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SHORT COMMUNICATION

Is the peak value truly maximal when measuring strength in young children? An updated study

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Objective: There is a lack of information about whether preschool-aged children are providing maximal attempts when measuring maximal strength. Therefore, this study aimed to investigate the association between handgrip strength and forearm muscle size across the age ranges, including children three years old.

Design and Methods: A total of 166 preschool children (87 boys and 79 girls) between the ages of 3.5 and 6.5 years were recruited from a local kindergarten with the cooperation of their parents. Maximum voluntary handgrip strength (HGS) was measured with the right hand using a Smedley handgrip dynamometer. Muscle thickness (MT-ulna) was measured using B-mode ultrasound at the anterior forearm of the right arm.

Results: All beta (B) coefficients are unstandardized. There was a statistically significant relationship ($r = 0.525$) between MT-ulna and HGS [B = 0.751 (95% CI: 0.563, 0.938) $p < 0.001$]. However, this relationship did not depend upon age [MT-ulna*Age in months: B = -0.0033 (95% CI: -0.01, 0.01), $p = 0.658$]. In other words, the strength of the relationship between MT-ulna and HGS did not vary by age in months. This was also true when age was expressed in years (MT-Ulna*Age in years: $p = 0.697$).

Conclusion: Our results indicated that the association between baseline forearm muscle size and HGS might provide suggestive evidence that children are maximally contracting. However, we acknowledge that this correlation analysis has significant limitations. Further research is needed to observe the association between these variables through longitudinal studies to confirm the results of this study.

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Key words: grip strength ■ muscle size ■ kindergarten ■ young children

INTRODUCTION

Handgrip strength (HGS) assessment is included in many health-related physical fitness testing batteries for children and adolescents.[1] Maximal HGS can help identify children and adolescents at risk for major public health problems such as the increased future risk for cardiovascular diseases and impaired skeletal health.[2,3] Considering the emerging physical inactivity detected among preschool-aged children and the future health problems that may be developed as a consequence, HGS measurement seems to be especially important in early childhood. Several studies investigated the normative values of HGS in young, healthy children, including three years old and younger,[4-6] and recommended methodological conditions and test-retest reliability of HGS in early childhood[4,7,8]. However, a study suggested that based on their clinical experience, it is generally too difficult to measure children as young as three years reliably.[9] Another study reported that children aged 5-6 could precisely adjust the different levels of HGS production as directed by an investigator, but children aged three could not do so at all.[10] These observations may be related to maturity (understanding the verbal instructions) and motivation (voluntary activation level) during strength tests.

In the upper portion of the anterior forearm, two major extrinsic flexor muscles of the fingers are located near the ulna, i.e., flexor digitorum profundus and flexor digitorum superficialis.[11] However, there are various shapes in those two muscles, and the boundary surrounding those two muscles is difficult to visualize with the imaging techniques.[12] Ultrasound-measured forearm muscle thickness of the ulna (MT) is closely associated with magnetic resonance imaging (MRI)-measured forearm flexor muscle cross-sectional area in healthy men and women.[13] Therefore, MT may be desirable when assessing the muscle size of the extrinsic forearm flexor muscle of the fingers. We recently investigated whether the relationship between MT and HGS depended upon age in young children between 4.5 and 6.5 years.[14] Our previous sample showed no moderating effect of age, suggesting that the relationship between MT and HGS did not differ across that age group. However, given the ages of children that have been measured in previous studies, it is necessary to determine the possibility of maximal strength measurement with children younger than our last sample. It is expected that there

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Table 1 Anthropometric variables, handgrip strength, and muscle thickness of the participants

	Pre-school grades		
Variables	First (Pre-K3)	Second (Pre-K4)	Third (Kindergarten)
N (girl, boy)	55 (22, 33)	56 (31, 25)	55 (25, 30)
Age (month)	48.2 ± 3.2	59.4 ± 3.5	72.2 ± 4.0
Height (cm)	99.8 ± 4.4	105.9 ± 4.3	113.3 ± 4.7
Body mass (kg)	15.9 ± 1.7	17.0 ± 2.2	19.8 ± 2.9
Body mass index (kg/m^2)	15.9 ± 1.0	15.1 ± 1.3	15.3 ± 1.4
Forearm length (cm)	13.3 ± 0.8	14.4 ± 0.9	15.5 ± 1.1
Forearm girth (cm)	16.5 ± 0.8	16.5 ± 1.1	17.2 ± 1.2
Hand length (cm)	12.9 ± 0.8	13.3 ± 0.8	14.3 ± 0.8
Palm length (cm)	6.5 ± 0.3	6.7 ± 0.4	7.2 ± 0.5
Handgrip strength (kg)	6.0 ± 2.1	8.4 ± 2.5	10.6 ± 1.7
Muscle thickness-ulna (cm)	2.07 ± 0.18	2.12 ± 0.18	2.26 ± 0.22

will be a relationship between baseline muscle thickness and HGS. We would also expect that maturity/ability to receive instruction would improve as children got older. Therefore, if the relationship between baseline muscle thickness and HGS depends upon age then that might suggest that another factor is contributing to HGS (this assumption is not without limitations). This study aimed to investigate the association between HGS and MT across the age ranges in preschoolers, including three-year-olds.

METHODS

Participants

This cross-sectional study included 166 Japanese preschool children (87 boys and 79 girls). The participants were recruited from a local kindergarten (Table 1). In Japan, children go to preschool from age 4 (pre-K3) to/until age 6 (kindergarten). The data collection took place between October 2021 and November 2021 at the kindergarten they attended. The inclusion criteria of this study were 1) children aged 3 to 6 years, 2) the parent or guardian gave their written informed consent, and 3) being in good health on regular physical examination. Few participants used their left hand or mixed hands to eat and write (n = 8). This study received approval from the University's Institutional Review Board (HSS #29-17 & SG #2021-2-2) and was conducted according to the World Medical Association Declaration of Helsinki.

Handgrip Strength Measurements

Maximum voluntary HGS was measured with the right hand using a Smedley handgrip dynamometer (TKK Grip-A, Niigata, Japan; ranges 0-30 kg strength and 2-5 cm grip span).[14] All participants were instructed to maintain an upright standing position to keep their arms at their sides. The participants held the dynamometer in the right hand with the elbow extended downward without squeezing. The distance of the dynamometer grip bars (grip span) was adjusted to the hand size of the participants (the middle phalanx rested on the inner handle), which ranged between 3.5 to 4.0 cm. Participants were allowed to perform one test trial and two maximal trials with a one-minute break. In addition, the tester provided verbal encouragement to all attempts to support their motivation and effort. The highest value achieved on the right side was used for analysis. Test-retest reliability (one week apart) of handgrip strength measurements in preschoolers (n = 13) was reported from our laboratory (unpublished observation); 0.815 for the intraclass correlation coefficient, 0.58 kg for standard error of measurement, and 1.60 kg for the minimal difference.

Forearm Muscle Thickness Measurements

Muscle thickness was measured using brightness-mode ultrasound (Logiq e; GE, Fairfield, CT, USA) on the anterior forearm at 30% proximal of forearm length (between the styloid process and the head of the radius) on the right side of the body. The measurements were made while the participants were seated on a chair with the right hand on a table at an elbow joint angle of approximately 40 degrees (0 degrees at full extension). A paper-coated expanded polystyrene board (7 mm thickness) was placed between the forearm and the table, and the four fingers except for the thumb and the palm were fixed to the board with elastic bands (palm up). A linear scanning head was coated with transmission gel and placed on the skin surface of the measurement site with the minimum pressure to achieve a clear image. Two images from the site were stored for offline analysis following data collection. To determine MT-ulna, muscle boundaries were manually determined by an experienced ultrasonographer (TA). MT-ulna was quantified as the distance between the subcutaneous adipose tissue-muscle interface and the muscle-bone interface of the ulna (Figure 1). The average value measured on two images was used for data analysis. Test-retest reliability of MT-ulna measurements was reported previously.[14]

Anthropometric measurements

Body mass and standing height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using a digital height and weight scale (DST-210S, Muratec KDS Corp, Kyoto, Japan). Body mass index was defined as body mass (kg) divided by

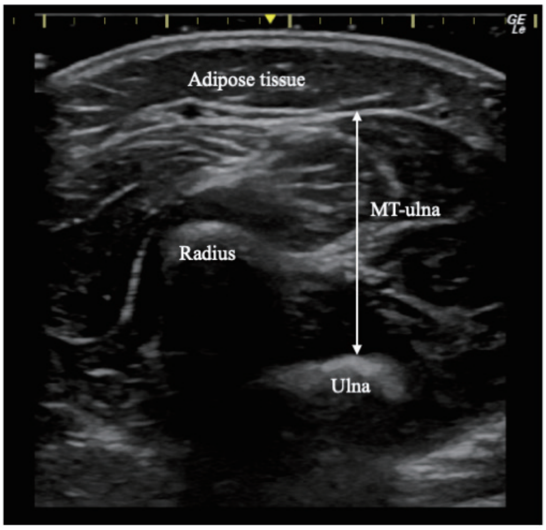

Figure 1 Typical ultrasound image (participant HM, 45 months old) showing transverse scan on the anterior forearm at 30% proximal between the styloid process and the head of the radius. MT = muscle thickness.

height squared (m^2). The forearm circumference of the right arm was measured at 30% proximal to the forearm length using a tape measure. Full hand length was measured as the linear distance between the distal wrist crease and the tip of the middle finger. Palm length was measured as the distance between the distal wrist crease and the midpoint of proximal flexion crease of the middle finger.[15]

Statistical Analysis

All statistical analyses were completed using jamovi (The jamovi project version 1.6.23). Linear regression was used to assess the relationship between MT-ulna and HGS. In addition, we added an interaction term (MT-ulna*age) to the model to assess whether age (in months) moderated the relationship between MT-ulna and HGS. Statistical significance was set at $p \leq 0.05$. All beta (B) coefficients are unstandardized.

RESULTS

There was a statistically significant relationship ($r = 0.525$) between HGS and MT-ulna [B = 0.751 (95% CI: 0.563, 0.938) $p < 0.001$]. However, this relationship did not depend upon age [MT-ulna*Age in months: B = -0.0033 (95% CI: -0.01, 0.01), $p = 0.658$]. In other words, the strength of the relationship between HGS and MT-ulna did not vary by age in months (Figure 2). This was also true when age was expressed in years (MT-Ulna*Age in years: $p = 0.697$). During the review process, we post-hoc assessed whether the relationship between HGS and MT-ulna depended upon forearm length. However, we were unable to find evidence that forearm length moderated the relationship between HGS and MT-ulna [MT-ulna* forearm length: B = -0.044 (95% CI: -0.161, 0.073), $p = 0.461$].

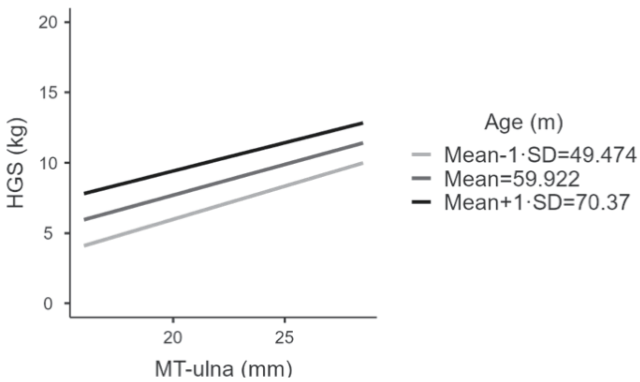

Figure 2 The relationship for the handgrip strength (HGS) and muscle thickness of the ulna (MT-ulna) across levels of the moderator (age in months). The individual lines represent different levels of the moderator with the light grey line representing 1 SD below above the mean, the dark grey line representing the average age in months, and the black line representing 1 SD above the mean.

DISCUSSION

This study examined the association between HGS and MT-ulna in preschool children, including those as young as three. We found a positive relationship between MT-ulna and HGS but this relationship did not depend upon age. In other words, the relationship between these two variables did not differ across age groups (age ranging from pre-school to kindergarten). These results broaden the age range of the previous study.[14]

As mentioned previously, the maximal voluntary HGS can help identify children and adolescents at risk for major public health problems.[2,3] Previous studies have evaluated the HGS in preschool-aged children, and the measurement of 3-year-olds was the youngest target.[4-6] However, some methodological difficulties have been pointed out in measuring HGS in early childhood.[9,10] One of the difficulties is to determine the level of voluntary activation during strength tests, which is essential in measuring maximum voluntary HGS. Furthermore, in order for preschool children to try maximal effort during the tests, they need to fully understand the instructions regarding the generation of muscular strength. Unfortunately, little attention has been paid to these difficulties during HGS tests in preschool-aged children.[4-8]

The twitch interpolation technique,[16] which superimposes an evoked contraction over a maximal voluntary contraction, is the gold standard for the noninvasive measurement of adults' maximal voluntary activation level. However, there are ethical concerns about using this technique in young children.[17] An alternative method is needed in order to provide support for the utility of maximal HGS testing in preschool-aged children. One method is to create a ratio between muscle size and strength but this assumes that dividing these two variables appropriately scales across different individuals. We suggest that testing the relationship between baseline muscle size and strength might provide suggestive evidence that children are maximally contracting.[14] For example, there is a known baseline relationship between muscle size and strength. We would expect that maturity/ability to receive instruction would improve as children got older. Therefore, if there was a difference in the relationships observed then that might suggest that another factor is contributing to HGS. We acknowledge that this has significant limitations and might best be used in combination with the researchers' subjective judgment. In other words, does the researcher perceive that the children understood the instructions and does it appear the children were giving maximal effort during the HGS test? This combination of quantitative and qualitative assessments might be something to consider in future research investigating this topic.

A study reported a clear association between HGS and ultrasound-measured MT-ulna in young men and women.[18] This study also found a significant relationship between the two parameters. However, the expected HGS using the ratio between HGS and forearm muscle size was quite lower in preschool-aged children (3.8 ± 1.2 kg/cm) compared to young men (12.1 ± 1.6 kg/cm) and women (9.7 ± 1.3 kg/cm) reported previously[19]. Notwithstanding the potential issues with using ratios, the difference in the HGS to MT ratio between children and adults may associate with the development of the nervous system, which supports the results of the previous studies.[14,20] In addition, it is hypothesized that children may have a substantially lower ability to entirely use higher threshold Type II motor units than adults.[21] However, it should be noted that the results obtained in the previous studies are only cross-sectional studies. In other words, it is unclear whether a cross-sectional comparison of the relationship between forearm muscle size and HGS in young children is consistent with the relationship between changes in strength and changes in muscle size obtained in longitudinal studies. Further research is needed.

In conclusion, our results showed that the association between HGS and ultrasound-measured MT-ulna did not depend upon age, although the two variables (i.e., HGS and MT-ulna) had a significant association. The relationship between baseline muscle size and strength might provide suggestive evidence that children are maximally contracting. However, we acknowledge that this has significant limitations and might best be used in combination with the researchers' subjective judgment (i.e. did the children understand the instructions and were they giving effort during the HGS test). Further research is needed to observe the association between MT-ulna and HGS through longitudinal studies to confirm the results of this study.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

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