Isometric Strength of Upper Limb Muscles in Children and Adolescents using Hand-Held and Hand-Grip Dynamometry

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Research Article

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Abstract

Purpose: To determine the isometric strength profile of the upper limb muscles of children and adolescents between 7–15 years of age. Furthermore, to (i) identify the age at which differences in isometric strength are observed between sexes; to (ii) determine the age range at which significant progression of isometric strength could be observed in girls and boys; and (iii) identify the role of the isometric strength of each muscle group on the total upper limb strength.

Methods: Cross-sectional study that evaluated the maximum isometric strength of 9 muscle groups of the upper limb of 243 Chilean children and adolescences (female n = 114; male n = 129), split into 9 age groups, separated by 1-year intervals. For this, hand-held dynamometry (make test) and hand-grip dynamometry were used. The mean and standard deviation were calculated for each measurement of maximum isometric strength, grouped by age and sex. A two-factor analysis of variance (age and sex) was performed for the maximum isometric strength of each muscle group and the total upper limb strength. A stepwise multiple linear regression analysis was then performed. The dependent variable was the total upper limb strength, and the independent variables were the maximum isometric strength of each muscle group, sex, height, and age.

Results: From 11 years of age, wrist flexors were the first muscle group that revealed a significant difference in isometric strength in favor of boys ($p = 0.0143$). In boys, the narrowest and earliest age range in the progression of isometric strength was 10 to 12 years for wrist flexors ($p = 0.0392$). Shoulder flexors was the main factor that explained the performance of the total upper limb strength ($R^2 = 0.742$; $p < 0.001$).

Conclusions: The most progressive isometric strength development occurred from age 10 years in the ventral and distal muscles of the upper limb; and from this age the boys begin to present a greater isometric strength than girls. In addition, the isometric strength of shoulder flexors explained the higher total upper limb strength performance.

What Is Know?

- Isometric strength of the upper limb is relevant to assess muscle weakness in several dysfunctions where the assessment of eccentric strength is difficult and not exempt from injuries.
- Youths often have bilateral impairments, necessitating a "between-subject" comparison muscle group that provides reference values to identify possible muscle weaknesses.

What is New?

- The most progressive isometric strength development occurred from age 10 years in the ventral and distal muscles of the upper limb, and from this age, boys begin to present a greater strength than girls.

- The isometric strength of shoulder flexors explained the higher total upper limb strength performance.

Introduction

Muscle strength in children and adolescents can be assessed using isokinetic dynamometry and clinical or field tests [1]. Nevertheless, some of these methods have limitations for their application in pediatric clinical and research. For instance, isokinetic dynamometry presents severe implementation restrictions because the device is expensive, requires user training, requires additional child-specific mechanical arm segments, and has a poor portability. On the other side, manual muscle testing is a useful ordinal measurement scale for patients who have suffered a considerable loss of strength, but limited by their sensitivity in higher grades (4 and 5) and by the dependence of the force applied by the examiner on the evaluated limb [2, 3]. Since the 80s, hand-held dynamometry (HHD) has been widely used in the clinical research of children and adolescents and has proven to be an easy-to-use method with high reliability, validity and responsiveness for the evaluation of muscular strength of the majority of clinically significant muscle groups [4–9].

HHD can be used to assess the isometric strength of the muscle groups of an isolated joint [1]. Isometric strength is defined as an increase in tension of the contractile elements without detecting a change in muscle length or joint position [10, 11]. HHD can provide the maximum (peak) isometric strength during the performance of a standardized test [1, 8]. Two types of measurement tests are described using HHD [12]. An examiner pushes the dynamometer against a subject’s extremity until the subject’s maximal muscular effort is overcome (break test) or keeps the dynamometer stationary while the subject exerts maximum force against it (make test). Various investigations have recommended the use of the make test to obtain reference values of maximum isometric strength, showing greater reliability, validity and responsiveness in the muscle groups of the upper limb [9, 13, 14]. In addition, the make test appears to be more reliable than the break test for hip and elbow strength [12, 15] because performance of the break test may be influenced by the ability of the evaluator to produce the force to try to overcome the strength of the evaluated.

Boys and girls from North America, Latin America, Europe and Oceania do not show differences in the development of strength until the age of 10 years, but at approximately ages 11–12, boys develop greater strength than girls [4, 16–18]. In Chile, Escobar et al. (2017) showed that the difference in strength between boys and girls is observed from the age of 11. However, these observations were measured with the break test using HHD, which gives an approximation of eccentric strength, rather than isometric strength [1, 8]. Knowledge of the isometric strength profile of the upper limb is relevant to assess muscle weakness in neurological and musculoskeletal dysfunctions where the assessment of eccentric strength is difficult and not exempt from injuries [17, 19], especially in dysfunctions that affect upper limb muscles, such as Guillain-Barre syndrome, Duchenne muscular dystrophy, and upper limb fractures, among others [20–22]. For these reasons, it is relevant to register isometric strength of boys and girls through the make test in order to complement the strength profile of Chilean boys and girls. In addition, children and adolescents with musculoskeletal and neurological dysfunctions often have bilateral impairments, necessitating a "between-subject" comparison muscle group that provides reference values to identify possible muscle weaknesses [4, 17, 23].

For these reasons, the primary objective of the investigation was to determine the isometric strength profile of the upper limb muscles of children and adolescents between 7–15 years of age. The secondary objectives were to (i) identify the age at which differences in isometric strength are observed between sexes; to (ii) determine the age range at which significant progression of isometric strength could be observed in girls and boys; and to (iii) identify the role of the isometric strength of each muscle group on the total upper limb strength, adjusted for the variables of sex and age.

Materials & Methods

Design

This study featured a cross-sectional design and was reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [24]. The research complied with all the relevant national regulations and institutional policies, including the Declaration of Helsinki, and was approved by the scientific ethics committee of the Universidad Santo Tomás, Chile (Folio ID-98-19).

Participants

Before participating in the study, all children and their parents were fully informed about the protocol and written informed parental consent and participant assent were obtained. The sample size was calculated based on the largest width of the confidence interval (W) and the largest standard deviation (S) of maximum isometric strength reported in a previous study [17]:

$$Sample\ Size = \frac{4z\alpha'^2 S^2}{W^2}$$

Where zα' = 1.96, S = 0.27, and W = 0.38. The required sample size was a minimum of seven participants per sex per age group. Children between 7–15 years of age from a school located in the central area of Chile were recruited. All participants presented with typical development, Latino ethnicity, and were Spanish language speakers. Ethnicity was reported following the Standards for the Classification of Federal Data on Race and Ethnicity [25]. Participants were included if they had intact cognitive function to understand the orders given by the evaluator. Participants were excluded if they presented with (i) pain during investigation procedures (ii) a history of medical, neurological, or musculoskeletal impairments that could affect strength measurements, (iii) use of medications for pain or musculoskeletal disorders, (iv) previous surgeries of the upper extremities and/or spine, or (v) participation in competitive sports during or in the six months prior to the study measurements.

Measures

Anthropometric measurements (body mass and height) were obtained using a stadiometer (model 220; Seca, Germany). All isometric strength measurements were performed on the dominant upper limb, determined by asking the participants which hand is used to hold a pen and throw a tennis ball. In the case of discrepancies between the test results, participants were asked to indicate their preferred hand. The maximum isometric muscle strengths of the shoulder flexors, shoulder abductors, shoulder medial rotators, shoulder lateral rotators, elbow flexors, elbow extensors, wrist flexors, and wrist extensors were assessed with HHD using a calibrated hand-held dynamometer (MMT 01165, Lafayette Manual Muscle Test System, Lafayette, IN, USA). The order of the muscles tested, the standardized positions, and hand-held dynamometer placement for each muscle group were based on previous reports and are described in Table 1 [4, 6, 16, 17]. The maximum isometric grip strength of the extrinsic and intrinsic hand muscles was assessed with hand-grip dynamometry (HGD) using a calibrated hand-grip dynamometer (Jamar 5030J1, Sammons Preston Rolyan, Bolingbrook, IL, USA) according to the recommendation of the American Society of Hand Therapists [26].

Table 1 near here

The principal researcher trained the evaluator (a physical therapist) in all dynamometry procedures for twelve hours. Participants wore sport clothes, were barefoot, and all measures were taken during one testing session (one hour per participant). To assess the maximum isometric strength of the shoulder, elbow and wrist muscle groups, a make test was used. The evaluator kept the dynamometer stationary while the participant exerted maximum strength against it [1, 12, 15]. For all assessments, the participants were asked to perform the maximum isometric strength on the dynamometer (HHD or HGD, as appropriate), while the evaluator encouraged the participants with a standardized phrase, "harder, harder, harder". For all muscle groups, three attempts were completed, and the peak force (N) was recorded for each one attempt. The average of the three attempts was used for the analysis. Before each muscle group assessment, the participant performed one submaximal contraction. This was performed as a warm-up and to ensure that the task was well understood, and also to ensure that joint stabilization was adequate [17]. Each contraction (attempt) was progressive and was held for five seconds, followed by a 30-second rest period to minimize fatigue affects. The recorded force (N) of all muscle groups, including the extrinsic and intrinsic hand muscles, was divided by the body mass (kg) of each individual. The total upper limb was calculated by adding the normalized maximum isometric strength of the shoulder flexors, shoulder abductors, shoulder medial rotators, shoulder lateral rotators, elbow flexors, elbow extensors, wrist flexors, and wrist extensors.

Statistical analysis

The software SPSS 25.0 was used to perform the statistical analysis of the data. In all tests, an alpha level < 0.05 was considered. To complete the primary objective of this research, the mean and standard deviation were calculated for each measurement of maximum isometric strength, grouped by age and sex. Data were considered to be outliers if they were > 3 standard deviations from the mean; in these cases, the data was removed. Intrarater reliability was assessed for maximum isometric strength using the standard error of the measurement (SEM) and intraclass correlation coefficient (ICC; two-way random, absolute agreement, average measure). The Shapiro-Wilk test was used to assess the normality distribution of all the data.

To complete the first secondary objectives, a two-factor analysis of variance (ANOVA) (age and sex) was performed for the variable maximum isometric strength of each muscle group and the total upper limb strength. In the case of significant interactions, a post-hoc analysis was performed with Bonferroni's multiple comparison test. To complete the second secondary objective, the narrowest age range of strength was identified by significant differences ($p < 0.05$) observed between the lowest and highest age of the interval selected.

Finally, to meet the third secondary objective, the relationship between the maximum isometric strength of each muscle group and the total upper limb strength was analyzed using Pearson's test, in which a correlation coefficient (r) from 0–0.4 was considered as weak, 0.41–0.7 as moderate, and 0.71–1.0 as strong. A stepwise multiple linear regression analysis was then performed. The dependent variable was the total upper limb strength, and the independent variables were the maximum isometric strength of each muscle group, adjusted for sex, height, and age. For this method, the independent variable that showed the strongest, simple, significant correlation with the total upper limb strength was initially selected for the analysis. The remaining variables that showed simple significant correlations (from highest to lowest correlation) were consecutively added to this model. The goodness of fit was determined by means of the R^2 coefficient and its percentage of change. In addition, collinearity diagnoses were verified through values less than 0.10 tolerance and the identification of the Variance Inflation Factor, opting to eliminate the variables that showed collinearity with a Variance Inflation Factor > 10, in order to define the definitive multiple linear regression model.

Results

A total of 252 individuals were recruited. Two hundred forty-three individuals (female, n = 114; male, n = 129) were included in the final analysis. Nine children were excluded: five children who were unable to clearly understand the evaluator's directions, two children who demonstrated greater strength than the evaluator during shoulder muscle tests, and two outliers. Figure 1 summarizes the maximum isometric strength by means of superimposed symbols (at the mean) for each muscle, age, and sex.

Figure 1 near here

Table 2 shows the total number of participants grouped by age and the average weight, height, and body mass index for each group. In addition, the results demonstrated excellent intrarater reliability for maximum isometric strength testing (ICC = 0.79–0.94; SEM = 0.04–0.06 N/kg). There were significant differences in height between the boys and girls from ages 13 and higher, but no differences in body mass or body mass index were observed for any age group.

Table 2 near here

The mean and standard deviation for the maximum isometric strength for all muscle groups and ages of both sexes are reported in Table 3 (strength values normalized to body mass in N/kg). The two-way ANOVA reported significant interactions between factors (age x sex) for elbow flexors (df = 8; F = 2.056; p = 0.0412), wrist flexors (df = 8; F = 2.483; p = 0.0134) and extrinsic and intrinsic hand muscles (df = 8; F = 2.067; p = 0.0400). Multiple comparisons showed significant differences in age and sex. As depicted in Table 3, for the boys, the narrowest age range in the progression of maximum isometric strength were: 10–12 years for wrist flexors (mean difference (MD) = -0.38; p = 0.0392), 11–13 years for elbow flexors (MD = -0.71; p = 0.0074), and 13–15 years for extrinsic and intrinsic hand muscles (MD = -0.16; p = 0.0012). In the girls, no significant differences were observed between those aged 7–15 years in the maximum isometric strength of any muscle group.

Table 3 near here

Figure 1 shows the significant differences in maximum isometric strength between the sexes. From 11 years of age, the wrist flexors were the first muscle group that revealed a significant difference in maximum isometric strength in favor of the boys (p = 0.0143). These differences in maximum isometric strength between the sexes were consolidated at 15 years of age, with the observation of three muscle groups with higher values in boys: elbow flexors (p = 0.0268), wrist flexors, and extrinsic and intrinsic hand muscles (p = 0.0001). In this sense, boys showed greater total upper limb strength compared to girls only at 15 years of age (p = 0.0269); figure 2 shows graphically these differences between sex only at 15 years.

Figure 2 near here

Total upper limb strength showed a moderate to strong significant correlation with all muscle groups (r = 0.62–0.86; p = 0.001). Conversely, total upper limb strength did not show significant correlation with age (r = 0.12; p = 0.058) or height (r = 0.01; p = 0.919). The stepwise multiple linear regression model (Table 4) revealed that the shoulder flexors, shoulder abductors, shoulder medial rotators, and wrist flexors explained the highest percentage of variance (R^2 = 0.933; p < 0.001) in total upper limb strength. Of these, the shoulder flexor group (b = 1.12; standard error = 0.06; 95% confidence interval [CI] = 1.00, 1.24) was the main factor that explained the performance of the total upper limb strength (R^2 = 0.742; p < 0.001). The remaining muscle groups explained a change in R^2 between 0.004–0.030 points (p < 0.001). The sum of age (p = 0.288), sex (p = 0.236), and height (p = 0.356) did not improve the prediction of total upper limb strength.

Table 4 near here

Discussion

This study presented a profile of upper limb isometric strength by registering nine muscle groups during the development period of boys and girls aged between 7–15 years. These isometric strength values may be used as a complement to the Chilean strength profile obtained in previous research that focused on the eccentric strength of the upper limb using HHD [16]. In this way, this isometric strength report may help not only as a "within-subject" comparison tool to assess the development of isometric strength, but also as a "between-subject" comparison tool to assess possible isometric strength deficits in relation to a standard profile of typically developing boys and girls. Our research also revealed that: (i) from 11 years of age, boys begin to present greater isometric strength than girls (wrist flexors), a difference that consolidates at 15 years of age (elbow flexors, wrist flexors, extrinsic-intrinsic hand muscles, and total upper limb strength); (ii) in boys, the most progressive development of isometric strength (with significant differences in a narrow range of two years) occurred from 10 years of age in the ventral and distal muscles of the upper limb; and (iii) the isometric strength of the shoulder flexors, shoulder abductors, shoulder medial rotators, and wrist flexors explained the highest performance of the total upper limb isometric strength.

Isometric strength has been investigated in boys and girls of various populations and ethnicities [4, 17, 23]. In Portuguese-speaking Latin American children, the earliest age (10 years) has been reported at which the greatest abrupt change in strength occurs, specifically of the elbow flexor and extensor muscles [4], followed by French-speaking North American children, which this change occurs at 11 years of age, mainly of the shoulder abductor and elbow flexor muscles [17]. In the present study, the greatest abrupt change in muscle strength occurs at age 10, with results similar to those mentioned above [4, 17]; however, this greater progressive development of strength occurred in the ventral and distal muscles of the upper limb. Although there are slight differences between children from different latitudes of the world, previous reports have shown that between 10–11 years is the age interval that is relatively stable between populations, at which the more abrupt age-related changes in the strength progression of the upper limb muscles occurs. The differences reported may be due to variations in the methodologies used to calculate and report muscle force output [27, 28] [i.e., the report of the torque/muscle force per lever arm [6, 17, 23] rather than force normalized by body mass [4, 9, 16]]. On the other hand, the differences observed may be due to the isometric strength evaluation methods, such as the use of belts for joint stabilization [6, 17, 23] or the use of the break test. In addition, this last method has questionable reliability for measuring muscle strength using HHD and the procedure may put children at a higher risk of injuries than a make test [17]. For these reasons, we recommend adequately informing the evaluation methodology and reporting results in studies related to maximal muscle isometric strength.

Strength throughout the childhood and youth periods is influenced by the development of lean and fat mass [29–31], maturation of the central nervous system [32], and gonadal steroid hormone concentrations [33]; all these factors are strongly influenced by genetic expression [33]. These factors are observed during puberty, which explains why girls and boys show a greater change in strength development during the 10–13 years. A pubertal growth spurt, that is, the fast and intense increase in the rate of growth in height and weight that occurs during the adolescent stage [33], take off, on average, at 9–10 years of age in girls and 11–12 years in boys, and have an average peak height velocity of 12 and

14 years, respectively [34]. For these reasons, the anticipated development of bone length (height) in girls may justify the tendency of higher values of isometric strength in muscles with a greater muscle fiber length, and therefore, a greater lever arm at the joint level, such as the flexors of the elbow, elbow extensors, and wrist flexors (Figure 1). On the other hand, accelerated growth during puberty is not only experienced by the bone, but also by the muscle [29, 30]. In fact, it has been observed that muscle mass experiences greater growth during middle adolescence (12 –16 years) in boys and girls [30, 33]. In this sense, our results on isometric strength, and those of Escobar et al. (2017) on eccentric strength, show that at approximately 11 years of age, the first differences between the sexes are observed, apparently influenced by bone length (height), more than by body mass. However, in the late stage of puberty, fat mass mainly increases in females [33, 35], which negatively affects the metabolic and contractile properties of muscle fibers in girls [31] and in this way could partly explain the consolidated differences in muscle strength between the sexes at 15 years (see Figure 2).

To our knowledge, the present investigation is the only study that has evaluated the isometric strength of most of the muscle groups of the upper limb. Previous reports have evaluated the strength of some muscles of the lower and upper limb, and their role in total body strength [16, 17], in which it was observed that total body strength is predicted in a higher percentage of variability by the elbow and knee extensor muscles. In our investigation, the shoulder flexors, shoulder abductors, medial shoulder rotators, and wrist flexors explained the higher total upper limb strength performance (R^2 = 0.933). Of these, the shoulder flexors were the muscle group that contributed the greatest proportion (change in R^2 = 0.742) to the prediction model of total upper limb strength; therefore, it can be considered as the target muscle group to be prospectively evaluated in the development of the total upper limb strength in girls and boys, in a simple and abbreviated way.

The present investigation has some limitations. First, the sample was selected for the convenience of a population of children and adolescents from a single school. This did not allow the isometric muscle strength data to be considered as reference values. Finally, although the study identified that the sample was mostly Latino and Spanish-speaking, the ethnicity of the participants was not specifically investigated, considering that in Chile, there are a large number of indigenous peoples.

Conclusions

This study determined the isometric strength profile of the upper limb muscles of Chilean children and adolescents between 7–15 years of age. This study illustrated that the most progressive isometric strength development occurred from age 10 years in the ventral and distal muscles of the upper limb, and from this age, boys begin to present a greater isometric strength than girls; a difference that consolidates at 15 years of age. In addition, the isometric strength of the shoulder flexors, shoulder abductors, shoulder medial rotators, and wrist flexors explained the higher total upper limb strength performance. These results may be useful as a "within-subject" comparison tool to assess the development of isometric strength, and as a "between-subject" comparison tool to assess possible isometric strength deficits, especially in bilateral impairments, in relation to a standard profile of typically developing boys and girls.

Abbreviations

HHD	Hand-held dynamometry
HGD	Hand-grip dynamometry
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
ANOVA	Analysis of variance

Declarations

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Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Authors Contributions

GMR, ARG, SSV, EGM, SSR, and EUS contributed to study concept, design, data analyses, interpretation of data and drafting of the manuscript. ARG and SSV contributed to data collection.

Ethics approval

The research complied with all the relevant national regulations and institutional policies, including the Declaration of Helsinki, and was approved by the scientific ethics committee of the Universidad Santo Tomás, Chile (Folio ID-98-19).

Consent to participate

All participants gave informed consent to participate. Likewise, informed consent was obtained from the parents.

Consent to publish

All participants gave informed consent to publish data from the study.

References

1. Jones M, Stratton G (2000) **Muscle function assessment in children**. Acta Paediatr **89**:753–761. https://doi.org/10.1111/j.1651-2227.2000.tb18258.x
2. Bohannon RW (2005) **Manual muscle testing: does it meet the standards of an adequate screening test?** Clin Rehabil **19**:662–667. https://doi.org/10.1191/0269215505cr873oa
3. Herbison GJ, Isaac Z, Cohen ME, Ditunno JF (1996) **Strength post-spinal cord injury: myometer vs manual muscle test**. Spinal Cord **34**:543–548. https://doi.org/10.1038/sc.1996.98
4. Daloia LMT, Leonardi-Figueiredo MM, Martinez EZ, Mattiello-Sverzut AC (2018) **Isometric muscle strength in children and adolescents using Handheld dynamometry: reliability and normative data for the Brazilian population**. Braz J Phys Ther **22**:474–483. https://doi.org/10.1016/j.bjpt.2018.04.006
5. Davis PR, McKay MJ, Baldwin JN, **et al** (2017) **Repeatability, consistency, and accuracy of hand-held dynamometry with and without fixation for measuring ankle plantarflexion strength in healthy adolescents and adults**. Muscle Nerve **56**:896–900. https://doi.org/10.1002/mus.25576
6. Hébert LJ, Maltais DB, Lepage C, **et al** (2011) **Isometric Muscle Strength in Youth Assessed by Hand-held Dynamometry: A Feasibility, Reliability, and Validity Study A Feasibility, Reliability, and Validity Study**. Pediatr Phys Ther **23**:289–299. https://doi.org/10.1097/PEP.0b013e318227ccff
7. Mahony K, Hunt A, Daley D, **et al** (2009) **Inter-Tester Reliability and Precision of Manual Muscle Testing and Hand-Held Dynamometry in Lower Limb Muscles of Children with Spina Bifida**. Phys Occup Ther Pediatr **29**:44–59. https://doi.org/10.1080/01942630802574858
8. Schrama PPM, Stenneberg MS, Lucas C, **van** Trijffel E (2014) **Intraexaminer Reliability of Hand-Held Dynamometry in the Upper Extremity: A Systematic Review**. Arch Phys Med Rehabil **95**:2444–2469. https://doi.org/10.1016/j.apmr.2014.05.019
9. **van den** Beld W, **van der** Sanden G, Sengers R, **et al** (2006) **Validity and reproducibility of hand-held dynamometry in children aged 4–11 years**. J Rehabil Med **38**:57–64. https://doi.org/10.1080/16501970510044043
10. Hamill J (2015) **Biomechanical Basis of Human Movement**
11. Komi PV (1984) **Physiological and Biomechanical Correlates of Muscle Function: Effects of Muscle Structure and Stretch-Shortening Cycle on Force and Speed**. Exerc Sport Sci Rev **12**:81–122. https://doi.org/10.1249/00003677-198401000-00006
12. Stratford PW, Balsor BE (1994) **A Comparison of Make and Break Tests Using a Hand-Held Dynamometer and the Kin-Com**. J Orthop Sports Phys Ther **19**:28–32. https://doi.org/10.2519/jospt.1994.19.1.28
13. Fieseler G, Molitor T, Irlenbusch L, **et al** (2015) **Intrarater reliability of goniometry and hand-held dynamometry for shoulder and elbow examinations in female team handball athletes and asymptomatic volunteers**. Arch Orthop Trauma Surg **135**:1719–1726. https://doi.org/10.1007/s00402-015-2331-6

14. Romero-Franco N, Fernández-Domínguez JC, Montaño-Munuera JA, **et al** (2019) **Validity and reliability of a low-cost dynamometer to assess maximal isometric strength of upper limb: Low cost dynamometry and isometric strength of upper limb**. J Sports Sci **37**:1787–1793. https://doi.org/10.1080/02640414.2019.1594570
15. Schmidt J, Iverson J, Brown S, Thompson PA (2013) **Comparative reliability of the make and break tests for hip abduction assessment**. Physiother Theory Pract **29**:648–657. https://doi.org/10.3109/09593985.2013.782518
16. Escobar RG, Munoz KT, Dominguez A, **et al** (2017) **Maximal isometric muscle strength values obtained By hand-held dynamometry in children between 6 and 15 years of age**. Muscle Nerve **55**:16–22. https://doi.org/10.1002/mus.25180
17. Hébert LJ, Maltais DB, Lepage C, **et al** (2015) **Hand-Held Dynamometry Isometric Torque Reference Values for Children and Adolescents**. Pediatr Phys Ther **27**:414–423. https://doi.org/10.1097/PEP.0000000000000179
18. McKay MJ, Baldwin JN, Ferreira P, **et al** (2017) **Normative reference values for strength and flexibility of 1,000 children and adults**. Neurology **88**:36–43. https://doi.org/10.1212/WNL.0000000000003466
19. Seagraves FE, Horvat M (1995) **Comparison of Isometric Test Procedures to Assess Muscular Strength in Elementary School Girls**. Pediatr Exerc Sci **7**:61–68. https://doi.org/10.1123/pes.7.1.61
20. Demir G, Bulut N, Yılmaz Ö, **et al** (2020) **Manual ability and upper limb performance in nonambulatory stage of Duchenne muscular dystrophy**. Arch Pédiatrie **27**:304–309. https://doi.org/10.1016/j.arcped.2020.06.007
21. Lee JH, Sung IY, Rew IS (2008) **Clinical presentation and prognosis of childhood Guillain-Barré syndrome**. J Paediatr Child Health **44**:449–454. https://doi.org/10.1111/j.1440-1754.2008.01325.x
22. Wang H, Feng C, Liu H, **et al** (2019) **Epidemiologic Features of Traumatic Fractures in Children and Adolescents: A 9-Year Retrospective Study**. BioMed Res Int **2019**:1–8. https://doi.org/10.1155/2019/8019063
23. Eek MN, Kroksmark A-K, Beckung E (2006) **Isometric Muscle Torque in Children 5 to 15 Years of Age: Normative Data**. Arch Phys Med Rehabil **87**:1091–1099. https://doi.org/10.1016/j.apmr.2006.05.012
24. **von** Elm E, Altman DG, Egger M, **et al** (2007) **The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for Reporting Observational Studies**. PLoS Med **4**:e296. https://doi.org/10.1371/journal.pmed.0040296
25. **White House** (1997) **Revisions to the Standards for the Classification of Federal Data on Race and Ethnicity**. https://obamawhitehouse.archives.gov/omb/fedreg_1997standards. **Accessed 28 May 2021**
26. Fess E (1992) **Grip strength**. **In**: **Casanova JS**, **editor**. **Clinical Assessment Recommendations**, **American Society of Hand Therapists**. **2nd ed**, **Chicago**, **IL**, **USA**
27. Bohannon RW (2011) **Literature reporting normative data for muscle strength measured by hand-held dynamometry: A systematic review**. Isokinet Exerc Sci **19**:143–147. https://doi.org/10.3233/IES-

2011-0415

28. Garcia MAC, Souza VH (2020) **The (un)standardized use of handheld dynamometers on the evaluation of muscle force output**. Braz J Phys Ther **24**:88–89. https://doi.org/10.1016/j.bjpt.2019.10.004
29. Baxter-Jones ADG, Eisenmann JC, Sherar LB (2005) **Controlling for Maturation in Pediatric Exercise Science**. Pediatr Exerc Sci **17**:18–30. https://doi.org/10.1123/pes.17.1.18
30. Corso M (2018) **Developmental changes in the youth athlete: implications for movement, skills acquisition, performance and injuries**. J Can Chiropr Assoc **62**:150–160
31. Orsso CE, Tibaes JRB, Oliveira CLP, **et al** (2019) **Low muscle mass and strength in pediatrics patients: Why should we care?** Clin Nutr **38**:2002–2015. https://doi.org/10.1016/j.clnu.2019.04.012
32. Hedman AM, **van** Haren NEM, Schnack HG, **et al** (2012) **Human brain changes across the life span: A review of 56 longitudinal magnetic resonance imaging studies**. Hum Brain Mapp **33**:1987–2002. https://doi.org/10.1002/hbm.21334
33. Soliman A, Sanctis V, Elalaily R, Bedair S (2014) **Advances in pubertal growth and factors influencing it: Can we increase pubertal growth?** Indian J Endocrinol Metab **18**:53. https://doi.org/10.4103/2230-8210.145075
34. **Committee on the Neurobiological and Socio-behavioral Science of Adolescent Development and Its Applications**, **Board on Children, Youth, and Families, Division of Behavioral and Social Sciences and Education**, **et al** (2019) **The Promise of Adolescence: Realizing Opportunity for All Youth**. National Academies Press, **Washington, D.C.**
35. Orsso CE, Colin-Ramirez E, Field CJ, **et al** (2020) **Adipose Tissue Development and Expansion from the Womb to Adolescence: An Overview**. Nutrients **12**:2735. https://doi.org/10.3390/nu12092735

Tables

Table 1. Order of muscles evaluated, standardized positions, and hand-held dynamometer placement for each muscle group.

Muscle Group	Participant position	Dynamometer position
Shoulder Flexor	Sitting neutral position with feet on the ground. 90º shoulder flexion, 90º elbow flexion, and supinated forearm.	Perpendicular, on the anterior surface of the distal third of the arm.
Shoulder Abductors	Sitting neutral position with feet on the ground. 90º shoulder abduction, 90º elbow flexion, and forearm in a neutral position.	Perpendicular, on the lateral surface of the distal third of the arm, just above the lateral epicondyle.
Shoulder Medial Rotators	Sitting neutral position with feet on the ground. 0º shoulder abduction, 90º elbow flexion, and forearm in a neutral position.	Perpendicular, on the posterior surface of the distal third of the forearm, just proximal to the wrist.
Shoulder Lateral Rotators	Sitting neutral position with feet on the ground. 0º shoulder abduction, 90º elbow flexion, and forearm in a neutral position.	Perpendicular, on the anterior surface of the distal third of the forearm, just proximal to the wrist.
Elbow Flexors	Supine position on a stretcher. 0º shoulder abduction, 90º elbow flexion, and forearm in full supination.	Perpendicular, on the anterior surface of the distal third of the forearm, just proximal to the wrist.
Elbow Extensors	Supine position on a stretcher. 0º shoulder abduction, 90º elbow flexion, and forearm in full supination.	Perpendicular, on the posterior surface of the distal third of the forearm, just proximal to the wrist.
Wrist Flexors	Supine position on a stretcher. 0º shoulder abduction, 0º elbow flexion, and forearm in full supination. 30º wrist flexion and fingers extended.	Perpendicular, on the palmar surface of the hand, proximal to the metacarpophalangeal joint.
Wrist Extensors	Supine position on a stretcher. 0º shoulder abduction, 0º elbow flexion, and forearm in full supination. 30º wrist flexion and fingers extended.	Perpendicular, on the dorsal surface of the hand, proximal to the metacarpophalangeal joint.

Table 2. Body mass, height and body mass index grouped by age.

		Age (years)								
	Sex	**7**	8	**9**	**10**	**11**	**12**	**13***	**14***	**15***
Number of participants (n)	F	13	16	14	15	11	14	13	11	7
	M	7	16	19	18	19	12	19	12	7
Body Mass (kg)	F	28.4	30.9	35.7	41.0	49.2	54.7	56.2	65.7	63.3
		5.9	8.2	7.0	8.4	14.0	14.7	9.8	15.4	8.9
	M	30.1	32.2	37.1	41.5	48.3	53.4	58.3	59.2	65.7
		4.5	8.8	9.9	7.6	11.7	15.5	13.3	12.8	11.8
Height (m)	F	1.26	1.31	1.35	1.41	1.44	1.52	1.56	1.60	1.64
		0.05	0.07	0.06	0.05	0.09	0.07	0.05	0.06	0.08
	M	1.29	1.29	1.36	1.42	1.49	1.51	1.62	1.66	1.70
		0.03	0.07	0.07	0.05	0.09	0.13	0.08	0.06	0.07
Body Mass Index (kg/m^2)	F	17.8	17.8	19.5	20.4	23.3	23.4	23.0	25.5	23.5
		2.8	2.9	3.4	3.5	4.7	5.2	3.5	5.8	2.0
	M	18.1	19.2	19.7	20.4	21.6	22.9	22.1	21.5	22.7
		2.4	3.9	3.8	3.1	3.9	3.6	4.4	3.7	2.8

[a] Mean and standard deviation (SD). *Significant differences in height between girls and boys ($p < 0.05$).

Table 3. Mean and standard deviation of maximal isometric strength normalized to body mass in N/kg for all muscle groups of both sexes (n = 243). The dark gray color shows the narrowest age range in the progression of strength –identified by significant differences ($p < 0.05$) between the lowest and highest age of the selected interval– in both girls and boys in all age groups.

Muscle Group	Sex		Age (years) 7	8	9	10	11	12	13	14	15
Shoulder Flexors	F	Mean	1.99	2.03	1.67	2.09	1.96	2.01	1.97	1.82	1.75
		SD	0.57	0.24	0.44	0.76	0.60	0.39	0.59	0.48	0.22
	M	Mean	1.99	2.07	1.70	2.18	1.93	2.12	2.39	2.21	2.47
		SD	0.53	0.49	0.44	0.69	0.55	0.51	0.53	0.57	0.57
Shoulder Abductors	F	Mean	2.02	1.78	1.79	1.92	1.92	1.94	1.95	1.83	1.77
		SD	0.65	0.36	0.63	0.66	0.50	0.40	0.65	0.55	0.35
	M	Mean	2.34	2.05	1.70	2.08	1.97	2.02	2.17	2.30	2.57
		SD	0.59	0.44	0.56	0.54	0.50	0.46	0.54	0.75	0.54
Shoulder Medial Rotators	F	Mean	1.57	1.55	1.44	1.45	1.51	1.46	1.37	1.36	1.50
		SD	0.33	0.32	0.38	0.47	0.51	0.42	0.32	0.36	0.31
	M	Mean	1.65	1.56	1.64	1.81	1.76	1.66	1.75	1.73	2.08
		SD	0.30	0.30	0.45	0.47	0.46	0.48	0.46	0.41	0.50
Shoulder Lateral Rotators	F	Mean	1.13	1.28	0.98	1.05	1.07	1.12	1.17	1.01	0.99
		SD	0.27	0.23	0.31	0.33	0.25	0.30	0.21	0.22	0.17
	M	Mean	1.16	1.20	1.06	1.04	1.37	1.39	1.16	1.29	1.30
		SD	0.26	0.24	0.30	0.30	0.45	0.39	0.32	0.63	0.14
Elbow Flexors	F	Mean	2.34	2.56	2.05	2.18	2.17	2.31	2.48	2.37	2.50
		SD	0.58	0.56	0.41	0.68	0.50	0.44	0.53	0.58	0.37
	M	Mean	2.14	2.43	2.29	2.33	2.31	2.37	3.03	3.01	3.44
		SD	0.44	0.69	0.58	0.64	0.55	0.69	0.62	0.72	0.69
Elbow Extensors	F	Mean	2.08	2.10	1.79	1.77	1.86	1.85	1.71	1.61	1.82
		SD	0.55	0.34	0.33	0.53	0.68	0.41	0.35	0.41	0.27
	M	Mean	1.65	1.85	1.92	1.89	2.15	2.08	2.12	1.89	2.01
		SD	0.29	0.54	0.49	0.32	0.46	0.56	0.47	0.50	0.25
Wrist Flexors	F	Mean	1.27	1.13	1.06	1.01	0.97	1.16	1.21	1.07	1.01
		SD	0.28	0.27	0.29	0.21	0.37	0.26	0.37	0.34	0.23
	M	Mean	1.18	1.14	1.13	1.12	1.35	1.51	1.27	1.41	1.52

		SD	0.34	0.29	0.30	0.38	0.43	0.33	0.30	0.44	0.36
Wrist Extensors	F	Mean	0.99	1.15	1.05	1.06	1.06	1.03	0.81	0.97	0.95
		SD	0.19	0.20	0.23	0.24	0.40	0.36	0.27	0.23	0.17
	M	Mean	1.23	1.23	1.22	1.13	1.27	1.32	1.04	1.18	1.28
		SD	0.47	0.35	0.35	0.30	0.44	0.51	0.28	0.39	0.15
Extrinsic-Intrinsic Hand Muscles	F	Mean	0.37	0.37	0.35	0.39	0.37	0.41	0.41	0.43	0.43
		SD	0.09	0.06	0.09	0.08	0.07	0.09	0.05	0.12	0.06
	M	Mean	0.40	0.41	0.39	0.42	0.39	0.42	0.47	0.49	0.59
		SD	0.11	0.08	0.09	0.08	0.08	0.11	0.13	0.11	0.10
Total Upper Limb	F	Mean	13.8	13.9	12.2	12.9	12.9	13.1	13.0	12.5	12.7
		SD	2.8	1.5	2.6	3.5	3.2	2.2	2.8	2.9	1.9
	M	Mean	13.7	13.9	13.0	14.0	14.5	14.9	15.4	15.6	17.3
		SD	2.8	2.8	3.0	2.9	3.0	3.0	3.0	3.9	2.7

Table 4. Multiple linear regression model of the total upper limb strength adjusted by the addition of factors (independent variables).

	R^2	ΔR^2*	b	SE	95% CI		*p*-value
Shoulder Flexors	0.742	0.742	1.12	0.06	1.00	1.24	0.001
Shoulder Abductors	0.815	0.073	1.08	0.05	0.97	1.18	0.001
Shoulder Medial Rotators	0.880	0.065	1.13	0.06	1.01	1.25	0.001
Wrist Flexors	0.933	0.053	1.09	0.08	0.92	1.25	0.001
Elbow Extensors	0.963	0.030	1.21	0.05	1.10	1.32	0.001
Extrinsic-Intrinsic Hand Muscles	0.971	0.008	2.15	0.26	1.63	2.67	0.001
Shoulder Lateral Rotators	0.979	0.007	0.92	0.07	0.77	1.07	0.001
Wrist Extensors	0.983	0.004	0.88	0.07	0.73	1.03	0.001
Elbow Flexors	0.991	0.009	0.56	0.03	0.48	0.63	0.001

SE, standard error; CI, confidence interval. *ΔR^2 represents the percentage of variability (change) that explains the consecutive addition of each of the independent variables to the regression model.

Figures

Figure 1

A linear development of maximum isometric strength for boys and girls. * Significant differences between girls and boys ($p < 0.05$)

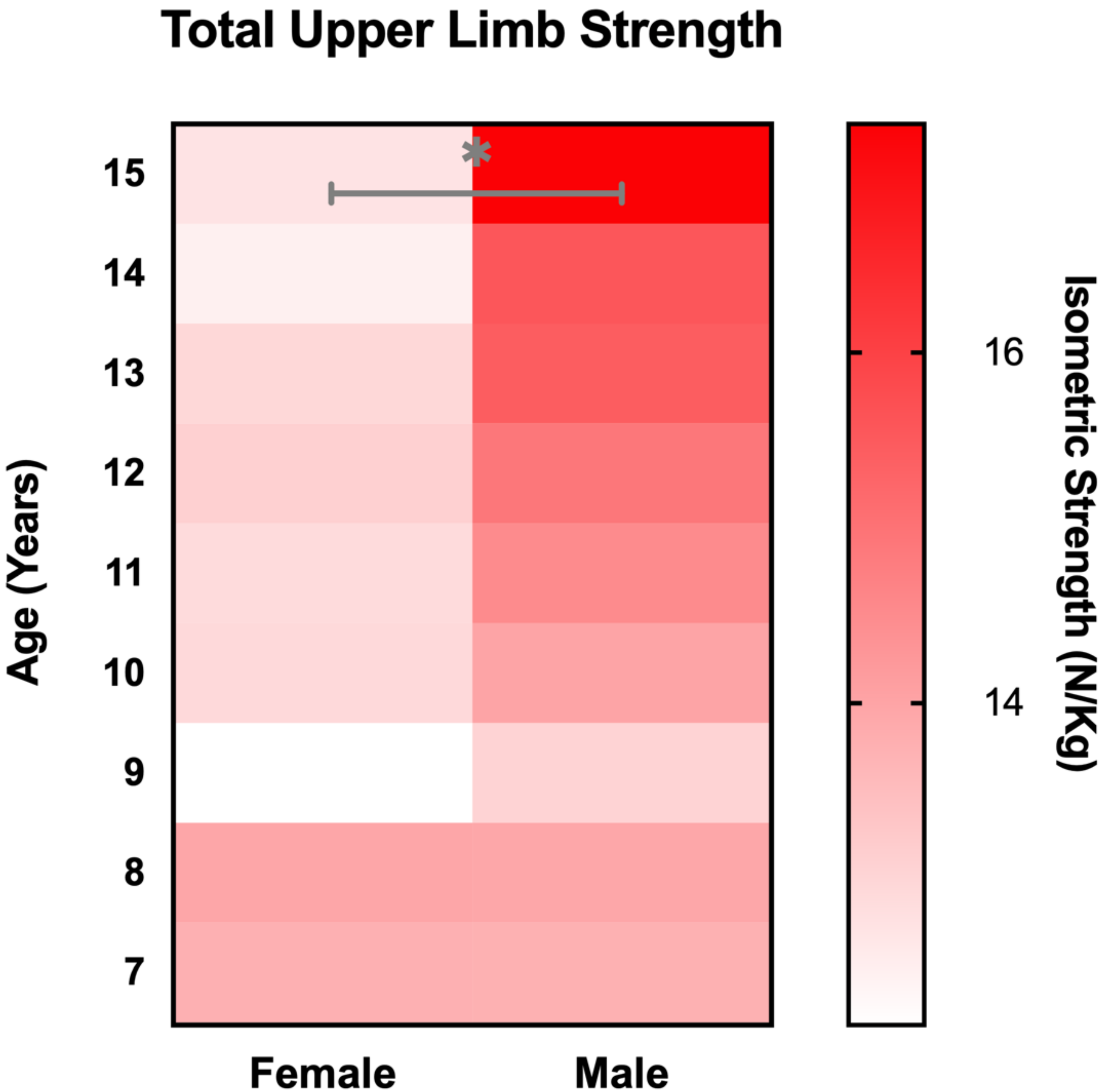

Figure 2

Total upper limb strength. Boys demonstrate greater total upper limb strength compared to girls only at 15 years of age. * Significant differences between girls and boys ($p < 0.05$)