Analysis of Hand-Forearm Anthropometric Components in Assessing Handgrip and Pinch Strengths of School-Aged Children and Adolescents: A Partial Least Squares (PLS) Approach

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Abstract

**Background** The purpose of this study was to examine the influence of hand-forearm anthropometric dimensions on handgrip and pinch strengths among 7-18 years children and adolescents and to investigate the extent to which these variables can be used to predict hand strength.

**Methods** Four types of hand strengths including handgrip, tip to tip, key, and three-jaw chuck pinches were measured in 2637 healthy children and adolescents (1391 boys and 1246 girls) aged 7-18 years using standard adjustable Jamar hydraulic hand dynamometer and pinch gauge. A set of 17 hand-forearm anthropometric dimensions were also measured with an accurate digital caliper and tape measure.

**Results** No significant differences were found between the hand strengths of boys and girls up to the age of 10 years. Gender related differences in handgrip and pinches were observed from the age of 11 years onwards, with boys always being stronger. The dominant hand was stronger than the non-dominant hand (8% for handgrip and by about 10% for all three types of pinches). The strongest correlations were found between the hand length and hand strengths ($r > 0.83$ for handgrip and three all pinches; $p < 0.001$, 2-tailed). Based on the partial least squares (PLS) analysis, 8 out of 17 anthropometric indices including hand length, hand circumference, thumb length, index finger length, middle finger length, and forearm length had considerable loadings in the PLS analysis, which together accounted for 46% of the total variance.

**Conclusions** These results may be used by health professionals in clinical settings as well as by designers to create ergonomic hand tools.

**Background**

Muscle strength is an important aspect of physical fitness, locomotor skills, nervous system maturation and health status in children’s development (1, 2). Therefore, growth-related changes in the muscle strength of healthy children may be considered as a reference for children and adolescents with acute and chronic diseases (3, 4). In children and adolescents, muscle strength has negatively related to the clustered metabolic risk independent of cardiorespiratory fitness (5, 6). A low level of muscular strength in children and adolescents is associated with poorer metabolic profile,
obesity, high blood pressure, all-cause premature, and mortality in adulthood (7–9).

Handgrip strength (HGS) is a useful marker of physical strength throughout an individual’s lifetime and is often estimated in screenings of normal motor function (7, 10). Handgrip and pinch strengths are determinative for performing prehensile and precision hand functions and daily muscular activities through the use of exquisitely arranged power and precision muscles, which acting through the extensor hood, work in synergistic precision to manipulate the digits (11, 12). Considered as the most reliable clinical tests for measuring maximum isometric strength of hand-forearm muscles, the values of handgrip and pinch strengths determine the efficacy of different treatment strategies (3, 13). These measures are often used as a functional index for nutritional status, insulin sensitivity, overall function of the upper limb, and cardio metabolic health (14, 15).

Age, gender, hand preference and anthropometric dimensions are among the most cited factors influencing handgrip and pinch forces (16, 17). Stronger handgrip and pinch strengths were reported for boys compared to girls, and for dominant hand compared to the non-dominant one (18, 19).

Moreover, handgrip and pinch strengths increases linearly with age in both boys and girls (20, 21). More precisely, HGS and PSs starts to grow from childhood and reaches a maximum level at the age of 30 s to dwindle afterwards (22, 23). Some studies have also shown that although height and weight are positively correlated with hand strengths in pubertal years, the influence of these variables is considerably smaller than that of either gender or age (20, 24). Considering anthropometric dimensions, previous studies have found a strong correlation with handgrip and pinch strengths in adults (25–27), which was confirmed in children and adolescents in few studies (28). In addition, there are contradictory findings in the studies on the anthropometric variables affecting hand strengths (HGS and PS) in different age ranges (23, 29, 30).

Due to a large number of variables affecting hand strengths (HGS and PSs), the presence of more than one response variable in the study as well as strong linear correlation among explanatory variables making it difficult to separate their effects on the dependent variable; engineering approaches are incapable of solving these problems. Several approaches have been introduced to address this issue, among which Partial Least Squares (PLS) is a good competitor (31). As a
multivariate method, PLS is strongly related to regression-like techniques which can be used as an exploratory analysis tool to select suitable predictor variables and to identify outliers before standard linear regression. More precisely, PLS predicts a set of dependent variables from a set of independent variables or predictors. Contrary to the standard regression which predicts one variable only, PLS is used to predict a whole table of data. These features make PLS a very versatile tool specified as a robust method, in which the model parameters do not significantly change if new samples are taken from the same population. PLS as a variance-based method is mainly used as an alternative for modelling structural equations, in contrast to older methods based on covariance (32).

To the best of the authors’ knowledge, only a limited number of studies have investigated the association between handgrip and pinch strengths with anthropometric dimensions among children and adolescents, particularly in Asia. Given the above, the present study was carried out to analyze the hand-forearm anthropometric components in assessing handgrip and pinch strengths in school-aged children and adolescents and to investigate if they can be used to predict these outcomes.

Methods
Participants and sampling
This cross-sectional study was conducted on 2637 school-aged children and adolescents (1391 boys and 1246 girls) between the age of 7 and 18 years from different districts of the major metropolitan city of Tehran, Iran. Data collection was carried out between May and September 2019.

The three-stage sampling method was utilized. At first, a stratified sampling method was used to identify 10 clusters based on population distribution in Tehran. In the second stage, after providing the list of all the schools located in selected clusters, a systematic random sampling method was applied to choose four schools per cluster (one elementary and one high school for each gender). The required minimum sample size at any of the girls' or boys' schools was estimated using Eq. (1) given in “General requirements for establishing anthropometric databases” (33). The 95% confidence interval was used for the 50th percentile or average values:

\[ n \geq \left(3.006 \times \frac{CV}{\alpha}\right)^2 \quad \text{and} \quad CV = \frac{s}{\bar{x}} \times 100 \]
In this formula, \( n \), \( CV \), and \( \alpha \) represents the sample size, coefficient of variation and percentage of the desired relative accuracy, respectively. Assuming a relative accuracy of 5% and using the empirical means and standard deviations (boys: 22.8 kg and 2.9 kg with CV = 12.7; girls: 17.4 kg and 2.3 kg with CV = 13.2) from the results of the initial pilot study of 80 participants (40 for each gender), the minimum required sample sizes were calculated as 58 for boys and 63 for girls in each school. Considering the “Design effect” for stratified sampling method (34), the desired sample size was obtained 2637 subjects with about 10% allowable error and non-response rate.

All students over 16 years and the parents/guardians of all minor participants (< 16 years) signed consent form describing the aims and procedures of this study. Using a short health screening questionnaire, students with history of fracture, deformity or surgery in upper extremities during the past year as well as those with history of specific diseases such as osteoarthritis, rheumatic arthritis, coronary heart disease, chronic obstructive pulmonary disease, sequelae after stroke, chronic kidney disease, and liver cirrhosis were excluded to ensure a healthy study sample. The impact of these diseases on upper extremities function, especially the arms and hands, has been shown in previous studies (35, 36). The study was conducted according to the World Medical Association Declaration of Helsinki and was approved by the ethics committee, Iran University of medical science (IR.IUMS.REC 1396.32516).

**Anthropometric measurements**

All measurements were obtained in a separate room dedicated to the school health supervisor during the school day from 8 to 12 AM. Age of participants was recorded from their academic records. Body mass was measured to the nearest 0.1 kg by a digital balance (Toledo, Model 2096PP/2, Inc., Brazil). Stature was measured for each subject using the Holtain Harpenden stadiometer (Holtain, Crosswell, UK). Body mass index was calculated in kg/m\(^2\).

A set of 17 hand-forearm anthropometric dimensions were measured for each student. Definitions and methods used for measurement correspond to the ISO7250:1997 (ISO, 2008). Description of anthropometric measurements as well as their relative landmarks are presented in Table 1 and Fig. 1,
respectively. Garrett et al. (1971) showed that wrist crease is the best landmark for easy identification of hand dimensions. Thus, the right hand is held out horizontally such that the palm faced upwards and the fingers are extended. When whole measurements are to be taken, the fingers are kept close together (adducted) to measure individual fingers length (38). These hand dimensions were measured with an accurate JEGS digital caliper (Model: 80519, Columbus, OH 43211, USA; ±0.01 mm) and a tape measure (HaB Essentials SKU: LCR01; ±0.1 cm). Measurements were repeated twice for each hand. The average of the two values for each dimension was calculated and recorded for analysis. All participants were wearing light clothing during measurements and were asked to remove heavy outer garments and jewelry. Also, proper care has been taken to avoid any excessive compression of the underlying tissues and to record the measurement precisely during the measurement.
Table 1
Description of hand-forearm dimensions measured in the study

| Hand-forearm dimension       | Definitions                                                                 |
|------------------------------|-----------------------------------------------------------------------------|
| 1) Hand length               | • The distance from the base of the hand to the top of the middle finger measured along the long axis of the hand. |
| 2) Palm length               | • The distance from the base of the palm to the base of the middle finger (at the palmar surface). |
| 3) Hand breadth across thumb | • The breadth of the hand measured at the level of the distal end of the first metacarpal of the thumb. |
| 4) Hand breadth metacarpal   | • The breadth of the hand as measured across the distal ends of the metacarpal bones. |
| 5) Hand circumference        | • The close measurement that follows a hand contour at the maximum palm level. |
| 6) Fist length               | • Length of the hand grip in the same line of the long axis of the hand from the base of the palm to the tip of the fist, wherever found. |
| 7) Fist circumference        | • Maximum circumference of the fist, wherever found, encompassing the knuckles of the middle finger and the thumb. |
| 8) Maximum internal grip diameter | • The measured by sliding the hand down a graduated cone until the tips of the thumb and the middle finger remain touched to each other |
| 9) Thumb length (digit 1)    | • The distance from the tip of the thumb to its proximal crease. |
| 10) Index finger length (digit 2) | • The distance from the tip of the index finger to its proximal crease. |
| 11) Middle finger length (digit 3) | • The distance from the tip of the middle finger to its proximal crease. |
| 12) Ring finger length (digit 4) | • The distance from the tip of the ring finger to its proximal crease. |
| 13) Pinky finger length (digit 5) | • The distance from the tip of the pinky finger to its proximal crease. |
| 14) Hand depth               | • The maximum depth from the volar side of the thenar pad to the dorsal surface of the hand (Hand is extended with palm facing down; fingers are close together with the thumb held against the side of the hand) |
| 15) Wrist circumference      | • This dimension is measured using a tape measure, which is wrapped around the bony part of wrist, snug but not tight. |
| 16) Forearm Length           | • The distance between radial styloid process and lateral humeral epicondyle. |
| 17) Forearm Circumference    | • The circumference of the forearm at the point of maximum prominence, slightly distal to the elbow joint. |

HGS and PSs Measurements
Handgrip and PSs (tip to tip, key, and three-jaw chuck pinches) strengths were measured with a Jamar hydraulic hand dynamometer and pinch gauge (Model 5030J1, Sammons Preston Rolyan, Bolingbrook, IL, USA) according to the recommendation of the American Society of Hand Therapists (ASHT) (39).

For standardization, the dynamometer was set at the second handle position for measurement of handgrip strength (13). Before starting the test, hand dominance was determined by asking participants the following question: "Which hand do you write with? ". Handgrip and then pinch strengths were measured while students were seated with feet on the floor, arms hanging relaxed at the side and neutrally rotated, elbows flexed 90 degrees, and forearm and wrist in neutral position (0–15 degrees of extension and 0–15 degrees of ulnar deviation) (40, 41). In all the cases, the forearm
and arm were not supported by the examiner or by an armrest. Students were asked to squeeze the handle of the dynamometer as well as the pinch gauge button as hard as they can and to sustain the effort for 3 seconds. Verbal encouragement was provided to ensure maximal effort during each test. The readings were recorded from three trials for each hand, and the average of the three values was considered as the HGS and PSs (tip to tip, key, and three-jaw chuck pinches) values for subsequent analyses. These procedures have been previously well documented as reliable (42, 43). The calibration of instruments was tested periodically during the study according to the manufacturer’s manual. The dynamometer and pinch gauge were set to zero kg before each measurement.

Data analysis
Statistical analysis was performed by SPSS 23 (IBM Corporation, New York, NY, United States). In the beginning, normality test was carried out using the one-sample Kolmogorov-Smirnov (K-S) test and confirmed for all data sets. Test-retest reliability was analyzed using interclass correlation coefficient (ICC). Independent sample t-test was carried out to determine the HGS and PSs differences between boys and girls students. Paired t-tests were performed to compare the handgrip and pinch (tip to tip, key, and three-jaw chuck) strengths of both hands (dominant vs. non-dominant hand). One-way ANOVA test was used to compare dominant and non-dominant hand strengths (HGS and PSs), allocated according to age groups and gender. The Tukey post-hoc test in separate analyses of variances was used to examine differences between specific age groups for both genders. Pearson’s correlation coefficient test was used to determine the correlations of the hand-forearm anthropometric and demographic variables with HGS and three pinches values.

SMART-PLS 3.0 software was additionally used to determine the possible correlations between anthropometric/demographic measures and hand strengths (HGS and PSs) outcomes in a multivariate approach, which has advantages over regression-based methods in evaluating several independent (manifest) variables with various dependent (latent) variables (44). This fact underlines that the most essential part of a PLS analysis is the estimation of the weight relations. Of course, it would be easier simply to assume equal weights for all variables, but this approach has two disadvantages: First, there is no theoretical rationale for all indicators to have the same weighting. Because it can be
assumed that the resulting parameter estimates of the structural model depend on the type of weighting used, at least as long as the number of indicators is not excessively large (45). Second, as Chin et al. (2003) stressed, such a procedure does not take into account the fact that some indicators may be more reliable than others and should, therefore, receive higher weights (46). For this purpose, four different types of hand strengths (HGS and tip to tip, key, and three-jaw chuck pinches) were considered as dependent variables, while independent variables were hand-forearm anthropometric measures. Based on the PLS method, items which had a factor loading greater than 0.25 were selected as the most important variables to explain the majority of the total variance of the model (47). The significance level was set at 0.05.

Results

Demographic and hand-forearm anthropometric data

Demographic information including age, gender, hand dominance, and hand-forearm anthropometric characteristics of the study participants are shown in Tables 2 and 3. The sample consisted of 2637 healthy children and adolescents students-aged 7–18 years including 1391 (52.7%) boys and 1246 (47.3%) girls. Right-hand dominance was reported by 2506 (95%) students comprising 1319 (50%) boys and 1187 (45%) girls. None of the students reported ambidexterity.

Results of test-retest reliability were analyzed from 80 participants out of whole sample. Participants showed high to very high test-retest reliability for Jamar dynamometer (0.84 ≤ ICC ≤ 0.96; P ≤ 0.001) and pinch gauge (0.86 ≤ ICC ≤ 0.92; P ≤ 0.001).
| Age (years) | N  | Boys | Girls |
|------------|----|------|-------|
|             |    | Dominant Hand | Dominant Hand |
|             |    | Right | Left | Right | Left |
| 7          | 230| 126   | 5    | 104   | 4    |
| 8          | 213| 110   | 7    | 103   | 5    |
| 9          | 235| 125   | 4    | 110   | 5    |
| 10         | 223| 116   | 5    | 107   | 7    |
| 11         | 208| 108   | 3    | 100   | 4    |
| 12         | 212| 116   | 6    | 96    | 4    |
| 13         | 218| 114   | 7    | 104   | 1    |
| 14         | 218| 107   | 4    | 111   | 6    |
| 15         | 208| 109   | 7    | 99    | 4    |
| 16         | 226| 118   | 8    | 108   | 4    |
| 17         | 224| 120   | 9    | 104   | 8    |
| 18         | 222| 122   | 7    | 100   | 7    |
| **Total**  | 2637| 1391 | 1319 | 72    | 1246 | 1187 | 59  |

N: number of participants per age group.
n: number of participants per gender.
| Variable                              | Boys (n = 1391) | Girls (n = 1246) |
|--------------------------------------|----------------|-----------------|
|                                      | Mean ± SD      | Min-Max         |
| Age (years)                          | 13.2 ± 3.7     | 7-18            |
| Stature (cm)                         | 158.1 ± 9.1    | 108-193         |
| Weight (kg)                          | 54.4 ± 8.5     | 24.1-84.3       |
| BMI                                  | 23.5 ± 9.0     | 18.8-34.8       |
| Hand length (cm)                     | 17.6 ± 1.1     | 11.8-21.6       |
| Palm length (cm)                     | 9.5 ± 0.8      | 7.1-12.0        |
| Hand breadth across thumb (cm)       | 8.6 ± 0.66     | 6.7-10.3        |
| Hand breath metacarpal (cm)          | 7.1 ± 0.51     | 5.4-8.1         |
| Hand circumference (cm)              | 19.5 ± 1.9     | 14.7-23.4       |
| Fist length (cm)                     | 8.3 ± 0.68     | 6.4-10.2        |
| Fist circumference (cm)              | 22.4 ± 1.5     | 13.5-27.2       |
| Maximum Internal grip diameter (cm)  | 3.3 ± 0.55     | 1.8-4.6         |
| Thumb length (digit 1) (cm)          | 5.2 ± 0.49     | 4.1-6.3         |
| Index finger length (digit 2) (cm)   | 6.4 ± 0.43     | 5.3-7.8         |
| Middle finger length (digit 3) (cm)  | 7.0 ± 0.46     | 5.8-8.4         |
| Ring finger length (digit 4) (cm)    | 6.6 ± 0.51     | 4.8-7.5         |
| Pinky finger length (digit 5) (cm)   | 5.4 ± 0.48     | 4.2-6.5         |
| Hand depth (cm)                      | 4.2 ± 0.40     | 2.8-5.3         |
| Wrist circumference (cm)             | 15.2 ± 1.3     | 10.9-19.8       |
| Forearm Length (cm)                  | 22.1 ± 1.6     | 17.8-26.9       |
| Forearm Circumference (cm)           | 23.2 ± 1.4     | 14.5-29.6       |

Table 4 shows the mean values for HGS, tip to tip, key, and three-jaw chuck pinches of the study population by gender, age group, and hand dominance. The ANOVA results showed significantly different levels of HGS and PSs outcomes in terms of the age group of participants in both genders (p < 0.05). According to the Tukey’s post hoc tests, boys and girls students in any age group exerted significantly higher levels of HGS as well as tip to tip, key, and three-jaw chuck pinches compared to their predecessor age group (p < 0.01). Boys of 11-14 and 15-18 years were stronger and had greater handgrip and pinch strengths than their girls peer groups (p < 0.001). Grip and pinch outcomes were marginally higher in 7-10 years boys compared to the girls of the same age range, but the differences were not statistically significant. More precisely, the average of girls’ HGS in 7-10, 11-14, and 15-18 years age groups were approximately 84%, 79%, and 60% of boys. Also, the average of girls’ tip to
tip, key, and three-jaw chuck pinches were approximately 84.4%, 82.2%, and 88.5% of boys, respectively. Among different types of pinch, the key pinch produced the greatest strength followed by the tip to tip and three-jaw chuck pinches, whatever the gender and hand dominance. Hand dominance had a significant effect on HGS and PSs outcomes (p < 0.001). The dominant HGS was greater than that of the non-dominant HGS by about 8% for both genders. Further, tip to tip, key, and three-jaw chuck pinches were significantly higher for the dominant, vs. non-dominant hand (about 9.3%, 10.5%, and 11.1% within boys and about 11.1%, 10.9%, and 10.4% within girls, respectively). The dominant hand tip to tip, key, and three-jaw chuck pinches exerted by boys’ students were 17.5%, 21.3%, and 13.2% higher than those exerted by girls, respectively. These values for the non-dominant hand tip to tip, key, and three-jaw chuck pinches exerted by boys’ students were 19.4%, 21.8%, 12.5% higher than of those exerted by girls, respectively.
| Age group (years) | Number | Hand | HGS Tip to tip | Key three-jaw chuck |
|------------------|--------|------|----------------|--------------------|
| **Boys**         |        |      |                |                    |
| 7-10             | 451    | D    | 12.8 ± 2.6 (7.1-19.3) | 3.3 ± 0.8 (1.6-4.8) | 5.1 ± 1.0 (3.2-6.7) | 4.1 ± 0.8 (1.8-6.4) |
|                  |        | ND   | 11.7 ± 2.4 (6.6-18.7) | 3.1 ± 0.8 (1.5-4.2) | 4.7 ± 0.9 (3.3-6.5) | 3.7 ± 0.9 (1.9-5.7) |
| 11-14            | 435    | D    | 24.1 ± 4.2 (13.4-37.0) | 4.5 ± 1.0 (2.8-6.1) | 7.3 ± 1.0 (5.0-9.2) | 6.1 ± 1.1 (3.2-8.4) |
|                  |        | ND   | 22.4 ± 4.2 (13.0-33.7) | 4.1 ± 1.2 (2.7-5.8) | 6.6 ± 1.2 (4.3-9.0) | 5.4 ± 1.2 (3.0-7.8) |
| 15-18            | 505    | D    | 39.5 ± 4.0 (29.3-48.7) | 6.2 ± 1.5 (3.9-8.1) | 9.8 ± 1.5 (7.1-11.3) | 8.0 ± 1.4 (4.8-10.1) |
|                  |        | ND   | 36.8 ± 4.2 (27.3-45.1) | 5.6 ± 1.4 (3.1-7.6) | 8.7 ± 1.4 (7.3-10.2) | 7.1 ± 1.4 (5.0-9.7) |
| **Total**        | 1391   | D    | 25.5 ± 3.6 (7.1-48.7) | 4.7 ± 1.0 (1.6-8.1) | 7.4 ± 1.1 (3.2-11.3) | 6.0 ± 1.1 (1.8-10.1) |
|                  |        | ND   | 23.6 ± 3.3 (6.6-45.1) | 4.3 ± 1.1 (1.5-7.6) | 6.7 ± 1.2 (3.3-10.2) | 5.4 ± 1.0 (1.9-9.7) |
| **Girls**        |        |      |                |                    |
| 7-10             | 357    | D    | 11.3 ± 2.7 (6.1-18.4) | 3.1 ± 0.8 (1.4-4.1) | 4.6 ± 1.0 (3.0-6.2) | 3.9 ± 1.0 (1.8-5.6) |
|                  |        | ND   | 10.2 ± 2.9 (5.3-17.8) | 2.8 ± 0.9 (1.3-3.7) | 4.1 ± 0.9 (2.9-5.8) | 3.5 ± 0.9 (1.9-5.3) |
| 11-14            | 421    | D    | 18.9 ± 3.7 (12.7-27.5) | 4.1 ± 1.0 (2.5-5.6) | 6.3 ± 1.2 (4.3-8.8) | 5.5 ± 1.1 (3.8-7.7) |
|                  |        | ND   | 17.8 ± 3.4 (13.0-29.2) | 3.7 ± 1.1 (2.6-5.2) | 5.7 ± 1.1 (4.5-8.0) | 4.9 ± 1.0 (3.2-8.0) |
| 15-18            | 468    | D    | 23.7 ± 3.3 (17.7-30.4) | 4.8 ± 0.9 (2.9-6.3) | 7.6 ± 1.2 (4.6-9.4) | 6.5 ± 1.0 (4.3-9.1) |
|                  |        | ND   | 22.1 ± 3.4 (16.5-29.8) | 4.3 ± 0.8 (2.6-6.0) | 6.8 ± 1.3 (4.9-9.0) | 5.8 ± 1.1 (3.9-8.6) |
| **Total**        | 1246   | D    | 17.8 ± 3.0 (6.1-30.4) | 4.0 ± 0.9 (1.4-6.3) | 6.1 ± 1.1 (3.0-9.4) | 5.3 ± 1.0 (1.8-9.1) |
|                  |        | ND   | 16.5 ± 3.1 (5.3-29.8) | 3.6 ± 0.9 (1.3-6.0) | 5.5 ± 1.1 (2.9-9.0) | 4.8 ± 1.0 (1.9-8.6) |

Data are Means ± SD (Minimum–Maximum).

**Correlation analysis**

Table 5 shows the Pearson’s correlation coefficients of the study variables. It was found that the correlations between 17 hand-forearm anthropometric dimensions and demographic factors with HGS are statistically significantly different from zero except fist circumference (r = 0.032; judged at p < 0.05, 2-tailed) and hand depth (r = 0.108; judged at p < 0.05, 2-tailed). The strongest correlations were found between the hand length and all types of hand strengths (0.845, 0.876, 0.892, and 0.835...
for handgrip, tip to tip, key, and three-jaw chuck pinches, respectively; p < 0.01, 2-tailed). This was followed by the correlations of the stature and forearm length with HGS and PSs measurements (with the correlation coefficients being generally above 0.7). Moreover, there were significant correlations between different pinch types with demographic variables and some hand-forearm dimensions (age, stature, weight, BMI, hand length, hand circumference, thumb length, index finger length, middle finger length, wrist circumference, forearm length, and forearm circumference).
| Variables | HGS | Tip to tip | Key (lateral) | Palmar |
|-----------|-----|------------|---------------|--------|
| Age       | r   | p          | r  | p          | r   | p          | r   | p          |
| Stature   | 0.697** | 0.000 | 0.623** | 0.000 | 0.630** | 0.000 | 0.662** | 0.000 |
| Weight    | 0.787** | 0.000 | 0.783** | 0.000 | 0.765** | 0.000 | 0.755** | 0.000 |
| BMI       | 0.351** | 0.000 | 0.411** | 0.000 | 0.428** | 0.000 | 0.383** | 0.000 |
| Hand length | 0.335** | 0.001 | 0.331** | 0.001 | 0.316** | 0.001 | 0.307** | 0.001 |
| Palm length | 0.845** | 0.000 | 0.876** | 0.000 | 0.892** | 0.000 | 0.835** | 0.000 |
| Hand breadth across thumb | 0.363** | 0.000 | 0.161 | 0.165 | 0.137 | 0.229 | 0.171 | 0.153 |
| Hand breadth metacarpal | 0.443** | 0.000 | 0.154 | 0.176 | 0.117 | 0.277 | 0.139 | 0.230 |
| Hand circumference | 0.361** | 0.000 | 0.317** | 0.001 | 0.376** | 0.000 | 0.351** | 0.000 |
| Fist length | 0.301** | 0.001 | 0.188 | 0.155 | 0.171 | 0.231 | 0.109 | 0.334 |
| Fist circumference | 0.032 | 0.361 | 0.047 | 0.310 | 0.127 | 0.246 | 0.097 | 0.360 |
| Maximum internal grip diameter | 0.563** | 0.000 | 0.117 | 0.293 | 0.145 | 0.209 | 0.107 | 0.333 |
| Thumb length (digit 1) | 0.582** | 0.000 | 0.521** | 0.000 | 0.672** | 0.000 | 0.664** | 0.000 |
| Index finger length (digit 2) | 0.475** | 0.000 | 0.265* | 0.010 | 0.247* | 0.018 | 0.272* | 0.009 |
| Middle finger length (digit 3) | 0.478** | 0.000 | 0.320** | 0.001 | 0.318** | 0.001 | 0.302** | 0.001 |
| Ring finger length (digit 4) | 0.245* | 0.015 | 0.133 | 0.209 | 0.145 | 0.194 | 0.127 | 0.231 |
| Pinky finger length (digit 5) | 0.210* | 0.025 | 0.143 | 0.220 | 0.165 | 0.151 | 0.176 | 0.142 |
| Hand depth | 0.108 | 0.331 | 0.122 | 0.282 | 0.100 | 0.353 | 0.087 | 0.378 |
| Wrist circumference | 0.393** | 0.000 | 0.251* | 0.012 | 0.237* | 0.020 | 0.206* | 0.030 |
| Forearm Length | 0.745** | 0.000 | 0.771** | 0.000 | 0.727** | 0.000 | 0.707** | 0.000 |
| Forearm Circumference | 0.433** | 0.000 | 0.203* | 0.030 | 0.241* | 0.006 | 0.210* | 0.023 |

*Correlation is significant at the 0.05 levels (2-tailed).
**Correlation is significant at the 0.01 levels (2-tailed).
Bold numbers are significant at the 0.01 or 0.05 levels (2-tailed).

Prediction of HGS and PSs strengths

Based on the PLS analysis, only one factor was extracted which explained 46.14% and 58.81% of the
total variance for the independent (hand-forearm dimensions) and dependent (handgrip and pinches) variables, respectively. The extracted dependent factor was correlated to the HGS, tip-to-tip pinch, and key pinch, three-jaw chuck pinch strengths, with the coefficients of 0.63, 0.51, 0.47 and 0.54, respectively. PLS factor loadings for the independent variables were compared in Fig. 2. Accordingly, hand length, hand circumference, thumb length, index finger length, middle finger length, forearm length had considerable factor loadings of > 0.25 in the extracted factor.

To estimate of internal consistency in the PLS approach, Cronbach’s and item-delete Cronbach’s are used for the extracted factor and each item, respectively (Table 6). The extracted factor had good internal consistency in the present study (The internal consistency is excellent if , and good if 0.7 (48). According to the results of the analysis, if items (M2), (M7), and (M14) are deleted, Cronbach’s of the corresponding factor increases slightly.

**Table 6**  
*Internal consistency of factors*

| Cronbach’s | Item                               | Cronbach’s if item is deleted |
|------------|------------------------------------|-------------------------------|
| 0.885      | (M1) Hand length                   | 0.877                         |
|           | *(M2) Palm length                  | 0.894                         |
|           | (M5) Hand circumference            | 0.861                         |
|           | *(M7) Fist circumference            | 0.888                         |
|           | (M9) Thumb length (digit 1)        | 0.875                         |
|           | (M10) Index finger length (digit 2)| 0.869                         |
|           | (M11) Middle finger length (digit 3)| 0.866                        |
|           | *(M14) Hand depth                  | 0.891                         |
|           | (M15) Wrist circumference           | 0.875                         |
|           | (M16) Forearm Length               | 0.862                         |
|           | (M17) Forearm Circumference        | 0.879                         |

* Cronbach’s [] increases if item is deleted.  
Bold values indicate 0.7 ≤ Cronbach’s [] < 0.9.

Discussion

Measurements of the handgrip and pinch strengths are convenient means to evaluate forearm and hand function. They can also be used to gauge the need for further physiotherapy during hand rehabilitation. The present study was conducted to determine the effects of hand-forearm anthropometric and demographic components on handgrip strength (HGS) and three pinch strengths including tip to tip, key, and three-jaw chuck measurements among healthy school-aged children and adolescents and to investigate the extent to which hand-forearm anthropometric components can be used to predict hand strength.

Influence of age, gender, and handness on hand strengths

We identified a linear increase in handgrip and pinch strengths of both hands associated with
advancing age in boys and girls, in agreement with previous studies (10, 49). This could be due to an exponential progression in muscle strength along with a rise in androgen hormones of both genders in pubertal years (50). Considering gender and age, the present results showed almost similar handgrip and pinch strengths between boys and girls in 7-10 years age group when dominant or non-dominant hands were tested. This was consistent with the results of previous studies which found no differences in hand strengths between boys and girls until 10 years of age (10, 51). Consistent with the review conducted by Omar et al. (2015), boys were stronger than girls, particularly after 11 years of age (52). The onset of puberty, the period characterized by height gain and alterations in body composition, occurs about two years earlier in girls compared to boys. The body composition of boys and girls is similar before this period. During puberty, adipose deposition predominates in girls, whereas muscle mass increases in boys (53). This divergence may explain the differences in hand strengths between genders after puberty. This hypothesis is supported by the fact that fat-free mass of muscle is one of the variables that has the greatest influence on handgrip and pinch strengths (54, 55). Some studies also suggested that an increase in the testosterone of boys during puberty (56), muscle fiber type variability and neural adaptations in males (57), and higher usage of thenar muscles by males during sport and daily activities are known as factors for the gender-related differences (58).

The results of this study showed that hand dominance was a statistically significant factor in determining hand strength for the whole sample, a fact also reported in the literature (20, 49). This is consistent with the findings of Sartorio et al. (2002) and Omar et al (2018), which showed that the strength of the dominant hand was stronger than that of the non-dominant hand among children and adolescents (21, 59). It is interesting to note that the hand strengths differences between the dominant and non-dominant hands were generally similar in boys and girls studied. The present finding is consistent with previous study performed by Ng et al. (2019) who reported that there is almost similar strength difference between the dominant and non-dominant hands of boys and girls (60). The percentage differences between the two sides can be calculated and used to determine the degree of rehabilitation required. Furthermore, hand strengths (HGS and PSs) were positively
correlated with stature, weight, and BMI, where these results have been supported by Jurimaea et al. (14) and Rauch et al. (61). These relationships may explain the higher hand strengths observed in the school-aged children with higher weight and BMI.

Relationship between hand-forearm anthropometric and handgrip and pinch strengths

The present study reaffirms that hand size can be an important factor influencing handgrip and pinch strengths of children and adolescents. This finding is in more consistent with the results of Rostamzade et al. (2019), Boadella et al. (2005), and Gunther et al. (2008) studies, who found a correlation between hand length, hand breadth, forearm circumference with handgrip strength in healthy adults of different nations (26, 62, 63). Among the finger lengths that were measured, thumb length, index finger length, and middle finger length showed also strong correlations with all the three pinch outcomes of both sides. These findings were supported by the results of PLS analysis, which showed higher loading of these components compared to the others. However, it should be noted that in addition to these six anthropometric dimensions, there were two other anthropometric dimensions that had considerable loadings in the PLS analysis, which together accounted for 46% of total variance. One advantage of the PLS analysis is that it can be used as a method to identify more effective factors on dependent variables. In other words, when prediction is the goal and there is no practical need to limit the number of measured factors, PLS can be a useful tool (48). Therefore, the results from this method provide a detailed understanding of the relationship between anthropometric traits and hand strengths (HGS and PSs). These findings can be used to establish predictive models for HGS and PSs, practical implications for the design of hand tools and stationeries, determine efficacy of rehabilitation, and assess the integrity of upper limb functions.

This study had a number of strengths. First, it was performed using a large sample of school-aged children and adolescents. Second, it used the standard protocols for handgrip and pinch strengths, hand-forearm anthropometric assessment as well as data monitoring processes during data collection, data entry and data analysis in order to minimize the risk of bias. Moreover, to the best of the authors’ knowledge, this study may be the first to investigate the relationship of 17 hand-forearm anthropometric dimensions with handgrip and pinch strengths among children and adolescents in
Asia. However, it should be noted that this study is somewhat limited because it was cross-sectional in design, so the presence or otherwise of a causal relationship could not be established. In addition, some variables such as nutritional status, physical activity, and maturity stages were not considered, which may be a limitation due to the potential for misreporting.

**Conclusion**

According to our findings, it can be concluded that ascending variability of the hand strengths (handgrip and pinches) in healthy children and adolescents can be explained by age, gender, handedness, and hand-forearm dimensions such as hand length and forearm length. A reference equation could be established based on these hand-forearm dimensions and demographic variables. These results can be used by health professionals in the clinical applications and hand rehabilitation as well as by designers to design hand tools and stationeries that should be balanced properly based on hand anthropometric dimensions. It can be argued that low hand strengths among children and adolescents warrants particular attention in order to identify the root cause, especially if there is no proportionality between the size of the hand tools and stationeries with the hand-forearm anthropometric dimensions.

**Abbreviations**

PLS: Partial least squares; HGS: Handgrip strength; PSs: Pinch strengths; ICC: Interclass correlation coefficient; D: Dominant; ND: Non-dominant

**Declarations**

**Abbreviations**

PLS: Partial least squares; HGS: Handgrip strength; PSs: Pinch strengths; ICC: Interclass correlation coefficient; D: Dominant; ND: Non-dominant

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**Authors’ Contribution**

Study concept and design: Sajjad Rostamzadeh, Shahram Vosoughi, Ali Asghar Farshad
Acquisition of data: Sajjad Rostamzadeh
Analysis and interpretation of data: Sajjad Rostamzadeh, Leila Janani
Drafting of the manuscript: Sajjad Rostamzadeh, Mahnaz Saremi, Bruce Bradtmiller
Critical revision of the manuscript for important intellectual content: Shahram Vosoughi, Mahnaz Saremi.

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**Availability of data and materials**

Data are not publicly available. These study data were not anonymous. Due to sensitive nature of the data and privacy and confidentially guidelines, the data must be housed in a secured lab and cannot be made publicly available.

**Ethics approval and consent to participate**

This study was a voluntary survey that provided respondents privacy and confidentially. Parents and children provided their written consent to participate. Iran University of Medical Sciences Ethics Board approved the consent and study procedures.

**Consent for publication**

Not Applicable.

**Competing interests**

The authors declare that they have no competing interest.

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Figures
Figure 1
Hand-forearm anthropometric relative landmarks

Figure 2
Factor loadings results from PLS for the independent (17 hand-forearm anthropometric) variables. Note: M1) Hand length; M2) Palm length; M3) Hand breadth across thumb; M4) Hand breath metacarpal; M5) Hand circumference; M6) Fist length; M7) Fist circumference; M8) Maximum Internal grip diameter; M9) Thumb length; M10) Index finger length; M11) Middle finger length; M12) Ring finger length; M13) Pinky finger length; M14) Hand depth; M15) Wrist circumference; M16) Forearm Length; M17) Forearm Circumference.

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