to squeeze maximally when using GripAble.
Although Jamar is considered the gold-standard device for measuring MGS, it needs updating to reflect evolving digital mobile health (mHealth) technology trends. With the recent global COVID-19 pandemic, the rehabilitation paradigm has shifted from inpatient to outpatient venues, including remote management using virtual platforms. Presently, clinicians who are managing their patients remotely need to rely on self-reported grip strength capabilities. Patients may benchmark against a change in their ability to carry out ADLs, which is not sensitive or objective. GripAble’s custom mobile software platform provides an objective measurement of MGS completely remotely. Such a feature allows patients to regularly test their grip strength whilst allowing therapists to monitor and assess patients both accurately and reliably over time without their physical presence. Moreover, the integrated sensors within GripAble and software can provide researchers with additional information on the exact positioning of the device and hand postures during MGS assessment. For example, the ASHT guideline for measuring MGS recommended that the device be held vertically. Using the data provided by the motion sensors within GripAble, it would be possible to explore user compliance with this guideline.

Hand grip is vital for activities of daily living, and an extensive body of research has shown that it is a reliable biomarker of overall physical health and wellbeing, including predicting mortality and morbidity risks (Gale 2007). Nevertheless, the true impact of impaired grip strength on one’s functional performance of ADLs is poorly understood. Most commonly, grip strength is only assessed as a single maximum effort, which only measures capability during one short instance. In functional activities, grip needs to be employed in many different ways, such as sustained over a more extended period or repeatedly applied. GripAble provides a range of grip tests, including but not limited to grip endurance, sustained gripping, grip in various forearm rotational positions (LaStayo 2001), rapid exchange (Westbrook et al., 2002) and sine wave grip accuracy tests (Rinne et al. 2018), to allow for a more holistic view of hand function. Ultimately, this opens the opportunity for a deeper understanding of the association between grip and functional performance, where the multiple aspects of grip may uncover such associations.

Conclusion

This study provides evidence of GripAble’s good-to-excellent inter-instrument reliability and agreement to the Jamar+. This finding suggests that GripAble can be used clinically as a dynamometer whilst providing additional software benefits, including the display of postural and procedural instructions, standardised narrative and automated result computation and analysis. GripAble also has the additional benefit of assessing multiple facets of grip strength beyond the standard single maximum grip test. Furthermore, integrating a dynamometer into a training device gives the potential for objective assessment both in the clinic and remotely for home users.

Further studies investigating the other facets of grips and test-retest reliability are needed. Updated device-specific normative values for age and gender subsets are also needed and, once available, can be integrated into the software for immediate comparison.

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Ethical approval
Ethical approval was gained from the Science Engineering Technology Research Ethics Committee (SETREC) of Imperial College of Science, Technology and Medicine, London, UK (REF: 20IC5831).

Declaration of conflicting interests
SAM, MM, CS and NG are the employees of GripAble Ltd.

Responsibilities
SAM wrote the manuscript. SAM and NG designed the protocol for the study. CS and NG collected the data. SAM and MM performed data analysis using Python. SAM, MM, NG, VM and EB performed data analysis, interpretation, and discussion. SAM, NG and EB gained ethical approval from SETREC, Imperial College of Science, Technology and Medicine, London. All authors reviewed and edited the manuscript and approved the final version of the manuscript.