APPENDIX B

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Title: Hand Shape Effects on Maximal Isometric Grip Strength and Its Reliability in Teenagers

ABSTRACT

Hands can be classified by their shape; width divided by length. This study examined the impact of shape of the hand (as relatively long, average, or square-shaped hands) on maximal voluntary isometric grip strength and test retest reliability in a group of healthy teenagers aged 13 to 17 years. When 116 males and 112 females were measured with a GripTrack™ (computer-linked Jamar™-like isometric hand grip dynamometer) males were significantly stronger than females (by 11.02 Kg force, p<0.01), and dominant hands were significantly stronger than non-dominant hands (by 2.53 Kg force, p<0.01). There were no significant differences due to hand shape.

To examine the reliability of the grip strength test 74 males and 75 females were retested, with a mean retest time interval of 15.5 days. There was a small but significant improvement in grip strength (by 0.62 Kg force, p<0.01). Regarding males, the test-retest Intraclass Correlation Coefficients (ICC 3,1) for both hands of the three hand shape groups were excellent, with ICC values ranging from 0.954 to 0.973. However for females reliability values declined across the three hand shape groups from long to square (ICC 0.920 to 0.476), such that strength test reliability examined by the 95% confidence intervals was significantly lower than males for average and square hand shapes. Although there may be several factors contributing to this difference between males and females in strength test reliability for different hand shape groups, it is possible that Jamar™-like handgrip dynamometers have a handle shape which impedes those females with relatively square hands from giving reliable grip strength readings over time.
INTRODUCTION

Most human anthropometric dimensions are distributed in a bell-shaped curve within the normal population, with slight male/female differences in the median and range values. One such dimension with these gender differences is hand shape. Hand shape has been defined in various ways, but often as simply the hand width/hand length ratio (W/L ratio). Thus hands with varying W/L ratios can be described as ‘long and narrow’, ‘average looking’, or ‘relatively square’ by how long the hand is in relation to the width of the palm (Figure 1).

![Figure 1](image)

Many hand-grip strength studies with healthy adults have shown that anthropometric variables, such as height, weight, hand length, and hand width, are positively associated with grip strength, as are other anatomical variations, such as the presence of a flexor digitorum superficialis tendon in the little finger. Paediatric studies have shown that the anthropometric variables of body mass index, height, weight, hand length, palm length and palm width are highly correlated with grip strength in children.

Further, amount of fat-free muscle is correlated highly with grip strength in teenagers. Increasing levels of testosterone and greater participation in sport have been found to be related to increasing grip strength in boys entering puberty. These findings help to explain the well-documented, increasing, grip strength difference between boys and girls throughout the teenage years. However, for most teenagers it would be expected that none of these variables, including hand shape, would change significantly over a four week period.

Past studies have shown that maximal grip strength varies throughout the day, from day to day and is influenced by such variables as amount of bed rest, medications, testing position and time since injury (in patients with upper limb injuries), but there remains a large amount of variation in grip strength in healthy people which has not been accounted for. Specifically, the relationship between the shape of a hand and its ability to generate maximal and reliable grip strength readings with an isometric handgrip dynamometer has not yet been investigated.
The data reported in this paper were gathered as part of a project examining factors affecting maximal isometric grip strength force generation (grip strength) and its reliability, in Australian teenagers. The current research was conducted to examine two hypotheses:

a) that there are differences in grip strength associated with gender, dominance and hand shape

b) that there are differences in the reliability of grip strength from test one (T1) to test two (T2) associated with gender, dominance and hand shape.

METHODS

Sample

The study aimed to test grip strength in a large injury-free population who would be available for repeat grip strength testing. Thirteen to seventeen year old teenagers were chosen for the study because it is in the early to mid teenage years that the gender difference in grip strength begins to emerge.\textsuperscript{10,13,16–18} Students amongst the 1,200 enrolled at a large, metropolitan high school in a middle-income earning area of northern Brisbane, Australia, were therefore appropriate subjects. Their ethnic mix was reflective of northern Brisbane, with the majority being of Anglo-Saxon origin, as observed by the fieldworker. Both the Principal and Science Master agreed to the project being conducted at the school, within normal school hours (between 9 am and 3 pm). This enabled good cross-sectional sampling with the potential recruitment of most of the student body and not just sporting-minded volunteers. Volunteers have been previously shown to be of a different psychological profile to that of randomly selected research participants for motor performance tasks.\textsuperscript{28}

Research participants were recruited using a passive consent process.\textsuperscript{29} Parents/guardians were asked to fill in and return a form if they did not wish their teenager to participate in the study. After two weeks, no forms had been returned. Consent by the teenagers was assumed if they attended for grip strength testing at their allocated appointment time. Thereafter, the teenagers were grip strength tested individually, with no other peers in the room at the time. The first author, who was not associated with the school prior to the research, was the sole fieldworker for all data gathering; this included grip strength testing and the taking of anthropometric measurements. At the time of data gathering, she had been a registered Occupational Therapist for 15 years and had been using the GripTrack handgrip dynamometer for 18 months prior to the commencement of the study. Ethical approval for the study was obtained from institutional ethics committees before data collection.

Inclusion criteria

In class groupings, students were asked to complete an Edinburgh Handedness Inventory\textsuperscript{30} and a demographic data form, which requested information about date of birth, gender, any past upper limb pathology which had required surgery, and any current upper limb injuries, or upper limb pain. No teenager was called for grip strength testing if they indicated that they had previously undergone upper limb surgery, or were experiencing upper limb pain, or pathology, at the time of the testing. Classes were chosen to reflect the full range of academic abilities. The following analyses are based on 232 teenagers (118 males and 114 females) aged 13 to 17 years.
Hand measurements

Only the dimensions of the dominant hand (as determined by the Edinburgh Handedness Inventory) were recorded, as the surface area and hand lengths of the two hands have previously been shown to be not significantly different. From this it was assumed that the two hands would be of sufficiently similar width and length to place them both in the one hand shape category (long, average or square), even if one hand had a slightly different W/L ratio to the other.\(^2\)

Hand length of the dominant hand, defined as the distance from the tip of the middle finger to the midline of the distal wrist crease when the forearm and hand are supine on a table, was measured with a standard 300 mm metal ruler. Hand lengths were recorded to the nearest millimetre. Hand width has been defined as the distance between the radial side of the 2\(^{nd}\) metacarpal joint to the ulnar side of the 5\(^{th}\) metacarpal joint.\(^3\) In the present study the width was calculated by dividing the circumference by two, thus also taking into account palmar thickness. To overcome inaccuracies of inconsistent tensioning, hand circumferences were taken with the Figure Finder Tape Measure (Novel Products, Rockton, IL., USA), which applies a fixed compression force of 100 gm of tension. The tape was placed around the 2\(^{nd}\) to 5\(^{th}\) metacarpal-phalangeal joints. During measuring, pronated hands were gently pressed down onto a tabletop to flatten the distal palmar arch. Circumferences were then recorded to the nearest millimetre. The hand dimensions were measured only once, as previous paediatric studies have found other upper limb anthropometric measurements to have good reliability.\(^1\)

The males and the females were divided into three hand shape groups using their frequency distribution of W/L ratio, with the relatively long-handed (LONGhand) and relatively square-handed (SQUAREhand) groups corresponding to those beyond the lower and upper quartiles respectively. The average-handed (AVGEhand) group represented the 50% of hands between these two quartiles.

Grip strength testing

All grip strength testing took place in a quiet, air-conditioned laboratory which was dedicated to the grip strength-testing project. Participants were tested with the GripTrack\(^{\text{TM}}\) (JTech Medical Industries, Utah, USA), a computer-linked handgrip dynamometer (Figure 2). The linking of the device to a computer assisted in the elimination of possible transcription and interpretation errors that may occur with manual recording.\(^3\) The GripTrack\(^{\text{TM}}\) has identical dimensions to and the same five handle positions as the analogue Jamar\(^{\text{TM}}\) model, with the only difference between the two instruments being that the GripTrack\(^{\text{TM}}\) does not have the analogue dial mounted at the top of the handle, thus it is 120 grams lighter. The computer was set to display the force reading to the nearest kilogram of force, which can be converted to Newtons by multiplying the kilogram force readings by 9.81.

Calibration

Government-certified weights were used to check the calibration of the GripTrack\(^{\text{TM}}\) before, monthly during, and after all data was collected, according to the method
The GripTrack™ was given a zero calibration reference check, at the beginning of each testing day. When a 10 Kg mass was suspended from each of the 5 handle positions of the GripTrack™ the mass error never exceeded +/- 1 Kg and was often zero. When a 20 Kg mass was suspended, the error never exceeded +/- 2Kgs and was generally only +/- 1 Kg at the most, but was usually zero. Errors of the magnitude of 3 Kg were only found when masses of 50 Kg or more were suspended from the handles on handle positions 4 or 5 (the two largest handle sizes).

Only 4 (1.7%) of the right hands and 3 (1.25%) of the left hands achieved their maximal grip strength value on handle position 4 and no teenager achieved a maximal grip strength value on handle position 5, as expected from findings in other studies. Only one of these 7 hands had a maximal grip strength value of over 50 Kilograms force (Kg f), so any calibration errors would have minimal impact on the overall results.

**Test Positions**

Students were tested in the standard ASHT position with standardised verbal instructions. Although other paediatric grip strength studies have used only one handle position, the current study used all 5 to ensure that each teenager was able to be tested on their optimal handle position, since this is not always position 2 or 3 for a given individual.

Three repetitions were given on each handle position, progressing from the smallest to the largest. A timed rest break of 15 seconds was given between each squeeze. No warm ups were given and students were not familiarized with the GripTrack™ prior to testing. The non-dominant hand was tested on each handle position after the dominant hand had completed its three trials on that handle position. Each hand received a one minute rest break before proceeding to the next handle size. Each squeeze lasted for 2.5 to 3 seconds with the effort visually monitored to ensure that maximal grip had been achieved within that time period, as indicated by the rapid increase in strength and then a tapering of this on the force-time curve displayed on the monitor screen. The students were not able to view the screen during grip strength testing. The maximal grip strength score for each hand was considered to be the highest force reading of the 15 trials.

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**Figure 2** [Footnote: Monitor was temporarily re-aligned for the photograph]
STATISTICAL ANALYSIS

Hand Shape, Gender and Maximal Grip Strength Force

The frequency distributions of the hand W/L ratios for the two genders were examined. Because these were uni-modal, symmetrical and well-approximated by normal distributions, three hand shape groups within genders were formed by partitioning at the quartiles. Means, standard deviations and range for W/L ratio in these groups are given in Table 1.

Descriptive and chi square analyses were undertaken using SPSS for Windows, version 11(Chicago, Ill). An analysis of variance (ANOVA) with orthogonal contrasts was used to determine the possible effects of, and interactions between, two between-groups factors (gender and hand shape) and one repeated measures factor (dominance). Planned trend contrasts examined for the presence of linear and quadratic trend components in strength change across the three hand shapes. When a significant effect or interaction was found the magnitude of the effect (the difference between the means of two compared groups) in the original units of measurement and their associated 95% confidence intervals (CIs) were calculated using the PSY software for contrast analysis.

Results were considered to be significant if their associated p values were less than 0.05.

Reliability of the Maximal Grip Strength Forces of the Dominant and Non-dominant Hands

Due to school timetable clashes, absenteeism and time constraints a reduced group of 149 teenagers (74 males and 75 females) had their grip strength retested at either a one- or a four-week interval, giving a mean interval of 15.51 days (SD 12.32). The repeat test session was conducted with the same protocol as the original test session. After the students were tested, their hand shapes were re-distributed into quartile groups, using the same methods as above. Six students (four males and two females) shifted to an adjacent hand shape group via this process. The hand shape groups in this reliability sample were labelled with the subscript 2, so that LONG2, AVGE2, and SQUARE2 were distinguished from the previous larger sample. The reliability of the maximal grip strength results for dominant and non-dominant hands was then assessed from T1 to T2 using a single measure, the Intraclass Correlation Coefficient (ICC 3,1). Because the ICC 2,1 is sensitive to any additive or multiplicative bias at retest, whilst the ICC 3,1 is only sensitive to multiplicative bias, the ICC (2,1) was also calculated as a check for the presence of additive bias between measures. To assess measurement accuracy for each of the 12 groups (gender x dominance x hand shape) the standard error of measurement (SEM) was calculated as SEM = SD x √(1-ICC). The standard deviation (SD) was the pooled standard deviation for T1 and T2, for each group separately. An ANOVA was performed to determine any systematic effects on grip strength. Differences between means and their CIs were calculated using the PSY software.

RESULTS

There were complete hand dimension data sets for 232 teenagers, with complete grip strength data sets for 228. Complete repeat grip strength data sets were available for 149 of these. Means, standard deviations and ranges for W/L ratio in each hand shape
group and gender in the original sample are given in Table 1, and the W/L ratio means, standard deviations and ranges of the smaller, reliability sample (hand shape groups LONG$_2$, AVGE$_2$ and SQUARE$_2$) are given in Table 2. Comparison of the cut points for the hand shape groups between the two samples showed them to differ minimally, indicating a high degree of similarity between samples. Mean hand lengths, hand widths and their respective standard deviations have been reported for age and gender splits within the original sample of 232 and are presented in Table 3.

TABLE 1. Mean W/L Ratios, Standard Deviations (SD) and Range for the Original Male and Female Hand Shape Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th></th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>W/L ratio</td>
<td>Range</td>
<td>n</td>
<td>W/L ratio</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean (SD)</td>
<td></td>
<td></td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>LONGhand</td>
<td>29</td>
<td>0.517 (0.009)</td>
<td>0.486 – 0.526</td>
<td>27</td>
<td>0.494 (0.010)</td>
<td>0.472 – 0.5084</td>
</tr>
<tr>
<td>AVGEhand</td>
<td>59</td>
<td>0.546 (0.012)</td>
<td>0.527 – 0.564</td>
<td>59</td>
<td>0.530 (0.013)</td>
<td>0.5085 – 0.551</td>
</tr>
<tr>
<td>SQUAREhand</td>
<td>30</td>
<td>0.578 (0.019)</td>
<td>0.565 – 0.665</td>
<td>28</td>
<td>0.567 (0.014)</td>
<td>0.552 – 0.631</td>
</tr>
</tbody>
</table>
TABLE 2. Mean W/L Ratios, Standard Deviations (SD) and Range for the Reliability Sample of Male and Female Hand Shape Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th></th>
<th></th>
<th>Female</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>W/L ratio</td>
<td>Mean (SD)</td>
<td>Range</td>
<td>n</td>
<td>W/L ratio</td>
</tr>
<tr>
<td>LONG₂</td>
<td>18</td>
<td>0.520</td>
<td>(0.007)</td>
<td>0.508 – 0.528</td>
<td>19</td>
<td>0.495</td>
</tr>
<tr>
<td>AVGE₂</td>
<td>37</td>
<td>0.546</td>
<td>(0.010)</td>
<td>0.529 – 0.565</td>
<td>37</td>
<td>0.527</td>
</tr>
<tr>
<td>SQUARE₂</td>
<td>19</td>
<td>0.582</td>
<td>(0.023)</td>
<td>0.566 – 0.665</td>
<td>19</td>
<td>0.572</td>
</tr>
</tbody>
</table>

TABLE 3. Mean Hand Lengths in cm and Hand Widths in cm and Their Respective Standard Deviations (SD) for Age and Gender Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean Hand Length (SD)</th>
<th>Mean Hand Width (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 y.o. males</td>
<td>64</td>
<td>17.70 (1.25)!</td>
<td>9.81 (0.70)*!</td>
</tr>
<tr>
<td>13 y.o. females</td>
<td>51</td>
<td>17.49 (0.85)</td>
<td>9.38 (0.50)*</td>
</tr>
<tr>
<td>17 y.o. males</td>
<td>54</td>
<td>19.52 (0.86)*!</td>
<td>10.52 (0.53)*!</td>
</tr>
<tr>
<td>17 y.o. females</td>
<td>63</td>
<td>17.57 (0.87)*</td>
<td>9.24 (0.41)*</td>
</tr>
</tbody>
</table>

* = Indicates a significant difference between gender groups of the same age at p = or < 0.001
Hand Shape, Gender and Maximal Grip Strength Force

Male and female grip strength force means and CIs for the dominant and non-dominant hands of each hand shape group are displayed in Figure 3 as recommended by McClure. 49

FIGURE 3. Mean grip strength and 95% CIs for males and females with six different hand types

Results from the ANOVA on the strength data (detailed in Table 4) from the original group showed males to be significantly stronger than females \([F_{(1, 222)} = 82.35, p < 0.001]\) with a difference between the means of 11.02 Kg f (CI: 8.63 to 13.41 Kg f). Dominant hands were found to be significantly stronger than non-dominant hands \([F_{(1, 222)} = 121.62, p < 0.01]\), giving a difference between the means of 2.53 Kg f (CI: 2.08 to 2.98 Kg f). The downward linear trend in strength from LONG, through AVGE to SQUARE hands, with the greatest difference between means being 2.96 Kg f (CI: 0.27 to 6.18 Kg f), was not statistically significant at the 0.05 level \([F_{(1, 222)} = 3.26, p = 0.08]\). There was no significant quadratic trend in strength, nor any interaction effects between gender, dominance and hand shape.
Table 4. Male and Female Mean Grip Strengths and Standard Deviations (SD) Sorted by Dominance and Hand Shape

<table>
<thead>
<tr>
<th>Gender and Hand Shape Group</th>
<th>Dominant Hand</th>
<th>Non-dominant Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean Kg f (SD)</td>
</tr>
<tr>
<td>Male LONGhand</td>
<td>28</td>
<td>42.32 (11.81)</td>
</tr>
<tr>
<td>Male AVGEhand</td>
<td>59</td>
<td>38.17 (11.36)</td>
</tr>
<tr>
<td>Male SQUAREhand</td>
<td>29</td>
<td>38.21 (11.71)</td>
</tr>
<tr>
<td>Female LONGhand</td>
<td>27</td>
<td>28.82 (5.62)</td>
</tr>
<tr>
<td>Female AVGEhand</td>
<td>58</td>
<td>28.86 (4.89)</td>
</tr>
<tr>
<td>Female SQUAREhand</td>
<td>27</td>
<td>27.26 (4.71)</td>
</tr>
</tbody>
</table>

Both genders and both hands showed very similar patterns of optimal handle positions for generating maximal grip strength, the order of which was handle position (HP) 2 (75%), HP# 3 (19%), HP #1 (4%), HP #4 (2%) and HP#5 (0%). Chi square analysis showed no significant association between hand shape and handle position with respect to frequency of maximum grip strength, for either gender.

Reliability of the Maximal Grip Strength Forces of the Dominant and Non-dominant Hands

As with the larger group of teenagers, the males in the reliability group were significantly stronger than the females [F (1,143) = 69.63, p < 0.01], with a difference of 12.38 Kg f (CI: 9.48 to 15.31 Kg f). Dominant hands of both genders were stronger than non-dominant hands [F (1, 143) = 87.95, p < 0.01], with a difference between the means of 2.41 Kg f (CI: 1.90 to 2.91 Kg f). Repeating the test yielded a small but significant increase in grip strength [F (1, 143) = 7.57, p < 0.01] with a mean increase of 0.62 Kg f (CI: 0.17 to 1.06 Kg f). There were no significant interactions involving gender, dominance, hand shape, or time interval.

For males, the grip strength reliability of both hands, in each hand shape group was excellent, as judged by the high ICC 3,1 values which ranged from 0.954 to 0.973. The CIs for these six ICC values overlap, indicating that the reliability of strength retest for male hand shape groups, whether using dominant or non-dominant hands, was not significantly different (Figure 4). For females, the test-retest ICCs became
lower for both the dominant and non-dominant hands across the three hand-shape groups. Based on non-overlapping CIs, the SQUARE\textsubscript{2} groups had significantly lower ICC values than the most reliably measured group, the dominant LONG\textsubscript{2} group. The non-dominant hand of the LONG\textsubscript{2} group also had excellent reliability, while the two AVGE\textsubscript{2} groups had moderately high reliability for repeat testing. Further, only female teenagers with long hands had strength retest reliability that was not significantly different from that of their male counterparts (Figure 4).

The calculated ICC (2,1) values were found to be smaller than the ICC 3,1 values throughout, but as this difference was in the second or third decimal place, these are not reported. The SEM is a measure of the magnitude of error associated with a test and these values are presented in Table 5. Both males and females exhibited a similar range of SEMs for dominant and non-dominant hands, with the male dominant LONG\textsubscript{2} group having the greatest magnitude of errors. Grip strength values for the initial tests of the reliability groups are presented in Table 5.

![FIGURE 4. Reliability indices (ICCs) and 95% CIs for handgrip test-retest on males and females with six different hand types](image)

<table>
<thead>
<tr>
<th>HAND TYPE</th>
<th>Dom LONG</th>
<th>Non-dom LONG</th>
<th>Dom AVGE</th>
<th>Non-dom AVGE</th>
<th>Dom SQUARE</th>
<th>Non-dom SQUARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>filled symbols: male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>open symbols: female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Mean Grip Strengths and Standard Deviations (SD) Sorted by Dominance and Hand Shape for Initial Test of Reliability Group With Standard
Errors of Measurement (SEM) in Kg f

<table>
<thead>
<tr>
<th>Gender and Hand Shape Group</th>
<th>Dominant Hand</th>
<th>Non-dominant Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Kg f (SD)</td>
<td>SEM in Kg f</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Male LONG₂</td>
<td>18</td>
<td>44.11 (12.51)</td>
</tr>
<tr>
<td>Male AVGE₂</td>
<td>37</td>
<td>39.00 (12.00)</td>
</tr>
<tr>
<td>Male SQUARE₂</td>
<td>19</td>
<td>38.74 (12.05)</td>
</tr>
<tr>
<td>Female LONG₂</td>
<td>19</td>
<td>27.53 (5.71)</td>
</tr>
<tr>
<td>Female AVGE₂</td>
<td>37</td>
<td>28.87 (4.80)</td>
</tr>
<tr>
<td>Female SQUARE₂</td>
<td>19</td>
<td>27.90 (4.05)</td>
</tr>
</tbody>
</table>

DISCUSSION

The hand dimensions obtained here were compared with other databases of teenagers from various countries, since no Australian published database was found. As hand dimensions are linked to ethnicity, and even within the one ethnic group there can be differences in hand sizes, making comparisons between dissimilar populations is difficult. In addition, periodic revision of growth percentiles have been advocated, due to the changing mix of population and socio-economic factors in urban Australia. Thus the data presented here may serve as a current database for Australian teenagers.

For each age and gender group, the mean of the hand lengths were found to be similar to matched age and gender samples from other studies. The Swedish study of Häger-Ross & Röslad reported 13 y.o. males (n = 20) and 13 y.o. females (n = 22) to have mean hand lengths which were 0.70 cm and 0.39 cm shorter than the age-equivalent groups in the present study. Their 16 y.o. males (n = 22) and 16 y.o. females (n = 16) had mean hand lengths that were 0.06 cm and 0.03 cm longer than their age-equivalent groups here, respectively. The British data presented by Pheasant which
was collected in 1972, showed 50th percentile hand lengths for 13 year old males and 13 year old females to be 0.70 cm and 0.49 cm shorter than the current mean values, with SDs equal to the nearest whole millimetre. The 50th percentile hand lengths for 17 year old males and females was 0.52 cm and 0.07 cm shorter than the current mean values, again with similar variability. The mean heights of our teenagers were consistently taller than those of Pheasant by 1.5 to 4.1 cm. As hand length is proportional to body length and the height of teenagers has increased steadily over recent decades, results here can be seen as consistent with those from previous work.

From the adolescent years into adulthood, males’ hands become significantly wider than females; this is consistent with greater frequency of lower w/l ratios, as compared to the females, in the present study. Hand width data from Pheasant showed that hand widths of a British sample were 1.81 cm and 1.88 cm narrower than the widths of the males and females in the present sample respectively, but they did not take hand thickness into account with their linear measurement technique. In one study of farming women, the average hand thickness was found to be between 2 and 3 cm. Thus the greater hand widths of approximately 2 cm in the present study are consistent with this finding. A recent study in the Netherlands reported the hand circumferences of 40 males and 41 females in the collective age span of 13 to 19 years of age. Their means were 0.77 cm and 0.18 cm greater than the combined 13 to 17 year age groups of the present study, for the males and females respectively, with similar ranges and standard deviations. As grip strength can still be increasing between the ages of 17 and 19 years it can be assumed that hand width will increase with the greater muscle bulk of the 19 year olds, which in turn will correlate with the wider circumferences of the study of Merkies et al.

The effect of gender on grip strength is well documented. Once males enter the teenage years they are generally significantly stronger than age-matched females and the data obtained here is consistent with this. Similarly, previous studies have found a dominance effect in hand grip tests, with the dominant hand being stronger than the non-dominant hand, although the size of the difference is dependent upon the definition and the assessment of hand dominance. A conventional definition of hand dominance views the dominant hand as the hand which is most preferred for a number of skilled and common tasks as listed in a self-assessment questionnaire, such as the Edinburgh Handedness Inventory. Using this inventory for the current study the data here also confirmed this dominance effect on grip strength.

To compare the grip strength results of the dominant and non-dominant hands for this group of teenagers, comparisons were made with existing grip strength data bases from studies which used either Jamar or Jamar-like isometric hand grip dynamometers. Some of these studies only reported the grip strength values for the dominant hand, whilst others only reported the results for the non-dominant hand, whilst others reported results for the dominant and non-dominant hands pooling all the dominant hands together, irrespective of whether the dominant hand was a right hand or a left hand. Others combined the right and left hand grip strength data. The present study used the strongest grip strength score (maximum grip strength) of each hand from 15 trials over the five handle positions for each hand. Other studies used only one trial, or the mean of three trials, or the maximal trial out of
two or three trials having tested the teenagers on only one handle position. Further, the current study had two age groups for each gender, 13 year olds (mean = 13.4 years, SD = 0.38) and 17 year olds (mean = 17.1 years, SD = 0.46). Because grip strength increases significantly throughout the teenage years only comparisons with like age groups are meaningful.

Comparisons were made based on the most closely approximating data to that of the current study. For example, when only the non-dominant hand was presented it was compared with only the non-dominant hands in the current study. Other studies which presented the mean of three trials for the right hand, or combined right and left hand data where compared with the mean maximal grip strength score of the dominant hand of our age and gender matched groups. When presented, standard deviations and ranges were similar to the present data, but were not used for the following strength comparisons.

For the 13 year old males in the present study mean maximum grip strengths for their dominant (mean = 31.05 Kg f, SD = 7.80) and non-dominant hands (mean = 28.52 Kg f, SD = 7.2) were between 1.05 Kg f and 7.02 Kg f stronger than comparable data in the other studies of 13 year old males. For the 13 year old females in the present study, mean maximum grip strengths for the dominant (mean = 26.50 Kg f, SD = 4.40) and non-dominant hands (mean = 24.68 Kg f, SD = 4.5) were between 0.5 Kg f and 4.0 Kg f stronger than those reported in other studies of 13 year old females. For the 17 year old males, mean maximum grip strength for dominant (mean = 48.22 Kg f, SD = 8.05) and non-dominant hands (mean = 45.30 Kg f, SD = 8.2) were between 1.6 Kg f weaker and 9.6 Kg f stronger than other studies. Finally, for 17 year old females, mean maximum grip strength for their dominant (mean = 30.08 Kg f, SD = 4.89) and non-dominant hands (mean = 27.0 Kg f, SD = 4.3) were between 2.3 Kg f weaker to 2.4 Kg f stronger than other studies. Thus whereas the younger teenagers here were slightly but consistently stronger than age peers in previous research, grip strength for the 17 year olds more closely approximated data from other reports. Because some other studies used only one trial or the mean of three trials and they all only used one handle position (which may have disadvantaged some) it is not surprising that the current sample tended to appear stronger than samples. Considering these factors, overall it can be concluded that the data are in agreement.

From a literature search it would appear that the effect of the shape of the hand on its ability to generate grip strength force has not been previously investigated. Although in the current study the longer-shaped hands tended to be stronger than the other two hand shapes, the difference was not significant. Thus the hypothesis that there are differences in grip strength associated with gender and dominance was not rejected, however the hypothesis about differences due to W/L ratio was rejected. The finding of handle position #2 being the most frequently optimal handle position, followed by handle position #3, was consistent with previous studies. Our research demonstrated substantial gender differences in grip strength reliability as a function of hand shape. There appears to be no other research with which to compare these findings. For the males both the dominant and non-dominant hands achieved excellent reliability values for grip strength irrespective of their hand shape category with all ICC values greater than 0.95.
In contrast, the teenage females’ dominant and non-dominant hands in the SQUARE\textsubscript{2} group showed significantly poorer reliability (ICC= 0.547 and 0.476 respectively) upon repeat grip strength testing. This group also had decreased reliability compared to the female dominant and non-dominant hands of either the AVGE\textsubscript{2}, or the LONG\textsubscript{2} groups, whose ICC values ranged from 0.730 to 0.920, which are considered to be good to excellent reliability indicators (Figure 4).\textsuperscript{48} Thus the hypothesis that some hand shapes influence the ability to generate the same grip strength force over time was rejected for the males, but could not be rejected for the females.

The ICC is seen as being reflective of the ability of a test to discriminate among subjects, and the SEM as a measure of the magnitude of test error.\textsuperscript{50} Both male and females exhibited a similar range of SEM’s for dominant and non-dominant hands. In absolute terms, the highest SEM (and therefore the largest amount of change needed before a systematic effect from treatment could be inferred) was at the dominant hands of LONG\textsubscript{2} males; a 2.8 Kg f change would be needed from a mean grip strength of 44.1 Kg f. However, the greatest proportionate change would be needed for the female SQUARE\textsubscript{2} group, who had a combination of lower mean strength and poor strength test reliability; a force change of 2.6 Kg f would be required from a mean grip strength of 27.9 Kg f before real change could be inferred. Because ICC reliability values represent the proportion of the total variance in a set of scores that is associated with true differences between subjects, about half the variance in strength scores for this group of females reflects error rather than real differences.

Accordingly, this poses a challenge to devise a hand strength testing protocol for relatively square-handed females that will produce more reliable data.

All the teenagers in the current study took part with good will and had nothing to gain from either a better or worse performance at retest, so explanations for the reliability values in terms of motivation differences can be excluded. As also observed by other researchers, the teenagers “invariably enjoyed” having their strength tested and were eager to know their results.\textsuperscript{13,14} One possible account of the significant finding is that, for females, only average or relatively longer-shaped hands are suited to the shape of the GripTrack\textsuperscript{TM}. Relatively squarer handed females may be less able to conform to, or “map” onto the dynamometer handle, and may have experienced a greater amount of pain, compared to other females, during attempted maximum grip strength trials.

Stephens et al.,\textsuperscript{59} found that 27% of their research participants regarded the Jamar\textsuperscript{TM} dynamometer as uncomfortable to grip. If this was the case here, variability in the experience of pain may have been negatively correlated with reliability of grip strength effort. If it was the females with relatively squarer hands who experience a painful grip posture more frequently than the others, their performance may have been less consistent than the others. However, no student was allowed to continue with a grip strength test session if they reported pain, which they perceived as reducing their grip strength performance that day. During data collection three male students did report such pain, but their pain was due to recent fist-fights with siblings or peers. Their grip strength tests were terminated and their data was discarded. Alternatively, those females with relatively squarer hands may have had other unidentified physical, or psychological characteristics that led to their observed poorer reliability.

These results have clinical significance when considering sincerity of effort issues and the design of grip strength dynamometer handles. If during hand therapy a female
The teenage patient is giving inconsistent effort during repeated grip strength testing over a number of weeks, data from the current study suggest another possible explanation other than she is a malingering, affected by medications, or has a psychosomatic disorder. If the individual concerned has a squarer hand relative to other females, this alone may disadvantage her in being able to give consistent performance over time.

CONCLUSION

Results here suggest that hand-shape does not significantly influence the ability to generate maximal isometric grip strength, but that females with squarer-shaped hands are less able to reliably generate the same grip strength force readings over retest time intervals of 4 weeks or less.

IMPLICATIONS AND FUTURE STUDIES

Whether these results can validly be applied to adults with hand injuries requires investigation. Thus this hand-shape study could be extended to an injury-free adult population. Jamar™ and Jamar™-like handgrip dynamometers, such as the computer-linked GripTrack™ are commonly used in rehabilitation clinics throughout the world. In the first author’s laboratory, further research is being undertaken to investigate whether there are other handle shapes which do not disadvantage the female with relatively squarer hands. Comparisons could also be made with isokinetic tools. If Jamar™-like handle geometry is shown to be a factor related to the decreased reliability associated with these squarer-shaped hands then a design modification is needed for these existing dynamometers that permits equivalent reliability across different hand shapes.

REFERENCES


