muscles

MDPI

Article

Lateral Pinch Strength and Its Associations with Grip Strength, Age, Gender, and Anthropometric Characteristics in Saudi Schoolchildren

Mohamed Sherif Sirajudeen

Department of Physical Therapy and Health Rehabilitation, College of Applied Medical Sciences, Majmaah University, Al Majmaah 11952, Saudi Arabia; m.sirajudeen@mu.edu.sa

Abstract

Background: This study examined associations of lateral pinch strength with grip strength, age, gender, body mass index (BMI), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) in Saudi schoolchildren. **Methods:** This cross-sectional study included 270 children aged 8–14 years in Majmaah, Saudi Arabia. Welch's *t*-tests compared boys and girls, Pearson correlations assessed unadjusted associations, and separate multivariable regressions for each hand used HC3 robust standard errors. **Results:** Boys had slightly greater unadjusted lateral pinch strength than girls (mean difference: 0.31 kg left, 0.25 kg right). Corresponding-side grip strength was the strongest adjusted correlate (standardized $\beta = 0.445$ left and 0.460 right, both $p < 0.001$). Unadjusted age correlations were near zero, but each additional year of age was associated with lower adjusted pinch strength (left B = −0.154 kg, 95% CI −0.275 to −0.033; right B = −0.192 kg, 95% CI −0.303 to −0.080). The models provided no clear evidence of adjusted associations with gender, BMI, WHR, or WHtR and explained modest variation (adjusted $R^2 = 0.157$ left and 0.171 right). **Conclusions:** Direct lateral pinch assessment may complement grip testing when thumb–index force is of interest.

Keywords: lateral pinch strength; key pinch; grip strength; hand function; anthropometry; children; Saudi Arabia

1. Introduction

Hand strength plays a critical role in various childhood activities, such as writing, handling school materials, dressing, eating, playing, and participating in recreational and sports activities. Clinicians typically assess hand strength using grip and pinch measures, which provide objective data on upper-limb function. Grip strength reflects the combined force generated by the forearm and hand muscles during grasping, while pinch strength estimates the specific force produced by the thumb and one or more digits of the hand [1–5]. Lateral pinch, or key pinch, measures force by pressing the thumb against the lateral surface of the index finger. Lateral pinch is used for functional tasks like holding a key, turning pages, and securing small objects [6]. Hand grip and lateral pinch strength are related because they rely on the stability and strength of the hand joints and the muscles of the forearm and hand, respectively. They illustrate different elements of hand function and should not be regarded as interchangeable. Definitive interpretation requires reliable reference data because hand outcome measures can vary based on factors such as body dimensions, population, and measurement procedure [7–9].

Growth and development affect muscular strength, neuromuscular coordination, and bone size. Studies involving children have shown age-related increases in hand grip and

Check for updates

Academic Editor: Corrado Angelini

Received: 2 October 2026
Revised: 15 November 2026
Accepted: 20 November 2026
Published: 23 November 2026

Copyright: © 2026 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

pinch strength [10–15]. Notably, Saudi reference data for grip strength among children aged 6 to 12 years further support these findings [16,17]. Gender-based hand strength disparities often become apparent as children mature, with boys typically exhibiting greater strength than girls in older age groups. Yet, the extent of these differences varies across populations and may be affected by factors such as physical activity, pubertal maturation, and lifestyle [18–25]. Anthropometric measures may influence hand strength in children because muscle mass and skeletal proportions change as the body develops. Height, weight, and gender are strongly linked to grip strength in children [26], while the association between hand strength and body mass index (BMI) is less clear. BMI reflects weight relative to height but does not distinguish between muscle and fat. Waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR) indicate central body proportions [27], yet neither directly assesses the muscular or anatomical attributes involved in pinch-force generation [28]. Therefore, it is unclear whether these indices offer additional insight into lateral pinch strength beyond what age, gender, and overall grip strength explain.

Population-specific research is essential because hand strength in children may differ by ethnicity, lifestyle, and nutrition. A recent study established normative grip and pinch strength measures among Saudi children and adolescents aged 6 to 18 years [29]. However, very few studies have focused specifically on lateral pinch strength or assessed its independent association with corresponding-side grip strength and central anthropometric measures in Saudi school children. Therefore, this study investigated the association between lateral pinch strength and corresponding-side grip strength, age, and gender among school children aged 8 to 14 years in Saudi Arabia. It also examined whether BMI, WHR, and WHtR were independently associated with lateral pinch strength after adjusting for grip strength, age, and gender.

2. Results

This section presents findings from data on 270 children. Table 1 presents the sociodemographic data of the study participants. The mean age was 10.76 years, with a slightly higher proportion of girls (54.4%) than boys (45.6%), and the mean BMI was 19.51 kg/m^2. The mean waist circumference and hip circumference were 65.65 cm and 79.88 cm, respectively. The mean waist-to-hip ratio and waist-to-height ratio were 0.822 and 0.473, respectively. Mean left grip strength was 9.40 kg, and right grip strength was 10.07 kg. The mean left and right lateral pinch strengths were 4.07 kg and 4.11 kg, respectively.

Table 1. Descriptive characteristics of the study participants (N = 270).

Characteristics	Mean (SD) or *n* (%)
Age (years)	10.76 (1.24)
Gender	
Boys	123 (45.6%)
Girls	147 (54.4%)
Height (cm)	138.73 (9.55)
BMI (kg/m^2)	19.51 (4.76)
Waist circumference (cm)	65.65 (9.99)
Hip circumference (cm)	79.88 (10.65)
Waist-to-hip ratio	0.822 (0.054)
Waist-to-height ratio	0.473 (0.063)
Left grip strength (kg)	9.40 (3.97)
Right grip strength (kg)	10.07 (4.15)
Left lateral pinch strength (kg)	4.07 (1.07)
Right lateral pinch strength (kg)	4.11 (0.99)

Table 2 presents findings on gender differences in lateral pinch strength; boys demonstrated slightly greater unadjusted lateral pinch strength on the left (mean difference, 0.31; 95% CI, 0.05–0.57; $p = 0.018$; Hedges' g = 0.29) and right (mean difference, 0.25; 95% CI, 0.01–0.49; $p = 0.040$; Hedges' g = 0.25).

Table 2. Comparison of lateral pinch strength between boys and girls.

Hand	Lateral Pinch Strength Boys (kg)		Lateral Pinch Strength Girls (kg)		Lateral Pinch Strength (kg)	95% CI	*p* Value	Hedges g
	Mean	SD	Mean	(SD)	Mean Difference (Boys–Girls)			
Left	4.24	1.12	3.93	1.02	0.31	0.05 to 0.57	0.018 *	0.29
Right	4.25	1.05	4.00	0.93	0.25	0.01 to 0.49	0.040 *	0.25

* Statistically Significant—$p < 0.05$.

Table 3 presents unadjusted correlations of lateral pinch strength with corresponding-side grip strength, age, BMI, WHR, and WHtR for each hand. Corresponding-side grip strength showed moderate, significant positive correlations with lateral pinch strength on the left (Pearson r = 0.378, $p < 0.001$; Spearman rho = 0.327, $p < 0.001$) and right (Pearson r = 0.381, $p < 0.001$; Spearman rho = 0.322, $p < 0.001$). Age, BMI, WHR, and WHtR were not significantly correlated with lateral pinch strength on either side.

Table 3. Pearson and Spearman Correlations of Bilateral Lateral Pinch Strength with Grip Strength, Age, and Anthropometric Indices.

Variable	Pearson r	*p* Value	Spearman rho	*p* Value
Left side				
Grip strength	0.378	<0.001	0.327	<0.001 *
Age	0.019	0.758	0.020	0.743
BMI	0.012	0.849	0.016	0.799
Waist-to-hip ratio	−0.026	0.671	−0.002	0.974
Waist-to-height ratio	−0.049	0.426	−0.038	0.533
Right side				
Grip strength	0.381	<0.001	0.322	<0.001 *
Age	−0.011	0.857	−0.030	0.628
BMI	0.063	0.300	0.052	0.398
Waist-to-hip ratio	−0.030	0.621	0.003	0.956
Waist-to-height ratio	−0.006	0.916	0.005	0.932

* Statistically Significant—$p < 0.05$.

Table 4 presents the results of the multiple linear regression analyses for left and right lateral pinch strength. The model explained 17.6% of the variance in left lateral pinch strength ($R^2 = 0.176$) and, after adjustment for the number of predictors, 15.7% (adjusted $R^2 = 0.157$). Left grip strength was significantly and positively associated with left lateral pinch strength (B = 0.120, 95% CI: 0.086 to 0.155; standardized β = 0.445; $p < 0.001$). Age was significantly and inversely associated with left lateral pinch strength (B = −0.154, 95% CI: −0.275 to −0.033; $p = 0.013$). Gender, BMI, WHR, and WHtR were not independently associated with left lateral pinch strength. For right lateral pinch strength, the model explained 18.9% of the variance ($R^2 = 0.189$) and, after adjustment for the number of predictors, 17.1% (adjusted $R^2 = 0.171$). Right grip strength was significantly and positively associated with right lateral pinch strength (B = 0.110, 95% CI: 0.077 to 0.143; standardized β = 0.460; $p < 0.001$). Age was also significantly and inversely associated with right lateral pinch strength (B = −0.192, 95% CI: −0.303 to −0.080; $p < 0.001$). Gender, BMI, WHR, and WHtR were not independently associated with right lateral pinch strength.

Table 4. Multivariable Linear Regression Models of Factors Associated with Left and Right Lateral Pinch Strength.

Predictor	B	Robust SE	Standardized Beta	95% CI	*p* Value
Left side					
Left grip strength	0.120	0.018	0.445	0.086 to 0.155	<0.001 *
Age	−0.154	0.061	−0.178	−0.275 to −0.033	0.013 *
Female gender	−0.064	0.153	−0.030	−0.366 to 0.237	0.676
BMI	0.009	0.027	0.039	−0.045 to 0.062	0.743
Waist-to-hip ratio	−1.310	1.682	−0.066	−4.621 to 2.001	0.437
Waist-to-height ratio	−1.444	2.333	−0.085	−6.038 to 3.150	0.536
Right side					
Right grip strength	0.110	0.017	0.460	0.077 to 0.143	<0.001 *
Age	−0.192	0.057	−0.239	−0.303 to −0.080	<0.001 *
Female gender	−0.024	0.149	−0.012	−0.317 to 0.270	0.874
BMI	0.023	0.026	0.109	−0.029 to 0.075	0.392
Waist-to-hip ratio	−1.695	1.516	−0.092	−4.681 to 1.290	0.265
Waist-to-height ratio	−1.216	2.238	−0.077	−5.622 to 3.191	0.587

* Statistically Significant—$p < 0.05$. Note. N = 270 per model. B = unstandardized regression coefficient. CI = confidence interval. BMI = body mass index. Boys are the reference group for gender. Model fit. Left hand: $R^2 = 0.176$, adjusted $R^2 = 0.157$. Right hand: $R^2 = 0.189$, adjusted $R^2 = 0.171$.

Age was positively correlated with left and right grip strength (r = 0.398 and 0.396, respectively). Among the anthropometric indices, BMI and WHtR had the strongest correlation (r = 0.815, Table S1). These two indices also had the highest variance inflation factors in both full models (5.47–5.49 for BMI and 7.08–7.09 for WHtR). Variance inflation factors for age, corresponding-side grip strength, and gender were below 1.50 (Table S2).

The age coefficients were close to zero in the age-only models and became more negative after adding corresponding-side grip strength, changing from 0.016 to −0.136 kg per year for the left hand and from −0.009 to −0.154 kg per year for the right hand. The inverse associations persisted in the full models, and the estimates changed little when the analysis was restricted to children aged 8–12 years ($n = 261$, Table S3). When BMI, WHR, and WHtR were entered separately, the age coefficients remained negative for both hands (Table S3), and all 95% confidence intervals for the anthropometric coefficients included zero (Table S4).

3. Discussion

The results of this study showed that same-side grip strength was the most consistent correlate of lateral pinch strength in a sample of Saudi schoolchildren aged 8 to 14 years. The association was moderate in unadjusted analyses and persisted as the largest standardized association across multivariable models for both left and right pinch strength. Regarding the association between gender and lateral pinch strength, boys' pinch strengths were slightly higher than girls', but this difference did not persist after adjusting for the potential confounding variables. The adjusted models provided no clear evidence of associations between BMI, WHR, or WHtR and lateral pinch strength on either side.

The observed positive association between grip and lateral pinch strength is biologically plausible, since both activities require coordinated recruitment of forearm and hand muscles, joint stability, and voluntary force production [29]. The correlations were moderate and positive (left r = 0.378, right r = 0.381). Children with higher grip strength tended to have higher lateral pinch strength. The magnitude of these correlations suggests that direct pinch testing can provide information beyond grip strength. A comprehensive hand examination assesses multiple features of hand strength. Grip strength reflects the force generated while grasping with the entire hand. Lateral pinch strength, by contrast, measures the force

generated between the thumb and the lateral aspect of the index finger during a key-pinch action. Thus, although these measures are related, they represent distinct components of hand strength. This distinction aligns with hand-assessment frameworks that treat grip strength and different forms of pinch strength, including key, tip, and palmar pinch, as related but separate measures of hand function [3,4,8,15].

Furthermore, the relationship between grip strength and lateral pinch strength was similar in both hands. Previous pediatric studies have reported grip and pinch reference values by hand [30]. In this study, the comparisons refer to anatomical sides because hand dominance was not recorded. In the unadjusted comparison, boys had slightly higher lateral pinch strength than girls. This finding agrees with previous pediatric studies reporting that gender differences in hand strength can become more obvious as children grow and mature [4,10,16,18,20,22,29]. However, after multiple regression analysis accounting for grip strength, age, BMI, WHR, and WHtR, the adjusted gender estimates were close to zero. The attenuation after adjustment is consistent with the possibility that the unadjusted difference partly reflected differences in overall strength or growth characteristics [29,30].

Most normative studies report that hand strength increases with chronological age [14–17,29]. In the present study, however, the unadjusted correlations between age and lateral pinch strength were close to zero (left $r = 0.019$, right $r = -0.011$). After adjustment for grip strength, gender, BMI, WHR, and WHtR, older age was associated with lower lateral pinch strength on both sides. Among children with comparable grip strength and similar values for the other included variables, older children tended to demonstrate slightly lower lateral pinch strength than younger children. Age was positively correlated with corresponding-side grip strength (Table S1), and grip strength was positively associated with lateral pinch strength. In the sequential models, the age coefficient shifted most when grip strength was added, before gender and the anthropometric indices entered the models (Table S3). The inverse association changed little when the analysis was restricted to children aged 8–12 years and persisted when the anthropometric indices were entered separately (Table S3). This pattern illustrates how adjustment can change an association [31]. Growth and maturation may contribute to this pattern, but pubertal stage and hand dimensions were not measured. The cross-sectional comparison cannot establish how lateral pinch strength changes within a child over time.

The adjusted models provided no clear evidence of associations between BMI, WHR, or WHtR and lateral pinch strength. These measures represent general or central body proportions but do not directly estimate forearm muscle mass, hand dimensions, or muscular recruitment patterns. Previous pediatric studies have linked body size to hand strength [7,10,11,17,20,26]. BMI and WHtR were strongly correlated ($r = 0.815$) and had the highest variance inflation factors in both full models, limiting the precision of their individual estimates (Tables S1 and S2). When the indices were entered separately, the confidence intervals for their coefficients still included zero (Table S4). These results apply to the indices and models examined and do not rule out biologically relevant associations with body composition or muscle function. Body mass index (BMI) fails to differentiate between muscle and fat, and body ratios may conceal differences in actual body measurements. Further studies should assess height, weight, forearm circumference, hand length and breadth, lean body mass, physical activity, and maturation in addition to BMI and waist measurements. This approach may determine whether muscle mass and skeletal dimensions are more closely associated with lateral pinch strength than central anthropometric indices such as waist-based measures.

3.1. Clinical and Research Implications

The moderate correlations identified in this study suggest partial overlap between grip strength and lateral pinch strength. Grip strength primarily indicates the force produced during whole-hand grasping. Lateral pinch depends on coordinated force production between the thumb and the lateral aspect of the index finger, as well as thumb stability, joint control, neuromuscular coordination, and sensory feedback. Direct lateral pinch testing may therefore complement grip testing when thumb–index force is of interest. Previous pediatric research has examined the relationship between strength and functional dexterity, supporting the assessment of muscle strength and task performance as complementary domains [3].

Tasks such as turning a key, fastening a zipper, or opening a small container illustrate situations in which thumb–index force may be relevant. Previous studies have reported impaired manual dexterity in children with hemiplegic cerebral palsy despite grip or pinch strength in the less-affected hand that aligned with normative values [32] and have identified an association between lateral pinch strength and bimanual performance in children with congenital hand differences [33]. Other studies have assessed grip strength, lateral pinch, other pinch patterns, dexterity, and activity performance as distinct outcomes in children with autism spectrum disorder and pediatric hand burns [34,35]. The present study did not include these clinical populations or assess dexterity or daily task performance. Whether the grip and pinch differences observed here correspond to functional limitations therefore remains uncertain.

Grip strength and the other measured variables accounted for a modest proportion of the variability in lateral pinch strength (adjusted $R^2 = 0.157$ for the left hand and 0.171 for the right hand). Prior research has associated hand anthropometric characteristics, including hand length, palm dimensions, and hand span, with pinch strength [36]. The proportion of variability explained may differ across populations, age groups, predictor sets, measurement procedures, and clinical conditions [29]. The adjusted R^2 values are therefore specific to this sample and these models.

3.2. Strengths and Limitations

The study's strengths included using multivariable analysis to examine grip and several anthropometric variables simultaneously, as well as applying HC3 robust standard errors to account for potential heteroskedasticity. This approach enabled assessment of the associations with lateral pinch strength conditional on the other variables in the models. Sensitivity analyses assessed whether the main findings persisted across alternative model specifications.

This study has several limitations. The cross-sectional design precludes causal or developmental inferences and does not clarify how lateral pinch strength evolves within individual children during growth and maturation. Participants were recruited exclusively from three schools in a single Saudi region, which limits generalizability. Although participants ranged from 8 to 14 years, most were aged 9–12 years (249 of 270, 92.2%). Eight were 13 years old, and one was 14 years old. Restricting the analysis to ages 8–12 years had little effect on the adjusted age estimates, but the small number of older participants limited inference for ages 13–14 years. Hand dominance was not recorded, so the left- and right-hand results cannot be interpreted as dominant-versus-nondominant comparisons. The analyses could not assess whether dominance contributed to between-side differences or whether the grip–pinch association differed by dominance.

BMI, WHR, and WHtR are indirect anthropometric indices. These estimates should be interpreted in the context of the models used; they cannot be generalized to direct measurements of muscle mass, body fat, or hand and skeletal dimensions. The models accounted for

a modest proportion of the variability in lateral pinch strength. The contributions of hand dominance, physical activity, hand dimensions, and pubertal development could not be evaluated because these factors were not assessed. Future longitudinal and multiregional studies should incorporate representative samples and evaluate hand anthropometry, maturation, physical activity, muscle mass, sensorimotor function, dexterity, and task-specific activity performance. These studies are needed to determine whether current findings are reproducible across pediatric populations and clinical groups.

4. Materials and Methods

This cross-sectional study included male and female children aged 8 to 14 years from the Majmaah region of Saudi Arabia. The Majmaah University Ethical Committee granted ethical approval (no. MUREC-Oct21/COM-2018/6). Of the 15 primary schools in this region, three were selected using cluster sampling, and all eligible children were invited to participate. A letter outlining the study design and requesting the cooperation of headteachers was sent. Parents of each child received information about the study and subsequently provided written informed consent for their child's participation. In addition, assent was obtained from all participating children prior to enrolment. Data were collected at the respective schools. Children with any cognitive, developmental, or physical disabilities were excluded [37].

Personal and anthropometric characteristics such as age (years), gender, height (centimeters), weight (kilograms), waist circumference (centimeters), and hip circumference (centimeters) were collected. Height and weight were measured using the gold standard method, with participants barefoot and measurements recorded to the nearest centimeter and 100 g, respectively. Body mass index (BMI) was calculated using the metric formula: weight in kilograms divided by height in meters squared [38,39]. Waist circumference was measured in centimeters at the midpoint between the lower rib margin and iliac crest, using a non-stretchable tape without compressing soft tissue. Hip circumference was measured in centimeters at the widest part of the buttocks, with the tape parallel to the floor. Measurements were taken with subjects standing upright, feet together, arms at their sides, body weight evenly distributed, at the end of normal expiration. Waist-to-hip ratio (WHR) was calculated by dividing waist circumference (cm) by hip circumference (cm), and waist-to-height ratio (WHtR) was calculated by dividing waist circumference (cm) by height (cm) [40].

Hand grip strength and lateral (key) pinch strength were measured as per the American Society of Hand Therapists' recommendations by using a Jamar Hydraulic Hand Dynamometer (Patterson Medical, Warrenville, IL, USA, 5030J1) and a Jamar Pinch Gauge (Patterson Medical, Warrenville, IL, USA, 081296656), respectively. To assess grip strength, the child sat with the hip and knee at 90 degrees of flexion. The shoulder was adducted, the elbow was flexed to 90 degrees, the forearm was midprone, and the wrist was neutral. The child was instructed to squeeze the dynamometer with maximum effort. For assessing lateral pinch strength, the arm, elbow, and forearm positions remained the same as for grip strength. The target wrist position was 0–30° of extension and 0–15° of ulnar deviation [29]. The examiner visually checked wrist position and provided verbal cues as needed to help the child maintain the target position, consistent with the approach described by Walukonis et al. [41]. During handgrip and lateral (key) pinch strength testing, the examiner alternated between the left and right hands. For each test and each hand, participants completed two practice trials to familiarize themselves with the task, followed by one maximal-effort trial. Only the maximal-effort reading was used in the analysis. Walukonis et al. recorded one trial per pinch condition [41], and Bohannon et al. reported that the NIH Toolbox grip protocol used one recorded maximal trial [42]. The Jamar pinch gauge had 1 kg

graduations, and pinch readings were entered as read from the dial. The Jamar handgrip dynamometer had 2 kg graduations. When the pointer fell between adjacent marks, the examiner estimated the reading from its position. For example, a pointer approximately halfway between the 0 and 2 kg marks was recorded as 1 kg. No further rounding was applied to either measure at data entry.

Statistical Analysis

SPSS version 29 was employed to analyze the data. Sociodemographic, anthropometric, grip, and pinch strength data were presented descriptively. Welch's independent-samples *t*-test was used to compare the lateral pinch strengths between girls and boys for each hand. Pearson correlation coefficients were used to evaluate unadjusted linear associations between lateral pinch strength and corresponding-side grip strength, age, body mass index (BMI), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR). Spearman rank correlations were also calculated to provide complementary nonparametric estimates. Separate multivariable ordinary least-squares regression models were fitted for left and right lateral pinch strength. Each model incorporated corresponding-side grip strength, age, female gender (with boys as the reference group), BMI, WHR, and WHtR. The coefficients are reported as unstandardized B values, standardized beta coefficients, HC3 robust standard errors, 95% confidence intervals (CIs), and *p*-values. Model fit is summarized using R-squared and adjusted R-squared values.

Pearson correlations were calculated among the predictors (Supplementary Table S1). Variance inflation factors (VIFs) and tolerance values were calculated for each predictor in both full models (Supplementary Table S2). To examine how adjustment affected the age coefficient, sequential models were fitted for each hand, starting with age alone, then adding corresponding-side grip strength, then gender, and finally BMI, WHR, and WHtR together (Supplementary Table S3). In sensitivity analyses, the full models were refitted among children aged 8–12 years (Supplementary Table S3). Each anthropometric index was also examined in a separate model adjusted for age, corresponding-side grip strength, and gender (Supplementary Tables S3 and S4). Confidence intervals for the supplementary regression analyses were based on HC3 robust standard errors. All statistical tests were two-sided, with $p < 0.05$ considered statistically significant.

5. Conclusions

In this sample of Saudi schoolchildren aged 8–14 years, corresponding-side grip strength was the factor most consistently associated with lateral pinch strength. Age was inversely associated with lateral pinch strength after adjustment, although the unadjusted correlations were close to zero. The models explained a modest proportion of the variation in lateral pinch strength and provided no clear evidence of adjusted associations with gender, BMI, WHR, or WHtR. Bilateral lateral pinch assessment may complement grip testing when thumb–index force is of interest. Dexterity and daily task performance were not assessed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/muscles5040084/s1, Table S1: Pearson correlation matrix among predictors of lateral pinch strength; Table S2: Collinearity diagnostics for the full left- and right-hand lateral pinch strength models; Table S3: Age coefficients for lateral pinch strength across sequential and sensitivity models; Table S4: Associations of BMI, WHR, and WHtR with lateral pinch strength in separate adjusted models.

Funding: The author extends the appreciation to the Deanship of Postgraduate Studies and Scientific Research at Majmaah University for funding this research work through the project number (R-2026-554).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Deanship of Scientific Research, Majmaah University (protocol code: MUREC-oct.21/COM-2018/6; date of approval: 13 October 2018).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article or Supplementary Material. The original contributions presented in this study are included in the article/Supplementary Material.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Ferreira, A.C.; Shimano, A.C.; Mazzer, N.; Barbieri, C.H.; Elui, V.M.; Fonseca, M.D. Grip and pinch strength in healthy children and adolescents. *Acta Ortopédica Bras.* **2011**, *19*, 92–97. [CrossRef]
2. Alqahtani, B.; Alenazi, A.; Alshehri, M.; Alqahtani, M.; Elnaggar, R. Reference values and associated factors of hand grip strength in elderly Saudi population: A cross-sectional study. *BMC Geriatr.* **2019**, *19*, 271. [CrossRef] [PubMed]
3. Lee-Valkov, P.M.; Aaron, D.H.; Eladoumikdachi, F.; Thornby, J.; Netscher, D.T. Measuring normal hand dexterity values in normal 3-, 4-, and 5-year-old children and their relationship with grip and pinch strength. *J. Hand Ther.* **2003**, *16*, 22–28. [CrossRef] [PubMed]
4. McQuiddy, V.A.; Scheerer, C.R.; Lavalley, R.; McGrath, T.; Lin, L. Normative values for grip and pinch strength for 6- to 19-year-olds. *Arch. Phys. Med. Rehabil.* **2015**, *96*, 1627–1633. [CrossRef] [PubMed]
5. Shah, U.N.; Sirajudeen, M.S.; Somasekaran, P.K.; Mohasin, N.; Shantaram, M. The association between hand grip strength and hand dimensions in healthy Indian females. *Int. J. Curr. Res. Rev.* **2012**, *4*, 36–42.
6. Polat, S.; Isık, E.I.; Kelle, B.; Göker, P. Evaluation of the Association Between Carrying Angle, Hand Grip Strength, Lateral Pinch Strength, and Hand Functional Index in Nursing Students. *Int. J. Morphol.* **2023**, *41*, 1357–1363. [CrossRef]
7. Hogrel, J.Y.; Decostre, V.; Alberti, C.; Canal, A.; Ollivier, G.; Josserand, E.; Taouil, I.; Simon, D. Stature is an essential predictor of muscle strength in children. *BMC Musculoskelet. Disord.* **2012**, *13*, 176. [CrossRef] [PubMed]
8. Mathiowetz, V.; Weber, K.; Volland, G.; Kashman, N. Reliability and validity of grip and pinch strength evaluations. *J. Hand Surg.* **1984**, *9*, 222–226. [CrossRef] [PubMed]
9. Moliner-Urdiales, D.; Ruiz, J.R.; Ortega, F.B.; Jiménez-Pavón, D.; Vicente-Rodriguez, G.; Rey-López, J.P.; Martínez-Gómez, D.; Casajús, J.A.; Mesana, M.I.; Marcos, A.; et al. Secular trends in health-related physical fitness in Spanish adolescents: The AVENA and HELENA studies. *J. Sci. Med. Sport.* **2010**, *13*, 584–588. [CrossRef] [PubMed]
10. Häger-Ross, C.; Rösblad, B. Norms for grip strength in children aged 4–16 years. *Acta Paediatr.* **2002**, *91*, 617–625. [CrossRef]
11. Molenaar, H.M.; Selles, R.W.; Zuidam, J.M.; Willemsen, S.P.; Stam, H.J.; Hovius, S.E. Growth diagrams for grip strength in children. *Clin. Orthop. Relat. Res.* **2010**, *468*, 217–223. [CrossRef] [PubMed]
12. Cohen, D.D.; Voss, C.; Taylor, M.J.; Delextrat, A.; Ogunleye, A.A.; Sandercock, G.R. Ten-year secular changes in muscular fitness in English children. *Acta Paediatr.* **2011**, *100*, e175-7. [CrossRef] [PubMed]
13. Tremblay, M.S.; Shields, M.; Laviolette, M.; Craig, C.L.; Janssen, I.; Gorber, S.C. Fitness of Canadian children and youth: Results from the 2007-2009 Canadian Health Measures Survey. *Health Rep.* **2010**, *21*, 7–20. [PubMed]
14. Yim, S.Y.; Cho, J.R.; Lee, I.Y. Normative data and developmental characteristics of hand function for elementary school children in Suwon area of Korea: Grip, pinch and dexterity study. *J. Korean Med. Sci.* **2003**, *18*, 552–558. [CrossRef] [PubMed]
15. Surrey, L.R.; Hodson, J.; Robinson, E.; Schmidt, S.; Schulhof, J.; Stoll, L.; Wilson-Diekhoff, N. Pinch strength norms for 5- to 12-year-olds. *Phys. Occup. Ther. Pediatr.* **2001**, *21*, 37–49. [CrossRef]
16. Omar, M.T.A.; Alghadir, A.; Al Baker, S. Norms for hand grip strength in children aged 6–12 years in Saudi Arabia. *Dev. Neurorehabil* **2015**, *18*, 59–64. [CrossRef] [PubMed]
17. Omar, M.T.A.; Alghadir, A.H.; Zafar, H.; Al Baker, S. Hand grip strength and dexterity function in children aged 6–12 years: A cross-sectional study. *J. Hand Ther.* **2018**, *31*, 93–101. [CrossRef] [PubMed]
18. Butterfield, S.A.; Lehnhard, R.A.; Loovis, E.M.; Coladarci, T.; Saucier, D. Grip strength performances by 5- to 19-year-olds. *Percept. Mot. Ski.* **2009**, *109*, 362–370. [CrossRef] [PubMed]
19. Shaheen, A.A.M.; Omar, M.T.A.; Ali, O.I. Normative values of handgrip and pinch strengths in healthy female college students in Riyadh, Saudi Arabia: A cross-sectional study. *Bull. Fac. Phys. Ther.* **2021**, *26*, 1. [CrossRef]

20. Rostamzadeh, S.; Saremi, M.; Abouhossein, A.; Vosoughi, S.; Molenbroek, J.F. Normative data for handgrip strength in Iranian healthy children and adolescents aged 7–18 years: Comparison with international norms. *Ital. J. Pediatr.* **2021**, *47*, 164. [CrossRef] [PubMed]
21. Bryden, P.J.; Roy, E.A. A new method of administering the Grooved Pegboard Test: Performance as a function of handedness and sex. *Brain Cogn.* **2005**, *58*, 258–268. [CrossRef] [PubMed]
22. Cohen, D.D.; Voss, C.; Taylor, M.J.; Stasinopoulos, D.M.; Delextrat, A.; Sandercock, G.R. Handgrip strength in English schoolchildren. *Acta Paediatr.* **2010**, *99*, 1065–1072. [CrossRef] [PubMed]
23. Espana-Romero, V.; Ortega, F.B.; Vicente-Rodriguez, G.; Artero, E.G.; Rey, J.P.; Ruiz, J.R. Elbow position affects handgrip strength in adolescents: Validity and reliability of Jamar, DynEx, and TKK dynamometers. *J. Strength Cond. Res.* **2010**, *24*, 272–277. [CrossRef] [PubMed]
24. Osailan, A. The relationship between smartphone usage duration (using smartphone's ability to monitor screen time) with hand-grip and pinch-grip strength among young people: An observational study. *BMC Musculoskelet. Disord.* **2021**, *22*, 186. [CrossRef] [PubMed]
25. Sirajudeen, M.S.; Shah, U.N.; Pillai, P.S.; Mohasin, N.; Shantaram, M. Correlation between grip strength and physical factors in men. *Int. J. Health Rehabil. Sci.* **2012**, *1*, 58–63. [CrossRef]
26. Ploegmakers, J.J.W.; Hepping, A.M.; Geertzen, J.H.B.; Bulstra, S.K.; Stevens, M. Grip strength is strongly associated with height, weight and gender in childhood: A cross-sectional study of 2241 children and adolescents providing reference values. *J. Physiother.* **2013**, *59*, 255–261. [CrossRef] [PubMed]
27. Palumbo, A.M.; Jacob, C.M.; Khademioore, S.; Sakib, M.N.; Yoshida-Montezuma, Y.; Christodoulakis, N.; Yassa, P.; Vanama, M.S.; Gamra, S.; Ho, P.-J.; et al. Validity of non-traditional measures of obesity compared to total body fat across the life course: A systematic review and meta-analysis. *Obes. Rev.* **2025**, *26*, e13894. [CrossRef] [PubMed]
28. Shah, M.; Palekar, P.J. Correlation of hand dominance, hand dimension, and hand span with grip strength and pinch strength in normal individuals: A cross-sectional study. *Int. J. Health Sci. Res.* **2024**, *14*, 426–448. [CrossRef]
29. Alqahtani, B.A.; Alenazi, A.M.; Elnaggar, R.K.; Alshehri, M.M.; Alhowimel, A.; Najmi, A.A.; Alasraj, M.; Alghadeir, M. Normative values for hand grip and pinch strength for 6 to 18 year-olds in Saudi Arabia. *BMC Musculoskelet. Disord.* **2023**, *24*, 96. [CrossRef] [PubMed]
30. Shetty, M.; Balasundaran, S.; Mullerpatan, R. Grip and pinch strength: Reference values for children and adolescents from India. *J. Pediatr. Rehabil. Med.* **2019**, *12*, 255–262. [CrossRef] [PubMed]
31. Tu, Y.K.; Gunnell, D.; Gilthorpe, M.S. Simpson's Paradox, Lord's Paradox, and Suppression Effects are the same phenomenon–the reversal paradox. *Emerg. Themes Epidemiol.* **2008**, *5*, 2. [CrossRef] [PubMed]
32. Tomhave, W.A.; Van Heest, A.E.; Bagley, A.; James, M.A. Affected and contralateral hand strength and dexterity measures in children with hemiplegic cerebral palsy. *J. Hand Surg.* **2015**, *40*, 900–907. [CrossRef] [PubMed]
33. Ardon, M.S.; Janssen, W.G.; Hovius, S.E.; Stam, H.J.; Murawska, M.; Roebroeck, M.E.; Selles, R.W. Relationships among manual body functions, manual capacity, and bimanual performance using the Prosthetic Upper Extremity Functional Index in children with congenital hand differences. *Phys. Ther.* **2014**, *94*, 767–775. [CrossRef] [PubMed]
34. Ali, O.I.; Sarsak, H.I.; Tarshi, M.M.; Marji, M.; Aljohani, S.T.; Badawood, M.N.; Bamusallam, M.M.; Alharbi, K.; Ibrahim, Z.M.; Sheeha, B.B.; et al. Assessment of hand grip and pinch strengths in children with autism spectrum disorders: A cross-sectional study. *Children* **2025**, *12*, 320. [CrossRef] [PubMed]
35. Kamel, F.A.; Basha, M.A. Effects of virtual reality and task-oriented training on hand function and activity performance in pediatric hand burns: A randomized controlled trial. *Arch. Phys. Med. Rehabil.* **2021**, *102*, 1059–1066. [CrossRef] [PubMed]
36. Sayadizadeh, M.; Daliri, M.; Rahimi, M.; Salehipour, P.; Sadeghi, M.; Mozafari, J.K.; Moradi, A. Grip and pinch strength prediction models based on hand anthropometric parameters: An analytic cross-sectional study. *BMC Musculoskelet. Disord.* **2024**, *25*, 809. [CrossRef] [PubMed]
37. Romeo, D.M.; Lucibello, S.; Musto, E.; Brogna, C.; Ferrantini, G.; Velli, C.; Cota, F.; Ricci, D.; Mercuri, E. Assessing joint hypermobility in preschool-aged children. *J. Pediatr.* **2016**, *176*, 162–166. [CrossRef] [PubMed]
38. Wu, Y.; Li, D.; Vermund, S.H. Advantages and limitations of the body mass index (BMI) to assess adult obesity. *Int. J. Environ. Res. Public Health* **2024**, *21*, 757. [CrossRef] [PubMed]
39. Seyam, M.K.; Alqahtani, M.; Sirajudeen, M.S.; Muthusamy, H.; Kashoo, F.Z.; Salah, M.M. Effect of circuit training with low-carbohydrate diet on body composition, cardiometabolic indices, and exercise capacity in adults with mild to moderate obesity in Saudi Arabia: A randomized control trial. *Medicine* **2022**, *101*, e30054. [CrossRef] [PubMed]
40. Assefa, M.; Tsegaye, A.; Addissie, A.; Worku, A. Body composition-derived abdominal circumference, waist-to-hip ratio, and waist-to-height ratio cut-offs for Ethiopian adults in Northwest Ethiopia, 2023. *J. Health Popul. Nutr.* **2024**, *43*, 185. [CrossRef] [PubMed]

41. Walukonis, K.R.; Beasley, J.; Powers, J.; Boerema, R.; Anderson, K. Impact of finger position on pinch strength. *Phys. Med. Rehabil. Int.* **2017**, *4*, 1108. [CrossRef]
42. Bohannon, R.W.; Wang, Y.C.; Yen, S.C.; Grogan, K.A. Handgrip strength: A comparison of values obtained from the NHANES and NIH Toolbox studies. *Am. J. Occup. Ther.* **2019**, *73*, 73022050801–73022050809. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.