Handgrip Strength: A Population-Based Study of Norms and Age Trajectories for 3- to 17-Year-Olds

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Purpose: To provide normative values and equations for grip strength obtained from a population-based sample of individuals 3 to 17 years of age.

Methods: This cross-sectional study used grip strength data from 2706 participants (49.2% males, 91% right-hand dominant) in the normative phase of the National Institutes of Health Toolbox project.

Results: Analyses showed greater strength in the dominant hand in boys and with each yearly increase in age. Normative data are presented separately for each side, sex, and age. Separate regression equations using age and weight as explanatory variables of grip strength are provided for each side by sex.

Conclusions: The normative data can serve as a guide for interpreting grip strength measurements. The trajectories can be used to investigate the effect of various pathologies and conditions on grip strength during physical maturation. (Pediatr Phys Ther 2017;29:118–123)

Key words: grip, hand, hand strength, NIH Toolbox, sex

INTRODUCTION

Strength impairments are a frequent sequela of cerebral palsy[1,2] and other diseases (eg, cancer and cystic fibrosis)[3,4] and developmental disorders[5-7] affecting children and adolescents. Accurate judgments regarding the presence and degree of strength impairments are dependent on the availability of normative reference values for comparisons. Studies focused on children and adolescents have provided normative data for grip strength and support that grip strength is influenced by age, side (eg, dominant vs nondominant), sex, and body size (Table 1).[4,8-18] The studies are limited, however, in that almost all have used convenience samples and none has included both very young children and adolescents. In this study we provide normative values for grip strength obtained from a population-based sample of boys and girls 3 to 17 years of age.

0898-5669/292-0118
Pediatric Physical Therapy

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Grant Support: This study is funded in whole or in part with Federal funds from the Blueprint for Neuroscience Research and the Office of Behavioral and Social Science Research, National Institutes of Health, under Contract No. HHS-N-260-2006-00007-C, with additional support from the National Children's Study, under Contract No. HHS-N-267-2007-00027-C.

The authors declare no conflicts of interest.

DOI: 10.1097/PEP.0000000000000366

METHODS

This cross-sectional study used grip strength data from the normative phase of the National Institutes of Health (NIH) Toolbox Assessment for Neurological and Behavioral Assessment.[19] This project was designed to develop a comprehensive integrated set of self-reported and performance-based measures of cognitive, motor, and sensory function and emotional health for people ages 3 to 85 years. The Northwestern University Institutional Review Board approved the project. Data were gathered from a general population-based sample of 4859 individuals during August to November of 2011. The norming sample included people with the following characteristics: (1) community-dwelling and noninstitutionalized, (2) ages 3 to 85 years, (3) capable of following test instructions in English or Spanish, and (4) able to give informed consent or, in the case of children, give assent with accompanying informed consent by proxy (ie, parent/guardian). Our goal was to assess a general population sample, which would include the range of health from healthy to unhealthy community-dwelling individuals. Ten sites for the norming study (Atlanta, Chicago,

TABLE 1

Summary of Previous Studies Providing Grip Strength Norms for Children and Adolescents

Study	Sample	Grip Strength Measurement	Significant Explanatory Variables
Rauch et al[4]	*Type*: convenience *Origin*: Germany *Total size/strata size (n)*: 158 boys, 157 girls/not reported *Age/age increments (y)*: 6-19/1	*Dynamometer*: Jamar—first position (younger children), second position (most children and adolescents), third position (some adolescents) *Measurement*: 2 with nondominant hand *Criterion*: best	Age Sex Weight Height Pubertal stage
Ploegmakers et al[8]	*Type*: convenience *Origin*: the Netherlands *Total size/strata size (n)*: 1112 boys, 1129 girls/46-124 *Age/age increments (y)*: 4-15/1	*Dynamometer*: Jamar—first position (4 and 5 y), second position (6-15 y) *Measurement*: 2 with each hand (dominant and nondominant) *Criterion*: not stated	Age Side Sex Weight Height
Yim et al[9]	*Type*: convenience *Origin*: Korea *Total size/strata size (n)*: 370 boys, 342 girls/38-95 *Age/age increments (y)*: 7-12/1	*Dynamometer*: Jamar—second position *Measurement*: 2 with each hand (dominant and nondominant, left and right) *Criterion*: best	Age Side Sex Hand dominance
Molenaar et al[10]	*Type*: convenience *Origin*: the Netherlands *Total size/strata size (n)*: 110 boys, 115 girls/11-15 *Age/age increments (y)*: 4-12/1	*Dynamometer*: "Jamar-like" (lode)—second position *Measurement*: 3 with each hand (dominant and nondominant) *Criterion*: mean of 3	Age Side Sex Weight Height
Ferreira et al[11]	*Type*: population *Origin*: Brazil *Total size/strata size (n)*: 81 boys, 188 girls/not indicated *Age/age increments (y)*: 6-19/2 or 3	*Dynamometer*: Jamar—second position *Measurement*: 3 with each hand (dominant and nondominant) *Criterion*: not stated	Age Side Sex
Cohen et al[12]	*Type*: convenience *Origin*: England *Total size/strata size (n)*: 3773 boys, 3374 girls/220-918 *Age/age increments (y)*: 10-15/1	*Dynamometer*: Takei—adjusted to hand size *Measurement*: 2 with the dominant hand *Criterion*: best	Age Sex Weight Height
Ager et al[13]	*Type*: convenience *Origin*: the United States *Total size/strata size (n)*: 247 boys, 227 girls/23-37 *Age/age increments (y)*: 5-12/1	*Dynamometer*: Jamar—adjusted to hand size *Measurement*: 1 with each hand *Criterion*: mean for 2 hands	Age Sex
De Smet and Vercammen[14]	*Type*: convenience *Origin*: Belgium *Total size/strata size (n)*: 268 boys, 219 girls/9-51 *Age/age increments (y)*: 5-15/1	*Dynamometer*: Jamar—second position *Measurement*: 1 with each hand *Criterion*: 1 of each hand	Age Sex
Mathiowetz et al[15]	*Type*: convenience *Origin*: the United States *Total size/strata size (n)*: 231 boys, 240 girls/26-43 *Age/age increments (y)*: 6-19/2	*Dynamometer*: Jamar—second position *Measurement*: 3 for each hand *Criterion*: not indicated	Age Side Sex
Häger-Ross and Rosblad[16]	*Type*: population *Origin*: Sweden *Total size/strata size (n)*: 267 boys, 263 girls/10-27 *Age/age increments (y)*: 4-16/1	*Dynamometer*: Grippit *Measurement:* 3 for each hand *Criterion:* best	Age Sex Height Weight Hand length Side
McQuiddy et al[17]	*Type*: convenience *Origin*: the United States *Total size/strata size (n)*: 741 boys, 767 girls/38-67 *Age/age increments (y)*: 6-19/1	*Dynamometer*: Jamar *Measurement:* 3 for each hand *Criterion:* not stated	Age Sex
Omar et al[18]	*Type*: convenience *Origin*: Saudi Arabia *Total size/strata size (n)*: 222 boys, 303 girls/20-56 *Age/age increments (y)*: 6-12/1	*Dynamometer*: J-Tech *Measurement*: 3 for each hand *Criterion:* mean	Age Sex

Cincinnati, Columbus, Dallas, Los Angeles, Minneapolis, Philadelphia, Phoenix, and St Louis) were selected to maximize the ability to meet sample size stratified by age, sex, and primary language. Separate samples were collected for people speaking English or Spanish. Within each age range, target quotas were set relative to the US population distribution of race, ethnicity, and level of education (parents' education for children). The sample was primarily urban and suburban dwelling.[19]

Participants

Of the entire sample of study participants, 4566 had grip strength data for both the dominant and nondominant sides. Of these participants, 90 were excluded as outliers because their grip strength values were more than 2.5 standard deviations from the mean for other participants of the same sex and age or because their between side difference in grip strength was 25% or more. Of the 4476 remaining participants, 3138 were between the targeted ages of 3 and 17 years. Four hundred thirty-two of these were excluded because their height or weight data were missing. Thus, data from a total of 2706 participants were included in the final analyses with a comparable representation of boys (49.2%) and girls (50.8%) (Table 2). By self-report, 91% of the sample was right-hand dominant. Although the majority of the sample was white, other races were represented. Nearly 30% of the participants were Hispanic. All participants assented to the study and participants' parents or guardians provided written consent after being informed about the study's purpose and procedures.

Procedures

Demographic information was determined by self-report. One or more trained testers at each testing site measured the grip strength of each hand. A calibrated digital Jamar dynamometer with its handle in the second position was squeezed while participants were seated with their arms by their sides, elbows flexed 90°, and forearms in a neutral position.[20] A single submaximal practice trial was followed after at least 30 seconds by a single maximal trial of 3 to 4 seconds from each hand. Participants were encouraged during this measure by the tester who chanted "harder, harder, harder." The peak force from the maximal trial on each side was recorded. Data obtained by this procedure were shown in the NIH validation phase to be reliable. All testers were trained before test administration and NIH Toolbox training manuals were provided in both English and Spanish. These manuals detail testing procedures.

Statistical Analysis

Analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 15. A 2 (side) × 2 (sex) × 14 (age) mixed general linear model (GLM) analysis was used to identify variables by which normative values should be stratified. For independent variables found to have a significant main or interactive effect on grip strength, pairwise post hoc comparisons were conducted using GLM. Normative descriptive statistics were tabulated. Pearson correlations, partial correlations, and forward multiple linear regression analyses were used to generate normative explanatory equations for grip strength. Based on the numerous hypotheses tested and to reduce the risk of type 1 error, an α level of $P < .005$ was used.

RESULTS

The dominant hand was significantly stronger than the nondominant hand ($F = 298.8$, $P < .0001$), boys were significantly stronger than girls ($F = 354.8$, $P < .0001$), and older children were significantly stronger than younger children ($F = 794.1$, $P < .0001$). There were significant interaction effects on grip strength between side and age ($F = 12.9$, $P < .001$) and between sex and age ($F = 48.2$, $P < .001$). A significant difference in the strength between the dominant and nondominant sides ($P < .005$) was present in 9- to 17-year-olds. There was a significant difference in the strength of boys and girls apparent among 13- to 17-year-olds (Figure 1). Every age group was significantly stronger than each younger age group. Demographic and stratified grip strength norms are presented in Table 2.

Sex, age, height, and weight were significantly associated with grip strength (Table 3). The correlations were higher when boys and girls were analyzed separately. Partial correlations between sex and strength were higher than bivariate correlations between sex and strength. Bivariate correlations of age, height, and weight with strength were higher than partial correlations of the variables with strength. Table 4 provides normative regression equations for describing grip strength. The equations included age and weight as explanatory variables, but age explained the majority of the variance in grip strength. As might be expected, age, height, and weight were collinear.

DISCUSSION

Interpreting measurements obtained from individuals or cohorts of individuals requires the availability of norms. Investigators have provided normative values for grip strength for children and adolescents.[4,8-18] Their studies, however, typically involve convenience samples[4,8-10,12-15,17,18] and rarely include very young children[8,10,16] or adolescents older than 15 years.[4,11,15-17] We are not aware of any study purporting to provide normative data for 3-year-olds. Given the changes in strength accompanying maturation and various diseases and disorders, grip strength norms for the 3- to 17-year age are needed. Based on the results of our GLM analysis and extant literature, normative grip strength data were stratified by side, sex, and age. Stratification by side involved summarizing data separately for the dominant and nondominant hands, an approach used in some,[8-11] but not all,[15] previous studies. Our pairwise comparisons indicated that such stratification may not have been necessary for children younger than 9 years as their grip strength was not significantly different between hands. This finding may have a developmental basis[21] or may be secondary in part to our use of a conservative α with hypothesis testing. Stratifying by sex involved presenting norms separately for boys and girls. This stratification is conventional[4,8-18] but may not be necessary before the age of 13 years. Only at that age and beyond did our pairwise comparisons show boys and girls to have

TABLE 2

Demographic and Grip Strength Values[a] for Boys and Girls 3 to 17 Years of Age

				Dominant Grip Force, kg						Nondominant Grip Force, kg					
					Percentiles						Percentiles				
Age	Sex (n)	Height, m Mean (SD)	Weight, kg Mean (SD)	Mean (SD)	5	10	25	50	75	Mean (SD)	5	10	25	50	75
3	Boy (68)	1.00 (0.09)	16.2 (2.7)	4.0 (1.9)	1.3	1.9	2.6	3.7	5.4	3.8 (1.9)	1.2	1.6	2.4	3.5	5.0
	Girl (62)	1.02 (0.09)	15.8 (2.1)	3.6 (1.4)	1.1	1.5	2.4	3.4	4.6	3.6 (1.7)	1.1	1.5	2.4	3.4	4.6
4	Boy (78)	1.08 (0.10)	18.5 (3.5)	5.7 (2.2)	2.5	3.2	4.1	5.6	7.1	5.4 (2.2)	2.2	2.5	3.8	5.2	6.6
	Girl (91)	1.08 (0.09)	17.5 (3.1)	4.9 (1.8)	1.6	2.4	3.6	4.7	6.0	4.8 (1.7)	2.2	2.4	3.5	4.6	6.2
5	Boy (74)	1.14 (0.12)	20.5 (4.3)	7.4 (2.3)	3.1	4.5	5.9	7.4	8.9	7.3 (2.3)	3.8	4.3	5.4	7.0	8.8
	Girl (81)	1.13 (0.09)	20.7 (4.9)	7.0 (2.2)	4.0	4.2	5.1	6.8	8.4	6.7 (2.0)	3.5	4.0	5.4	6.4	8.2
6	Boy (73)	1.23 (0.10)	24.5 (5.8)	9.9 (2.9)	5.6	6.3	7.5	10.0	11.7	9.7 (3.1)	5.1	5.7	7.1	9.6	12.1
	Girl (86)	1.20 (0.11)	23.9 (5.4)	9.0 (3.0)	3.6	4.1	7.2	9.2	10.7	8.7 (2.8)	4.0	4.7	6.9	8.9	10.6
7	Boy (101)	1.27 (0.11)	27.5 (6.6)	11.2 (3.4)	4.9	6.6	9.1	11.4	13.3	10.9 (3.4)	4.8	5.8	8.8	10.5	13.6
	Girl (90)	1.26 (0.12)	28.1 (6.7)	11.4 (3.8)	3.2	5.5	9.3	11.3	14.4	11.0 (3.3)	4.0	7.2	8.9	11.0	13.6
8	Boy (82)	1.32 (0.12)	28.9 (7.3)	13.3 (3.7)	7.5	8.5	10.6	13.0	16.1	13.2 (3.5)	7.6	8.4	10.6	13.4	15.8
	Girl (83)	1.33 (0.11)	31.0 (7.8)	12.7 (3.4)	7.5	8.1	9.9	12.5	15.0	12.1 (3.0)	7.6	8.4	9.7	12.3	14.1
9	Boy (82)	1.37 (0.10)	33.8 (7.4)	16.2 (4.2)	9.4	10.0	13.5	16.1	19.2	15.5 (3.9)	9.8	11.0	12.6	15.0	17.6
	Girl (78)	1.38 (0.08)	31.9 (6.6)	14.6 (3.3)	9.3	10.5	12.1	14.2	16.6	14.1 (3.6)	8.6	9.6	11.8	13.6	15.7
10	Boy (91)	1.41 (0.09)	40.1 (11.2)	17.8 (4.3)	9.8	12.7	15.7	17.7	19.8	17.0 (4.3)	10.7	11.9	14.6	16.4	19.6
	Girl (98)	1.44 (0.10)	38.8 (9.0)	17.5 (4.4)	10.2	11.9	14.9	17.4	20.9	16.5 (4.4)	9.3	10.9	13.7	16.4	19.0
11	Boy (95)	1.50 (0.09)	47.4 (11.8)	20.9 (4.8)	13.3	15.3	17.7	20.3	23.4	19.9 (4.4)	13.3	14.3	16.7	19.1	22.4
	Girl (94)	1.52 (0.10)	48.0 (12.2)	20.3 (4.7)	12.2	14.7	17.4	20.1	22.7	19.3 (4.3)	12.9	14.5	16.0	19.2	22.2
12	Boy (87)	1.56 (0.09)	51.8 (13.9)	24.2 (6.5)	15.1	17.3	19.4	23.4	27.7	23.1 (6.4)	13.8	17.0	19.8	22.5	25.7
	Girl (103)	1.56 (0.09)	50.8 (12.6)	23.5 (4.7)	14.1	17.9	20.5	23.6	26.6	22.0 (4.7)	13.0	16.5	19.5	21.4	24.7
13	Boy (105)	1.62 (0.10)	57.4 (15.6)	29.5 (7.8)	18.9	20.5	22.7	29.0	35.3	28.8 (7.4)	17.5	19.2	22.4	26.8	33.0
	Girl (92)	1.60 (0.07)	54.9 (12.4)	25.0 (5.3)	15.4	18.5	21.6	25.0	28.7	23.9 (4.7)	15.8	17.7	20.9	24.3	27.1
14	Boy (102)	1.71 (0.09)	65.8 (17.7)	34.2 (7.9)	20.5	23.6	29.1	33.7	39.8	31.6 (7.4)	20.2	23.4	25.5	30.8	36.9
	Girl (111)	1.63 (0.06)	59.1 (14.2)	26.9 (6.0)	14.5	19.0	22.5	26.7	31.9	24.9 (6.1)	14.5	17.6	20.9	25.3	29.2
15	Boy (94)	1.74 (0.09)	68.3 (15.7)	37.7 (8.9)	24.4	26.4	31.9	37.5	42.4	35.8 (8.7)	21.3	25.4	31.9	37.5	42.4
	Girl (102)	1.63 (0.07)	60.8 (14.4)	28.1 (5.3)	19.8	21.2	24.8	27.6	31.9	25.8 (5.1)	18.5	19.2	22.3	25.4	28.7
16	Boy (97)	1.77 (0.09)	73.8 (19.6)	41.0 (10.0)	28.5	30.6	34.5	39.6	47.8	38.6 (9.2)	25.1	29.0	32.7	37.2	43.8
	Girl (99)	1.64 (0.06)	61.3 (14.4)	28.2 (5.4)	19.7	22.5	24.9	27.6	31.5	26.4 (5.4)	15.6	19.1	22.9	27.0	29.2
17	Boy (102)	1.78 (0.07)	80.0 (18.2)	44.5 (10.0)	27.9	31.5	38.7	44.6	50.1	41.9 (9.0)	25.1	29.8	36.8	41.7	47.3
	Girl (105)	1.62 (0.07)	63.7 (20.1)	28.4 (5.8)	16.7	20.6	25.2	28.7	32.3	26.9 (6.3)	16.4	18.9	23.0	26.1	31.4

Abbreviation: SD, standard deviation.

[a]Significant differences ($P < .001$).

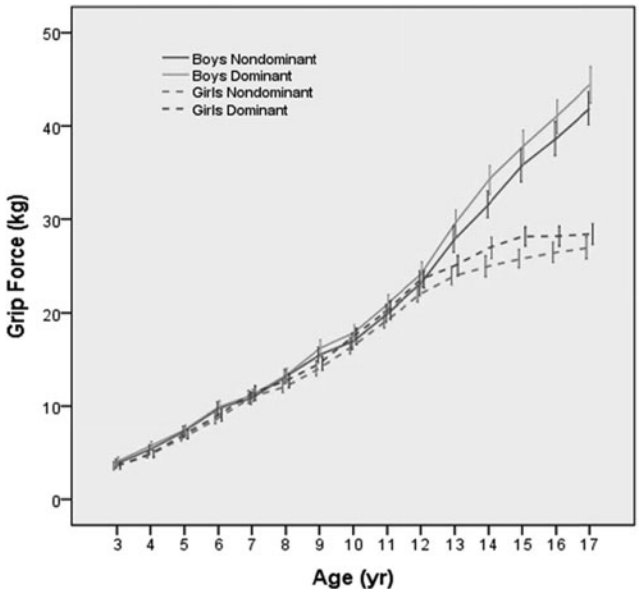

Fig. 1. Mean and 95% confidence intervals of grip forces of the nondominant and dominant sides of boys and girls 3 to 17 years of age.

significantly different grip strengths on both the dominant and nondominant sides. Although some studies report boys to have significantly greater grip strength than girls in all age groups,[9,15] others describe a divergence in the strength of boys and girls around 10 to 13 years of age,[8,14,16] an age at which boys may be reaching puberty. We were not able to relate changes in grip strength to puberty directly as sexual maturity was not measured using the Tanner scale or any other measure in the NIH Toolbox project. Stratification by age involved grouping participants into 1-year increments. Given the findings of our pairwise comparisons, the use of larger 2- or 3-year increments for grip strength norms[11,15] is not supported. This is in contrast with the results obtained from adults for whom consolidation over multiple ages is valid.[22]

On the basis of our correlational and regression analysis, we provided separate regression equations for indicating expected grip strength of the dominant and nondominant hands of boys and girls. The correlation analysis supported that age, height, and weight were all correlated highly with both the dominant and nondominant grip strength of both boys and girls ($r > 0.800$). This is not a novel finding.[8,10,12,16,23] Which of the 3 developmental variables might best explain grip strength? Age appears to be key as bivariate correlations between age and grip strength were higher than bivariate correlations between height or weight and grip strength. Partial correlations between the variables and grip strength were less for age than for height or weight. This suggests that the effect of age, although attenuated by height and weight, was not simply a consequence of increases in height and weight that accompany aging. The forward regression analyses supported that weight added only slightly (about 3.0 percentage points) to the explanation of grip strength supported by age. Height, which has been described as "an essential predictor of muscle strength in children,"[23] made no further independent contribution to the explanation of grip strength.

TABLE 4

Normative Regression Equations for Grip Strength

Sex	Side	Equation[a]	R (R^2 Adjusted)
Boy	Nondominant	−7.15 + 1.97 (age) + 0.17 (weight)	0.901 (0.812)
	Dominant	−7.95 + 2.04 (age) + 0.20 (weight)	0.906 (0.821)
Girl	Nondominant	−2.18 + 1.34 (age) + 0.13 (weight)	0.886 (0.785)
	Dominant	−2.73 + 1.44 (age) + 0.14 (weight)	0.897 (0.804)

[a]Age in years, weight in kilograms.

There are several limitations in this study. First, the sample used to generate grip strength norms was small because of missing or outlier data. Although the sample for each stratum (sample size ranges from 62 to 111) was larger than in many studies,[4,9-11,13-18] it was not sufficient to support additional stratification according to hand dominance or ethnicity. Second, although the sample used in this study was population based, it was limited to children and adolescents residing in the United States. Consequently, the norms may not generalize to other populations outside the United States. Third, in this study, grip strength and numerous other measures were a part of the NIH Toolbox. Whether the same results would have been obtained if grip strength alone was measured is not known. That noted, our normative data are comparable to those reported by other researchers who measured grip strength with a Jamar dynamometer.[14,17] Fourth, although the Jamar dynamometer is recommended by the American Society of Hand Therapists, measurements obtained with it may differ from those obtained with other dynamometers. Using different grip dynamometers generates different grip strength values.[24]

CONCLUSIONS

This study provides normative grip strength data for boys and girls 3 to 17 years of age. The norms provide a standard to which individual patients and patient cohorts can be compared.

TABLE 3

Zero-Order (Partial)[a] Correlations Of Demographic and Anthropometric Variables With Grip Strength

	Dominant Grip Strength			Nondominant Grip Strength		
Independent Variable	All	Boys	Girls	All	Boys	Girls
Sex	−0.167 (−0.272)			−0.173 (−0.280)		
Age	0.856 (0.337)	0.889 (0.393)	0.880 (0.408)	0.850 (0.408)	0.886 (0.402)	0.870 (0.400)
Height	0.857 (0.221)	0.868 (0.128)	0.861 (0.262)	0.848 (0.201)	0.861 (0.111)	0.848 (0.231)
Weight	0.831 (0.316)	0.847 (0.325)	0.819 (0.276)	0.821 (0.295)	0.838 (0.300)	0.808 (0.258)

[a]All correlations are significant at $P < .001$. Partial correlations were calculated while controlling for all other variables.

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