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Evaluation of Tactile Array Grip Force Data

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Abstract Data from a grip force measurement system, as previously described, consisting of a tactile array transducer for assessing the grip capability/capacity of the human hand was analyzed. Purpose: The purpose of this study was to 1) establish normative grip and individual finger strength values for the ForceMap™ and 2) compare the total force measurements collected using the ForceMap™ with those collected using the Jamar™. Methods: This was a retrospective analysis of data collected using the ForceMap™ and Jamar™ dynamometers. T-tests were used to compare the ForceMap™ and the Jamar™ dynamometers' force measurements, dominant and non-dominant hands, and intergender differences. Correlation testing was also done between the ForceMap™ data and Jamar™ data. Correlation testing was done between the subjects' maximum grip strength forces using both types of machine and their height, weight, and hand size. Results: It was found that the measurements from the ForceMap™ were significantly higher than those from the Jamar™. There was a strong correlation between these two methods except for the with the women's dominant hand. Normative total force and individual finger pressure measurements were found for men and women. There was no correlation between the body size and hand grip strength. A strong correlation existed between grip contact area and total grip strength measured with the ForceMap™. Conclusion: This study has shed light on a new tool and method for hand function evaluation that may provide more detailed information and eventually enhance clinical assessment and the rehabilitation process.

Keywords Grip strength measurement, Grip ForceMap™, Jamar™, Grip pressure distribution

1. Introduction

To date, parallel bar dynamometry has been the technique of choice for clinical grip strength measurement. The well-known Jamar™ (Asimov Engineering Co., Los Angeles, CA) hand-held dynamometer has long been considered the gold standard for assessing grip strength. The vast majority of clinicians think of the Jamar™ as being the most accurate, reliable, and valid measurement tool for assessing grip strength [1,2].

The Jamar™ dynamometer consists of a curved metal bar that is placed with the convex side into the thenar eminence of the hand being tested. In test position, the patient grasps two metal bars of the apparatus in a "U" grip shape. These two bars have adjustment rungs every 12.5mm which allows for use by patients with various hand sizes. These machines typically include an analog dial for indicating forces produced and can either be hydraulic or spring loaded in nature. While this device has become the standard of the industry, the device has shortcomings and new technology serves to better the clinical evaluation of grip strength (Figure 1).

Figure 1. The Jamar™ parallel bar dynamometer

In contrast to the Jamar™, the MMD ForceMap™ uses tactile array technology. The MMD ForceMap™ is a novel hand grip strength analyzer produced by MMD Incorporated of Boise, Idaho, USA that uses tactile array technology. The ForceMap™ tactile sensor array measuring grip forces is fixed to a solid cylinder with a diameter of 5.0 centimeters and a length of 15.0 centimeters. This configuration allows the machine to give a total force measurement for the entire hand including the distal phalanges of the fingers as well as the entire thumb [3]. Also, the cylindrical style of grip

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appears to be more applicable in activities of daily living than the style of grip used in the Jamar^{TM} grip test. The cylindrically arranged pressure sensors are hard wired into an amplifier that is attached to the bottom of a laptop computer used for analyzing data. The associated software allows real time view of the pressure as well as acquisition of the data for later viewing and assessment. This novel device allows a clinician to isolate components of grip while the Jamar^{TM} only provides a gross force measurement (Figure 2). A downside of MMD ForceMap^{TM} and/or any tactile array grip strength dynamometer is that there is a dearth of normative data for these types of machines.

Figure 2. The ForceMapTM tactile array grip force system

The purpose of this study was to 1) establish normative grip and individual finger strength values for the MMD ForceMap^{TM} tactile array dynamometer and 2) compare the total force measurements collected using the ForceMap^{TM} with the total force measurements collected on the same day during the same session using the Jamar^{TM} dynamometer. It was hypothesized that there would be a strong correlation between the total force produced when doing grip strength testing using the Jamar^{TM} dynamometer, compared to the grip strength measurements when using the MMD ForceMap^{TM}. It was also hypothesized that the total force values found when using the ForceMap^{TM} would be greater than those found when using the Jamar^{TM} as there are more areas of the hand being tested with the use of the ForceMapTM.

2. Methods

2.1. Procedures and Instruments

This was a retrospective analysis of previously collected data which was obtained by MMD Incorporated using the ForceMap^{TM} and Jamar^{TM} grip strength dynamometers. MMD Incorporated collected this data using the standard protocol that has been set by the American Society of Hand Therapists for the use of the Jamar^{TM} dynamometer where the subject is seated with the shoulder at zero degrees of abduction and flexion, the elbow at 90° of flexion, and the forearm at neutral pronation and supination [4].

Unidentifiable subject records were accessed with written permission from MMD Incorporated to allow for analysis of as many subjects as possible. There were 28 adult males and 28 adult females whose data were used for this study. The data analysis was conducted using the ForceMap^{TM} software. This software allows for general grip force in pounds to be assessed as well as forces from specific grip regions and region groups (i.e. individual or grouped fingers). Data that was analyzed for this study was subject age, their maximum grip strength using the Jamar^{TM} dynamometer, and their maximum grip strength and individual finger strength using the ForceMap^{TM}. Secondarily, the subjects' hand size, height, and weight, was correlated with the grip strength data.

2.2. Analysis

The Microsoft Excel spreadsheet software was used to analyze the data for this study. Paired, two-tailed t-tests, were used to identify a significant difference between the ForceMap^{TM} dynamometer and the Jamar^{TM} dynamometer's force measurements at both of the subjects' maximum grip strength trials. Pearson's R correlation testing was also done between the ForceMap^{TM} data and Jamar^{TM} data at both trials of 100% of the subjects' maximum grip strength in order to see if any relationship is present between the two instruments.

Differences between the subjects' dominant and non-dominant hand for total grip force using the ForceMap^{TM}, total grip force using the Jamar^{TM}, and individual finger pressures using the ForceMap^{TM} were also assessed using standardized t-tests, paired two samples for means. This test was also used to observe intergender differences between these same variables.

Pearson's r correlations were used to compare the subjects' maximum grip strength forces of both their dominant and non-dominant hands using the ForceMap^{TM} with their height and weight. There were also Pearson's R correlation tests done to look at the relationship between the subjects' total grip force using the Jamar^{TM} and their hand length from the distal wrist flexion crease to the tip of the third finger and between the total grip force using the Jamar^{TM} and the hand width, which was the width at the palmar creases. This was done for the right hand only as only scans of the subjects' right hands were available.

Mean total grip forces were also analyzed for all subjects. The mean total forces for all male subjects was calculated as well as those forces for the male subjects aged 18 to 30 years and the male subjects over 30 years old. Similarly, female subjects were analyzed as was the data for female subjects aged 18 to 30 years and those over 30 years old. Across subjects, grip force analysis was completed for the variables of total grip force using the ForceMap^{TM} on the dominant and non-dominant hands, total grip force using the Jamar^{TM} on both the dominant and non-dominant hand, and the individual finger pressures, which was the measurement of the cell with the maximum pressure in pounds per square inch (psi). These mean values were then translated into being normative values for each group.

3. Results

The main goal of this study was to compare total grip force values found using the ForceMap™ and Jamar™ dynamometer. When assessing men's total grip of the dominant hand using a standard two-tailed t-test, it was found that there was a significant difference between the measurements taken from the ForceMap™ and the Jamar™ with the average total force measurement found using the ForceMap™ being 184.55 pounds ± 47.32 and the measurement found using the Jamar™ being 109.25 pounds ± 23.83, n=28 (Figure 3).

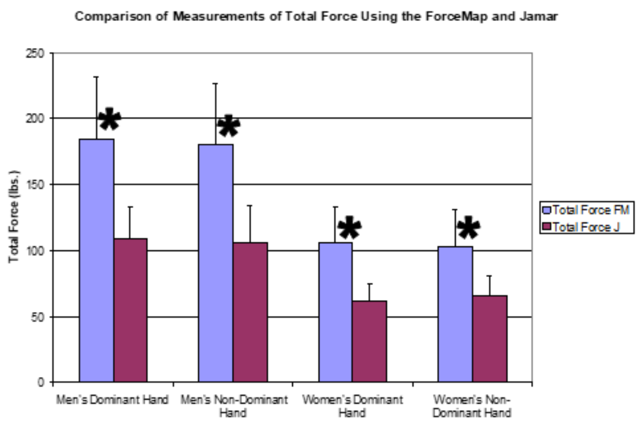

Figure 3. Comparative measurements in pounds found using ForceMap™ to those found using the Jamar™ for the men's dominant hand, men's non-dominant hand, women's dominant hand, and women's non-dominant hand, $p<0.05$

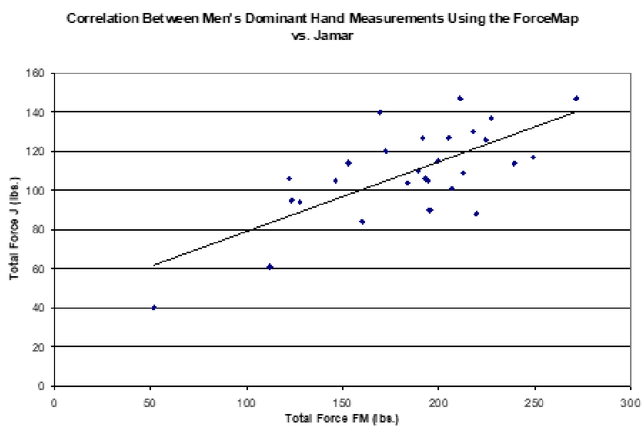

Figure 4. Correlation between the measurements found using ForceMap™ and those found using the Jamar™ for the men's dominant hand, r=0.709

There was also a strong correlation between the two measurement methods with and r value of 0.709 (Figure 4).

Similarly, when looking at the non-dominant hand of the male subjects, there was a significant difference between the two measurement methods with the average measurement found using the ForceMap™ being 180.47 pounds ± 46.17 and 106.36 pounds ± 27.57 using the Jamar™, n=28 (Figure 3). Again, there was a strong correlation between the two measurement methods with an r value of 0.732.

When comparing the women's measurements using the ForceMap™ and the Jamar™ for the dominant hand, it was found that there was a significant difference between the two measurements with the mean measurement found using the ForceMap™ being 105.92 pounds ± 26.89 and the Jamar™ being 65.93 pounds ± 12.80, n=28. There was a moderate correlation between these two methods of measurement with an r value of 0.577. When looking at the female subjects' non-dominant hands, there once again was a significant difference between the two measurement methods with a measurement of 102.54 pounds ± 28.22 when using the ForceMap™ and 61 pounds ± 14.49 when using the Jamar™, n=28.

A strong correlation was observed between the two measurement methods for the women's non-dominant hands and their dominant hands, with an r value of 0.781 (Figure 5).

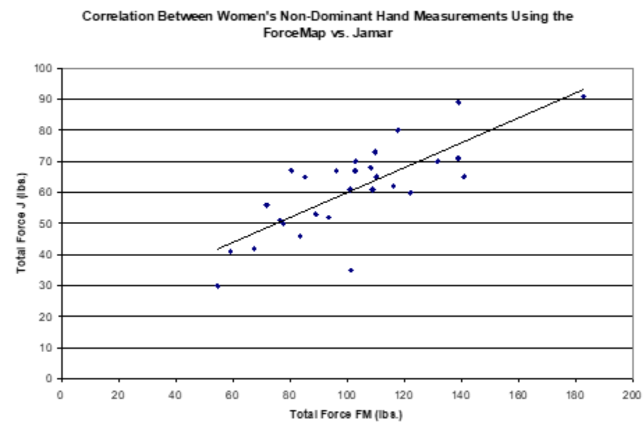

Figure 5. Correlation between the measurements found using ForceMap™ and those found using the Jamar™ for the women's non-dominant hand, r=0.781

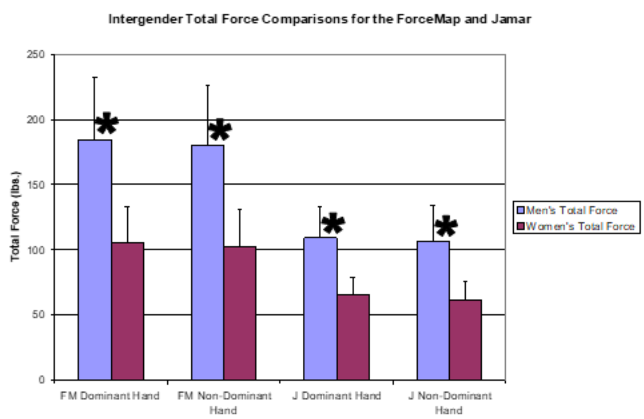

Figure 6. Comparison of total force measurements between men and women for both the dominant and non-dominant hands using the ForceMap™ and Jamar™, $p \leq 0.05$

When comparing genders, there were significant differences observed between the male and female subjects when using the ForceMap™ on the dominant with the mean measurements being 184.95 pounds ± 47.32 and 105.92 pounds ± 26.89 respectively, n=28. This was also true for the non-dominant hands with the mean ForceMap™ and Jamar™ measurements being 180.47 pounds ± 46.17 and 102.54 ± 28.22 pounds respectively, n=28. There were also significant differences between the male and female subjects when using the Jamar™ dynamometer for both the dominant hands with mean measurements of 109.25 pounds ± 23.83 and 65.93 pounds ± 12.80, n=28, respectively, and non-dominant hands with mean measurements of 106.36 pounds ± 27.57 and 61 pounds ± 14.49, n=28, respectively (Figure 6).

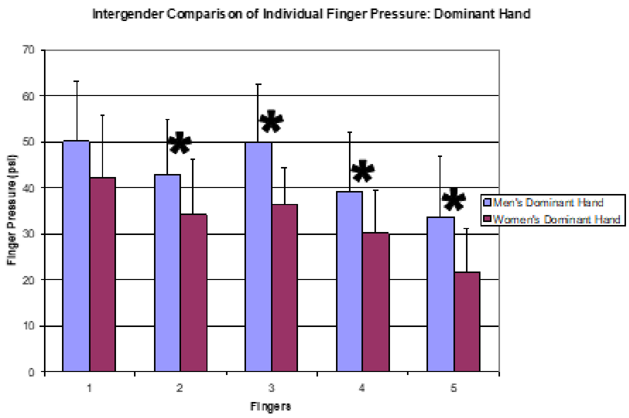

Figure 7. Comparison of individual finger pressures in maximum pounds per square inch (psi) between men and women on the dominant hand using the ForceMap™, $p \leq 0.05$

This study also examined the differences between the individual finger grip pressures. The comparison of independent variables observed in this study included the difference between genders for the same finger on the dominant and non-dominant hands as well as the difference between finger pressures on the dominant and non-dominant hands in the same gender. The differences for the intergender comparison for the dominant hands were that the men squeezed with significantly more pressure with their second, third, fourth, and fifth fingers than the women, but not their first finger (Figure 7).

The men squeezed with significantly more pressure than the women using their non-dominant hand with all fingers. When observing the differences between the individual fingers on the dominant versus non-dominant hands for the male subjects, none of the differences between any of the fingers reach significance. For the women, only the grip pressure produced by the dominant second finger was significantly higher than that produced by the non-dominant second finger. No other differences between fingers reached significance.

This study was also an attempt to establish normative values for total force of the entire hand for men's, women's, and adult group left and right as well as dominant and non-dominant hands. We attempted to identify normative individual finger pressures for left, right, dominant, and non-dominant hands for both men and women. For the entire adult group on the dominant hand, the mean men's value is 184.55 pounds ± 47.32, and the non-dominant hand total force mean is 180.47 pounds ± 46.17, n=28. For the women's dominant hand, the mean total force value was 105.92 pounds ± 26.89, and the non-dominant hand had a mean total force value of 102.54 pounds ± 28.22, n=28. For the entire adult group, the right hand normative value was 145.15 pounds ± 55.59. The left hand value was 141.59 pounds ± 54.05. The dominant hand normative value was 145.24 pounds ± 55.03. The non-dominant hand normative value was 141.51 pounds ± 54.62, n=56. A summary the normative values for grip (lbs.) and individual finger pressures (psi) are shown in the chart below (Table 1).

Table 1. ForceMap™ grip values and individual finger pressures for each gender and age group

	N	Total Force D (lbs.)	Total Force ND (lbs.)	1st D (psi)	1st ND (psi)	2nd D (psi)	2nd ND (psi)	3rd D (psi)	3rd ND (psi)	4th D (psi)	4th ND (psi)	5th D (psi)	5th ND (psi)
All Men													
Mean	28	184.5	180.1	50.1	53.2	42.8	41.1	49.8	47.8	39.1	40.7	33.6	33.5
SD		47.7	45.8	13.1	13.6	12.1	12.0	12.8	13.3	13.1	13.6	13.3	16.4
18-30 Yr Men													
Mean	12	178.3	165.6	52.2	55.6	40.9	37.8	52.5	46.7	39.1	40.5	38.7	33.0
SD		41.7	35.2	10.7	10.1	12.6	7.5	11.3	13.4	12.2	14.0	11.7	17.8
>30 Yr Men													
Mean	16	193.0	194.8	47.4	50.7	44.8	44.7	49.0	49.0	38.6	41.5	30.2	35.2
SD		52.3	53.2	10.7	10.1	12.5	15.0	14.4	14.2	14.8	14.5	13.2	16.5
All Women													
Mean	28	105.9	102.5	42.1	44.3	34.2	30.5	36.3	37.9	30.1	29.8	21.6	21.9
SD		26.9	28.2	13.6	10.6	12.0	10.0	8.1	11.8	9.2	8.6	9.5	6.5
18-30 Yr Women	8												
Mean		109.5	105.0	40.3	46.6	35.2	31.4	38.7	39.4	30.0	26.5	21.9	20.9
SD		29.0	19.9	17.0	9.4	16.2	12.2	8.8	12.3	11.4	8.4	10.9	6.5
>30 Yr Women	20												
Mean		104.5	101.6	42.9	43.5	33.8	30.2	35.4	37.3	30.2	31.1	21.5	22.3
SD		26.7	31.3	12.40	11.14	10.42	9.34	7.79	11.87	8.54	8.57	9.24	6.55
Adult													
Mean	56	145.2	141.5	46.1	48.8	38.5	35.8	43.1	42.8	34.6	35.2	27.6	27.7
SD		55.0	54.6	13.83	12.89	12.71	12.20	12.60	13.42	12.11	12.53	12.97	13.66

4. Discussion

It was observed that the ForceMap™ measurements were significantly higher than those recorded when using the Jamar™. It is possible that these differences are due to the fact that the force produced over the entire hand is measured by the ForceMap™, while the Jamar™ is only measuring the squeezing force of the four small fingers. The ForceMap™ also has the capability to measure the force produced by the distal phalanges of all five fingers, where when using the Jamar™, the distal phalanges of the fingers are strictly used to hook the bar of the Jamar™. The thumb is also used very little when using the Jamar™. The back bar of the Jamar™ actually rests across the thenar eminence. The thumb is not used to a large degree when squeezing the Jamar™. The fact that the thumb and the distal phalanges are not used to grip the Jamar™ suggests that a percentage of the gripping forces produced by the flexor digitorum profundus and the flexor pollicis longus muscles are negated since these muscles have their distal attachments to the distal phalanges. Nevertheless, it is of interest that there was a strong positive correlation shown between the total force measurements taken from the ForceMap™ and those taken from the Jamar™ dynamometer.

There were also significant differences between the men's and women's total force measurements for both hands using both measurement methods. This was anticipated based on results from Mathiowetz and colleagues who showed there to be a difference between the men's and women's normative values for total force using the Jamar™ dynamometer [5]. Since there is a strong correlation between the total force measurements from the ForceMap™ and Jamar™, one can assume that if there is a significant difference in the measurements retrieved from one of the machines there will be a significant difference in the measurements retrieved from the other. We hypothesize that the difference between the total force measurements observed when using the ForceMap™ and those observed when using the Jamar™ results from the addition of the forces being produced by the palm, the thumb, and the distal phalanges of the finger, which are measurable components of the grip when using the ForceMap™.

When observing the correlation between the subjects' total force produced measured by the Jamar™ and the length of the subjects' right hand, no relationship was found. This was also true for the subjects' hand width. The ForceMap™ is designed to take force readings over the entire hand or grip area. Since more force values are being recorded, this will increase the total force measured.

It appears that individual grasp styles may change when gripping with maximum pressure with age. For example, men of 18 to 30 years of age tended to have a higher grip pressure with their first finger (thumb) than men who were over 30 years of age. The opposite was true in these two age groups when examining data from the second (index) finger. Also, women 18 to 30 years of age gripped with a greater amount of pressure than the women who were over 30 years of age with their second (index) and third (middle) fingers, but the women who were over 30 years old gripped with more pressure than the women who were 18 to 30 years old with their fourth finger (ring finger). These strength differences support the concept of age-related adjustments in motor strategy.

More investigation may be of benefit to validate the ForceMap™ as an accurate grip force measurement tool. It may also be interesting to further quantify total force values for each finger in order to see what percentage of the total force is produced by each finger and compare that to the previous studies done by Kinoshita and colleagues as well as Radwin and Oh [6,7].

5. Conclusions

In conclusion, the Jamar™ hand dynamometer has served as a very reliable research and clinical hand evaluation tool for many years and the contributions of which to orthopedics and physical therapy cannot be overstated. This study has shed light on a new tool and method for hand function evaluation that may provide more detailed information and eventually enhance clinical assessment and the rehabilitation process.

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