Research Article

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Assessment of maximal isometric hand grip strength in school-aged children

Abstract: Background: Hand grip strength (HGS) test is commonly used as an indicator of overall muscle strength in medical and sport practices. Recently, several studies have proposed that the measurement of the maximal HGS depends on dynamometer's handle position. The aim of the present study was to identify the optimal handle position to obtain maximal HGS using the hand grip dynamometer (HGD) for school-aged children.

Methods: HGS was assessed with the Jamar digital HGD. Each participant performed three maximum contractions of each hand on three handle positions progressing from first to third position.

Results: A total of 135 healthy children aged 5–9 years participated in the study. Participants obtained significantly higher results using position 2 than using positions 1 or 3. The maximal mean (± SD) HGS achieved was 9.9 (± 3.1) kg with position 1, 10.4 (± 3.1) kg with position 2, and 9.0 (± 3.2) kg with position 3. Handle position 2 was the most comfortable position for 73% of participants.

Conclusions: Our results provide useful methodological information indicating that the second handle position of the Jamar digital HGD is optimal to measure maximal HGS in non-athletic healthy pediatric participants aged 5–9 years.

Keywords: Children; Dynamometry; Hand anthropometry; Hand grip strength; Muscle strength

1 Introduction

Hand grip strength (HGS) measurement is extensively used in many areas of medicine and sport science as a functional test of overall strength [1]. Grip strength is also used as an indicator of general health [2], nutritional status [3], and has been recently suggested as risk-stratifying method for all-cause death [4]. Widespread use of the isometric HGS test results from its practical utility and feasibility, such as availability and high reliability of the measurements [5]. Moreover, evaluating HGS using a hand-held dynamometer is noninvasive, inexpensive, and simple to implement [6,7].

One of the most popular and widely used dynamometers is the Jamar hand dynamometer [8]. In adults, this type of dynamometer is considered the gold standard instrument to measure maximal isometric HGS [8]. Specifically, it has five different handle positions. To avoid discrepancies between studies and to standardize the method to measure HGS in all adult participants, Trampisch et al. [9] recently recommended using handle position number 2 as the optimal one for the assessment of maximal HGS. To the best of our knowledge, only one study has examined which setting of the dynamometer is the most appropriate for pediatric participants to obtain maximal HGS [10]. Firrell and Crain found that almost 63% of examined children aged between 4 and 12 years had a maximal grip strength using the second position. Moreover, based on observed trend data, authors have indicated that maximal HGS at a setting less than or equal to the second position

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may be related to hand shape, i.e., to some hand dimensions [10]. Since then, no study has investigated whether the recommended position is the most appropriate for all pediatric participants to obtain maximal HGS using a dynamometer with fixed handle positions.

Therefore, the present study had two main aims. The first aim was to identify the optimal handle position to obtain maximal HGS using the Jamar digital dynamometer for preschool and primary school children. The second aim was to determine whether the hand shape, age, and/or sex affect the results in a selected numerous group of young participants.

2 Methods

2.1 Participants

A total of 135 participants of boys and girls who met typical developmental milestones between 5 and 9 years of age voluntarily participated in the study. The participants were divided into 2 groups using the following age ranges: age < 7 years – preschool children, and 7 ≤ age < 10 years – primary school children. The age classification was adopted from clinical findings [11]. All parents were asked about their children's training status and known upper-extremity impairments that could influence the HGS. Participants whose parents confirmed regular participation in athletic training (more than twice a week) and any upper-extremity disorders were excluded from this study. The participants and their parents were instructed that each child should refrain from intensive exercise the day before testing. A written description of the purpose of the study was provided to the participants and their parents/legal guardians. Informed written consent and assent forms were obtained from parents/legal guardians and their children, respectively. The study was approved by the University Bioethical Committee and followed the rules and principles of the Helsinki Declaration.

2.2 Study design

All measurements were performed in a quiet room in a primary school between 8 am and 2 pm. Firstly, the participants were informed about the measurement procedures. Secondly, body mass, body height, hand shape, and hand preference were recorded. Body mass and body height were measured according to standardized protocols with a precision of 0.1 kg and 0.1 cm, respectively [12]. Body mass

index (BMI) was calculated as body mass in kg divided by stature in meters squared (kg/m^2). The participant was measured in the standing position, without shoes, and wearing light clothes (underwear, pants, and a shirt). The hand preference was assessed by asking the participant which hand is used to hold a pen. Before the HGS measurements, all participants performed a warm-up exercise to familiarize themselves with a dynamometer: the familiarization involved grasping all handles. The participants were asked to try to adjust their grip to each handle, without squeezing. The appropriate examination of HGS started 5 min after the familiarization procedure.

2.3 Measurement of hand shape

Hand shape was defined as the ratio of hand width to hand length (W/L ratio) [13]. Participants were divided into three groups according to frequency distribution of the W/L ratio: relatively long-handed (LONG-h), average-handed (AVGE-h), and relatively square-handed (SQUARE-h). LONG-h and SQUARE-h groups corresponded to those below the lower (below 25th percentile) and above the upper (beyond 75th percentile) quartiles of the W/L ratio, respectively. The AVGE-h group represented the hand shape between the 25th and 75th percentiles.

Hand length was defined as the distance from the tip of the middle finger to the midline of the distal wrist crease. Hand width was defined as the distance between the radial side of the second metacarpal joint to the ulnar side of the fifth metacarpal joint [14]. The dimensions were measured with hand supinated on a table using an anthropometric tape measure to the nearest millimeter. All measurements were performed by the same investigator.

2.4 HGS measurement

The measurement was conducted according to standard procedures recommended by the American Society of Hand Therapists (ASHT) [15]. The participants sat upright on a height-adjustable chair with their feet supported. The tested arm was positioned on a table with the shoulders slightly abducted (~10°) and neutrally rotated, the elbow in 90° of flexion, the forearm in 0° between pronation and supination, and the wrist in neutral resting position [15]. The participants were instructed to maintain that position during the test.

The HGS of both hands was measured using the Jamar® Plus+ Digital Hand Dynamometer (Patterson Medical, Warrenville, IL, USA). Reliability of the Jamar

dynamometer was confirmed in many populations [16,17]. The Jamar included five different handle positions: I – 3.5 cm; II – 4.8 cm; III – 6.1 cm; IV – 7.3 cm; and V – 8.6 cm. Each participant performed three maximum voluntary contractions (tests) for each hand on three handle positions progressing from first to third position. The testing order was performed to replicate that of a previous study by Firrell and Crain [10]. The choice of the first three positions was dictated by the fact that during familiarization procedure most of the participants were not able to grasp fourth and fifth handle positions. Twelve children were able to grasp handle 4 and squeeze. Obtained results were nominally lower than obtained using the other handles, number 1 to 3.

The test always started with the dominant hand. A timed rest break of 30 s was given between each trial. Each hand received 1 min rest break before proceeding to the next handle size. Before each test, the verbal direction was given as follows: 'This task will measure your grip strength. The aim of the study is to check which handle position is appropriate to obtain your maximal hand grip strength'. Then the participants were asked to squeeze continuously for 2–3 s on a verbal statement: 'Squeeze as hard as you can!'. Children were instructed to stop squeezing when they felt pain or discomfort during measurement. The participants were encouraged to perform maximally during the tests. The display of the dynamometer was pointed toward the examiner, providing a measurement blinded to the participants. Finally, participants were asked which handle position was the most comfortable for them. All HGS measurements were performed by the same researcher. The HGS was measured in kg to one decimal point. The average of three tests was calculated and used in further analysis.

2.5 Statistical analysis

Statistical calculations were performed using the STATISTICA 12-StatSoft Inc. software (Tulsa, USA). All figures were created using Graph Pad Prism 5 (Graph Pad Software Inc., San Diego, CA, USA, 2005). Box-and-whisker figures represent means and SD. Data normality was assessed using the Kolmogorov-Smirnov test. To determine the effects of, and interactions between, one repeated measures factor: 'HAND DOMINANCE' (dominant and non-dominant) and two between-subject factors: 'AGE' (5–6-years-old – preschool children and 7–9-years-old – primary school children) and 'SEX' (boys and girls) on the W/L ratio ('HAND SHAPE'), the repeated-measures analysis of variance (ANOVA) was performed. To estimate the possible effects of, and interactions between, two repeated measures factors: 'HANDLE POSITION' (1, 2 and 3) and 'HAND DOMINANCE' (dominant and non-dominant) and three between-subject factors: 'AGE' (5–6-years-old – preschool children and 7–9-years-old – primary school children), 'SEX' (boys and girls) and 'HAND SHAPE' (LONG-h, AVGE-h and SQUARE-h) on maximal HGS, the repeated-measures ANOVA was conducted. Post-hoc comparisons used the Tukey HSD test. To determine the differences in the distribution of handle preference between participants a Chi-square test was conducted. The level of significance for all statistical analyses was accepted as $P < 0.05$.

3 Results

Of 135 participants, 122 were included in the statistical analysis. Thirteen children were excluded from the analysis due to regular participation in athletic conditioning more than twice a week (parental confirmation of reported events). During all testing, none of the participants complained of pain or discomfort during the measurements. A total of 92% of the participants were right-hand dominant and 8% were left-hand dominant. Detailed characteristics of the two groups: preschool children (5-6 years-old) and primary school children (7-9 years-old) are shown in Table 1.

Table 1: Detailed characteristics of the participants. Values are presented as mean ± SD.

	Preschool children			Primary school children		
	Boys	**Girls**	**Total**	**Boys**	**Girls**	**Total**
	(N = 37)	(N = 20)	(N = 57)	(N = 38)	(N = 27)	(N = 65)
Stature (cm)	114.6 ± 6.2	117.1 ± 5.3	115.4 ± 6.0	119.0 ± 5.3	116.5 ± 7.1	118.3 ± 6.2
Body mass (kg)	20.1 ± 2.7	20.5 ± 3.3	20.2 ± 2.9	24.1 ± 5.0	22.8 ± 4.1	23.6 ± 4.6
BMI (kg/m^2)	15.3 ± 1.3	14.9 ± 1.6	15.1 ± 1.4	16.7 ± 2.5	16.8 ± 2.3	16.7 ± 2.3

Abbreviation: N – number of participants

Based on a three-way ANOVA there were no significant interactions for the 'HAND SHAPE' (W/L ratio). Statistically significant independent effects of 'AGE' and 'SEX on the W/L ratio were observed. Preschool children presented significantly higher value of the W/L ratio than primary school children ($F(1, 122) = 5.17$, $P < 0.05$), i.e. the respective means (± SD): preschool children, 0.46 (± 0.02); primary school children, 0.45 (± 0.02). Boys presented significantly higher value of the W/L ratio than girls ($F(1, 122) = 4.04$, $P < 0.05$), i.e., the respective means (± SD): boys, 0.46 (± 0.01); girls, 0.45 (± 0.02). Based on the above results, the detailed characteristics of the W/L ratio for hand shapes for selected groups of participants are provided only for the dominant hand and presented in Table 2.

Based on a five-way ANOVA (factors: 'HANDLE POSITION', 'HAND DOMINANCE', 'AGE', 'SEX' and 'HAND SHAPE'), there were no significant interactions for maximal HGS. Statistically significant independent effects of 'HANDLE POSITION' and 'HAND DOMINANCE" on maximal HGS were observed ($P < 0.001$ for both). Participants obtained statistically higher results using position 2 than using position 1 or 3 ($F(2, 122) = 36.4$, $P < 0.001$). The

maximal mean HGS (± SD) achieved was 9.9 (± 3.1) kg with position 1, 10.4 (± 3.1) kg with position 2, and 9.0 (± 3.2) kg with position 3. Results of post-hoc analysis are presented in Figure 1.

Independently of other factors, higher results in HGS were obtained in the dominant hand ($F(2, 122) = 19.6$, $P < 0.001$) compared to the non-dominant hand. The maximal mean HGS for the dominant hand was 10.1 (± 3.3) kg, and for the non-dominant hand 9.5 (± 3.1) kg (Figure 2). A total of 73% of participants considered handle position 2 as the most comfortable for them, 18% handle position 1, and 9% handle position 3 ($P < 0.01$, χ^2).

4 Discussion

The HGS measurement is commonly used by professionals interested in hand strength and function in healthy populations and also in patients with various pathological conditions [8]. In most studies, a well-established standardized protocol concerning body positioning recommended by the ASHT was utilized [8]. The ASHT has
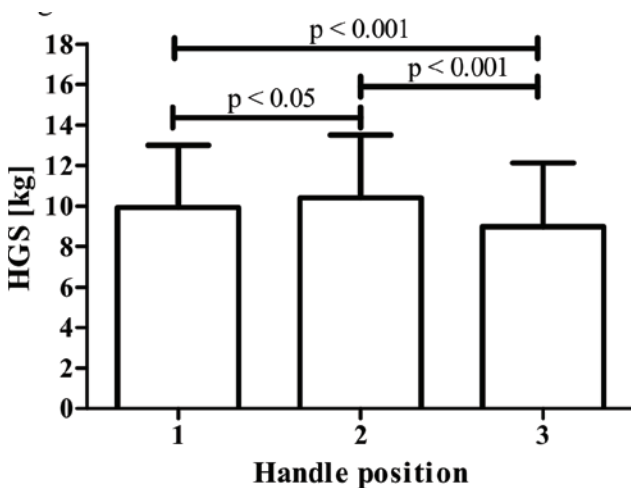

Figure 1: Comparison between the HGS achieved using each handle position. Box indicates mean, whereas the whiskers indicate SD.
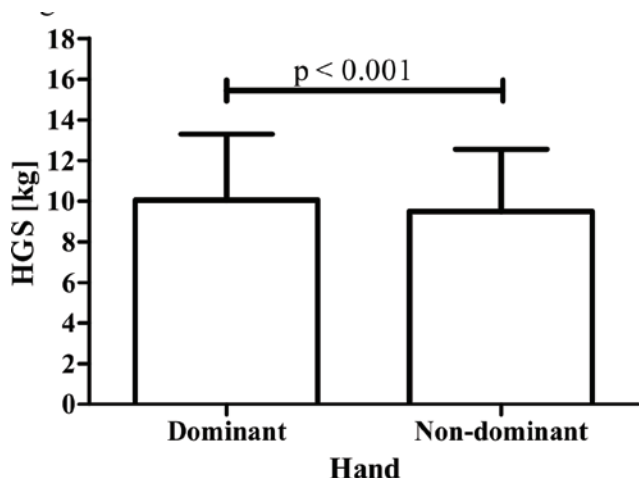

Figure 2: Comparison between dominant and non-dominant hand in the HGS. Box indicates mean, whereas the whiskers indicate SD.

Table 2: Mean W/L ratios, standard deviations, and ranges for the hand shapes for the dominant hand in groups of participants.

Mean ± SD		LONG-h		AVGE-h		SQUARE-h	
			Range		Range		Range
		Mean ± SD		Mean ± SD		Mean ± SD	
Preschool children	ALL	0.44 ± 0.01	0.41−0.45	0.46 ± 0.01	0.45−0.47	0.48 ± 0.01	0.47−0.51
	boys	0.44 ± 0.00	0.44−0.45	0.46 ± 0.00	0.45−0.47	0.49 ± 0.02	0.47−0.51
	girls	0.43 ± 0.02	0.41−0.45	0.46 ± 0.01	0.45−0.47	0.48 ± 0.01	0.47−0.48
Primary school children	ALL	0.42 ± 0.01	0.40−0.43	0.45 ± 0.01	0.44−0.46	0.47 ± 0.01	0.46−0.48
	boys	0.43 ± 0.01	0.42−0.43	0.45 ± 0.01	0.44−0.46	0.47 ± 0.01	0.46−0.48
	girls	0.42 ± 0.01	0.40−0.43	0.45 ± 0.01	0.44−0.46	0.47 ± 0.01	0.46−0.47

indicated the Jamar dynamometer as the gold standard to measure HGS [15]. Originally, it has five different handle positions. Few studies have been performed to investigate which position [9,10] or which grip span [18-20] is the most accurate to obtain maximal HGS in selected populations. As was emphasized by some authors, it could be expected that, e.g., young children may need a different optimal grip span/handle position than, e.g., teenagers or adults to achieve maximal HGS [21-23].

The results of our study show that the second handle position of the Jamar hand dynamometer is optimal to obtain maximal HGS in non-athlete pediatric participants with normal development. This observation applies to boys and girls aged 5 to 9 years old with long-, average-, and square-shaped hands for both the dominant and non-dominant hand. Most participants considered this handle position the most comfortable. Hand shape may vary depending on age or sex in childhood; however, there was no hand shape interaction with other variables nor with its independent effect on maximal HGS. Thus, the results indicate that the maximal HGS obtained using handle position 2 is unaffected by children's hand shape, estimated as the ratio of the hand width to hand length.

The HGS was tested in the order of handle position 1, 2, and then 3. We observed significant differences in HGS value between all positions. Nevertheless, there were no significant differences between testing trials in all positions independently (data not shown). All participants performed sufficient warm-up familiarization before and had adequate recovery between the HGS trials. The familiarization countered the learning effect and the recovery period was significant enough to reduce any fatigue. Therefore, significant changes in HGS value between handle positions should not influenced by the testing order.

Our results are supportive of the findings published by Firrell and Crain [10], who proposed that setting 2 should be routinely used to measure HGS in participants in a wide age range (4–78 years) irrespective of age, weight, or hand dimensions. In this group, there were 64 participants aged from 4 to 12 years; 63% of them had a maximal HGS using the second position. Authors indicated that maximal HGS at a setting equal to first or second position may be related to some hand dimensions, e.g., hand length, hand span, or their ratio. However, only a trend suggested that a smaller hand size is related to a higher maximal HGS at setting 1 or 2 was observed [10]. We performed measurements in more than a hundred pediatric participants between 5 and 9 years of age. Hand shape varied depending on age or sex in this population: older children and girls presented longer hands than younger children and boys, respec-

tively. We did not observe an interaction effect between hand shape and other variables nor its independent effect on maximal HGS. The results are also in accordance with recent recommendations for adults [9,10]. Trampisch et al. investigated an overall best handle position for measuring HGS using the Jamar Plus+ dynamometer and suggested the second one as a standard adjustment for all adults [9].

In the prior decade, a research group in Spain published several papers concerning test batteries of physical fitness in childhood and adolescence [22,24-28]. Researchers suggested, inter alia, that HGS test could be used to reliably assess musculoskeletal fitness in pediatric participants [22,27,28]. However, they made HGS measurements using an analogue dynamometer of different brand—the TKK dynamometer (Takei, Tokyo, Japan)—and performed tests using different positioning (standing position with elbow in full extension) [18,19,21]. The TKK dynamometer has the feature that the grip span can be adjusted, whereas other dynamometers, like Jamar, have five fixed positions [22]. Using the TKK dynamometer, the optimal grip span may be influenced by hand span [18,19]. The authors of those studies proposed an equation based on hand span that allows calculation of optimal grip span to obtain maximal HGS in children and teenagers [18,19]. The optimal grip span in participants aged 3–18 years with a hand span of 12–23 cm ranged between 4.0 and 6.3 cm [18,19,21]. We performed HGS measurements in children aged 5 to 9 years old, although we did not measure the hand span. In studies conducted by the aforementioned research group, children in a similar age range obtained maximal HGS with a grip span ranging between 4.0 and 4.4 cm [18,21]. Such grip spans correspond to Jamar handle positions 1 and 2. Thus, when using the Jamar dynamometer in children aged 5 to 9 years old, we propose that the second handle position is the most appropriate to obtain maximal HGS. Notwithstanding, whether this position is appropriate for younger children (< 5 years old) is unknown. It is possible that for younger participants the handle should be set to the first position, as conducted in a recent study [29].

Hand shape, defined as the proportion of the hand width to the hand length, revealed differences for selected age groups and for girls and boys independently. Significantly lower values of the W/L ratio indicate that primary school children and girls showed a tendency to have longer hands than preschool children and boys, respectively, which matches their overall larger body size. An age-related increase in hand size has been observed in preschool children by other authors [23]. It was found that male hands become wider than female hands with increasing age [13,30]; nevertheless, the hand shape did

not influence on HGS in our experiments. There were no interactions with other factors nor significant independent effects. This is in line with previous findings [13,31]. However, direct comparison of the data is not possible because other authors presented the effect of hand shape on maximal isometric grip strength in participants older than those in the present study [13,31].

Irrespective of age or sex, participants achieved higher values of HGS using the dominant hand in comparison to the non-dominant hand. Such results are similar to those observed recently in a cross-sectional study of more than two thousand children and adolescents [29]. These higher results found for the dominant hand in comparison to non-dominant hand are independent of any selected hand shape.

Some limitations should be noted: participants were children aged 5 to 9 years who met typical developmental milestones; therefore, caution is needed in applying the results to other populations. We did not examine hand span as a factor that could potentially influence the HGS results. Although we standardized the protocol according to the ASHT recommendations, it is possible that different postures attained in testing might alter the results.

The presents study provides useful information indicating that practitioners conducting tests of hand strength, function, and therapy can use the second handle position of the Jamar digital dynamometer as optimal to obtain maximal HGS in non-athlete pediatric participants with typical development. These findings apply to boys and girls aged 5 to 9 years old with long-, average-, and square-shaped hands for both the dominant and non-dominant hand.

Conflict of interest: Authors state no conflict of interest.

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