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ORIGINAL ARTICLE

Isometric muscle torque in Chilean children and adolescents evaluated by manual maintenance dynamometry: a reliability study

Torque muscular isométrico en niñas, niños, y adolescentes chilenos evaluado mediante dinamometría de mantención manual: un estudio de confiabilidad

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What do we know about the subject matter of this study?

There are few reliability studies on a hand-held dynamometry protocol to determine maximal isometric muscle torque in children and adolescents. In the Chilean pediatric population, no reliability values have been reported with this technique.

What does this study contribute to what is already known?

We developed a reliability study to determine the reliability of hand-held dynamometry to obtain maximal isometric torque in upper and lower limb muscles, reporting good to excellent inter- and intra-rater reliability in all muscle groups evaluated.

Abstract

The measurement of isometric muscle torque with hand-held dynamometry is a technique little studied in the pediatric setting for the evaluation of maximal isometric muscle strength. **Objective:** to determine the reliability of hand-held dynamometry to obtain the maximal isometric torque of upper and lower limb muscle groups in Chilean children and adolescents. **Patients and Methods:** Cross-sectional study. Seventy-two participants aged between 7 and 15 years were selected from a school in Talca. Maximal isometric torque was recorded in 15 muscle groups of upper and lower limbs through hand-held dynamometry. Intra- and inter-rater evaluation was used, applying the intraclass correlation coefficient (ICC) to determine the reliability of the tests and Bland-Altman plots to evaluate

Keywords:
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concordance. **Results:** The results demonstrated good to excellent inter-rater reliability (ICC = 0.85-0.98) and intra-rater reliability (ICC = 0.87-0.98). Only two groups, hip extensors and abductors, showed good inter-rater reliability (ICC = 0.85 and ICC = 0.88, respectively); and one group, the ankle dorsiflexors, showed good intra-rater reliability (ICC = 0.87). 100% of the tests presented at least 95.8% inter- and intra-rater agreement on the Bland-Altman plots. **Conclusion:** The evaluation of isometric muscle torque using hand-held dynamometry is a reliable procedure for use in different growth periods.

Introduction

The assessment of muscle strength is a relevant indicator for the public health of children and adolescents, as well as an important clinical measure in pediatric musculoskeletal, cardiac, and neurological rehabilitation[1-3]. It is estimated that children with decreased muscle mass and strength are more likely to be overweight and obese, and have other problems such as cardiovascular disease, metabolic disorders, neurodevelopmental disorders, and musculoskeletal injuries[4-6].

Muscle strength can be assessed by isokinetic dynamometry, hand-held dynamometry (HHD), or different clinical tests[7]. Some of these methods have limitations, for example, manual muscle testing based on the Medical Research Council's (MRC) 1 to 5 scale[8], has demonstrated to be useful and reliable in the presence of a significant strength deficit (score 1 to 3), but with low sensitivity at higher levels (4 and 5)[9]. On the other hand, isokinetic dynamometry uses expensive instrumentation and requires high training[8].

The strength measured with HHD depends on the distance between the application point of the dynamometer and the center of rotation of the joint[10,11], therefore, considering the gross measurement of the hand-held dynamometer as the "muscle force" is misleading since the measurement depends on the rotational lever arm, i.e., the distance or lever arm which, when multiplied by the force obtained from the dynamometer, expresses the muscle torque or moment of force[12]. The muscle torque also represents, from a biomechanical point of view, the rotational effect of a force on a joint axis[12].

For these reasons, it is necessary to consider muscle torque as a standard for measuring strength in children and adolescents, especially in the stages of growth and maturation where variations in bone length and muscle diameter occur in short periods[13]. It should be noted that the background on the measurement reliability of isometric muscle torque assessed by HHD in children and adolescents is scarce. The HHD evaluates through two methods: the eccentric *break* test and the isometric *make* test[14]. Of these tests, the most widely used is the *make* test due to its applicability in most muscle groups and lower risk of pain and injury[2,15,16]. Also, reliability values categorized between "moderate to excellent" have been demonstrated for the isometric *make* test in different studies in the school population[1,17]; however, neither in the Chilean pediatric nor adolescent population have reliability values been reported using the *make* test through HHD.

Thus, this research hypothesizes that the reliability of hand-held dynamometry measurements to obtain the maximal isometric muscle torque, both in inter- and intra-evaluator evaluations, may be sufficient to create an evaluation protocol for strength diagnosis in children and adolescents. We believe it is important to evaluate the HHD test in the different stages of growth[13], so that it can be validated throughout child and adolescent development without characterizing a single stage, and valuable information can be provided to the creation of professional practice standards in muscle diagnosis in the pediatric population. The objective of this study was to determine the intra- and inter-evaluator reliability of hand-held dynamometry to determine maximal isometric muscle torque in upper and lower limb muscle groups of Chilean children and adolescents.

Patients and Method

Design: Cross-sectional observational study that evaluated the reliability of maximal isometric muscle torque measurements in children and adolescents aged 7 to 15 years. 72 participants were selected by convenience, using a non-probabilistic sampling method. All children attended a school in Talca and constituted 9 age groups (from 7 to 15 years old), with 8 subjects (4 males and 4 females) participating for each age group. This sample selection procedure was based on previous research for the reliability evaluation of isometric torque measurements[1,14]. Both minors and their parents were informed about the protocol and informed consent was obtained from the parents/guardians and assent from the minors. The inclusion criteria for participants were: Spanish speakers, Latino ethnicity, age between 7 and

15 years, with typical development, and intact cognitive function to understand the commands given by the evaluator. Participants were excluded if they had: (i) a history of medical, neurological, or musculoskeletal impairments that could affect strength measurements; (ii) use of painkillers or history of musculoskeletal disorders; (iii) previous surgeries on the limbs and/or spine; (iv) participation in high-performance competitive sports during or in the 6 months before the study measurements, and (v) a body mass index categorized as obese. This study was approved by the South-Central Ethics Committee of the *Universidad Santo Tomás* for all its procedures (code no. 22-01; 2022).

Measurement process

Maximal isometric torque

All measurements were performed on the dominant limb of the participants. For the upper limb, it was determined by asking the participants which hand they use to write with a pencil, and for the lower limb, it was asked which foot they use to kick a ball. The maximal isometric strength of shoulder flexors, abductors, medial rotators, and lateral rotators; elbow flexors and extensors; wrist flexors and extensors; hip flexors, extensors, and abductors; knee flexors and extensors; and ankle plantar flexor and dorsiflexor were evaluated with HHD with the *make* test using a calibrated hand-held dynamometer (Lafayette Hand-Held Dynamometer - model 01165, Lafayette Instrument®, IN, USA). The standardized positions and location of the dynamometer for each muscle group were applied based on previous reports (Table 1)[1,2,14,20]. Maximal isometric handgrip strength of the extrinsic-intrinsic hand muscles was assessed with handgrip dynamometry (HGD) using a calibrated handgrip dynamometer (Jamar model 5030J1, Sammons Preston Rolyan, Bolingbrook, IL, USA), according to the recommendation of the American Society of Hand Therapists[21].

To calculate the maximal isometric torque (Nm) of each muscle group, the force in Newton (N) was multiplied by the distance of the lever arm (m) between the application point of the dynamometer and the corresponding joint center. Then, the result for each muscle group was divided by the body mass (kg) of each individual.

Participants wore sports clothes and were barefoot, and all measurements were performed in 1 session (1 hour per participant) in a space provided at the school. The evaluator held the stationary dynamometer while the participant exerted a maximal force against it[7,22-24]. For all assessments, participants were asked to perform maximal force against the dynamometer (HHD or HGD, as appropriate), while the evaluator encouraged participants with a standardized phrase "harder, harder, harder."

For all muscle groups, a warm-up was performed, then 3 attempts were performed, and the maximal force (N) was recorded for each attempt, where the highest value reached was considered for statistical analysis. Each attempt (contraction) was held for 3 seconds followed by a rest period of 30 seconds to minimize the effects of fatigue.

Maturity

Maturity was assessed in terms of the maturity offset. This is determined as the number of years since the Peak Height Velocity (PHV) by subtracting the age of the PHV from the chronological age at each measurement[18]. PHV is expressed in chronological years and is considered a benchmark of maturity and corresponds only to the period in which an adolescent experiences the most rapid upward growth in height[18,19]. For this, standing height and sitting height were measured to the nearest mm and body mass to the nearest 0.1 kg. Two measurements were made for each anthropometric variable.

Reliability assessment

Induction Period: Training was provided by an author of this article (GMR) to two evaluators (EA and EB) followed by at least 16 hours of practice, in all HHD procedures. Both evaluators were kinesiologists specializing in musculoskeletal rehabilitation, who had 10 years of professional experience.

The assessment of inter-rater reliability was determined by measurements performed by two raters (EA and EB), with an interval of 20 minutes between measurements to avoid fatigue. Participants were randomly assigned to one of the two evaluators, using a simple randomization method, with dark envelopes. The EA and EB measurements were made on the participant's second day of assessment[14].

Intra-rater reliability was determined by single-rater (EA) measurements on two different days (EA1 assessment and EA2 assessment), with an interval between 7 and 14 days between the two assessments, to avoid the learning effect of the first assessment[14].

Statistical Analysis

SPSS version 25.0 software was used for all analyses. The median and interquartile range of isometric muscle torque were calculated for the muscle groups of the upper and lower limbs, grouped by age and sex. Inter-rater reliability (EA and EB measurements) and intra-rater reliability (EA1 and EA2 measurements) were analyzed using the intraclass correlation coefficient (ICC) with a 95% confidence interval (95%CI) in the total sample of participants (aged 7 to 15 years). All reliability assessments were performed using a two-way random effects model, absolute agreement, and

Table 1. Protocol for Manual Maintenance Dynamometry (HHD) and Grip Strength Dynamometry (HGD). Standardized positions and location of the manual dynamometer for each muscle group

Muscle Group	Participant's Position	Joint/Segment/ Position	HHD or HGD Position	Lever Arm Measurement
Flexors Shoulder	Seated	Feet on the ground. Shoulder flexion 90°, Elbow flexion 90°, and supinated forearm	Distal third of the anterior surface of the arm	Coracoid process to HHD position
Abductors Shoulder	Seated	Feet on the ground. Shoulder abduction 90°, elbow flexion 90°, and forearm in neutral position	Distal third of the arm, just above the lateral epicondyle	Acromion to HHD position
Medial Rotators Shoulder	Seated	Feet on the ground. Shoulder abduction 0°, elbow flexion 90°, and forearm in neutral position	Distal third of the posterior surface of the forearm, just proximal to the wrist	Acromion to HHD position
Lateral Rotators Shoulder	Seated	Feet on the ground. Shoulder abduction 0°, elbow flexion 90°, and forearm in neutral position	Distal third of the anterior surface of the forearm, just proximal to the wrist	Acromion to HHD position
Flexors Elbow	Supine	On a stretcher. Shoulder abduction 0°, elbow flexion 90°, and forearm in supination	Distal third of the anterior surface of the forearm, just proximal to the wrist	Lateral epicondyle of the humerus to HHD position
Extensors Elbow	Supine	On a stretcher. Shoulder abduction 0°, elbow flexion 90°, and forearm in supination	Distal third of the posterior surface of the forearm, just proximal to the wrist	Lateral epicondyle of the humerus to HHD position
Flexors Wrist	Supine	On a stretcher. Shoulder abduction 0°, elbow flexion 0°, and forearm in supination Wrist flexion 30° and fingers extended	Palmar surface of the hand, proximal to the metacarpophalangeal joint	Styloid process of the radius to HHD position
Extensors Wrist	Supine	On a stretcher. Shoulder abduction 0°, elbow flexion 0°, and forearm in pronation. Wrist flexion 30° and fingers extended	Dorsal surface of the hand, proximal to the metacarpophalangeal joint	Styloid process of the ulna to HHD position
Hand Grip Strength	Seated	Feet on the ground. Shoulder abduction 0°, elbow flexion 90°, and forearm in neutral position. Wrist extension 0-30° and ulnar deviation 0-15°.	The handle is adjusted so that the line of the proximal interphalangeal joints rests exactly on the handle	Metacarpophalangeal joint of the 3rd finger to proximal interphalangeal joint.
Flexors Hip	Supine	On a stretcher. Hip flexion 90°, knee flexion 90°, and leg held on a box.	Distal third of the thigh, just at the upper patellar edge	Greater trochanter of the femur to HHD position
Extensors hip	Supine	On a stretcher. Hip flexion 90°, knee flexion 90°, and leg held on a box..	Distal third of the thigh, proximal to the popliteal fold	Greater trochanter of the femur to HHD position
Abductors Hip	Supine	On a stretcher. Hip flexion 0°, knee flexion 0°. Contralateral thigh stabilized with a strap around the distal third	Distal third of the thigh, at the lateral condyle of the femur	Greater trochanter of the femur to HHD position
Flexors Knee	Seated	On a chair. Hip flexion 90° and knee flexion 90°. Upright trunk without support	Distal third of the posterior surface of the leg, proximal to the ankle	Lateral joint line of the knee to HHD position
Extensors Knee	Seated	On a chair. Hip flexion 90° and knee flexion 90°. Upright trunk without support	Distal third of the anterior surface of the leg, proximal to the ankle	Lateral joint line of the knee to HHD position
Dorsal Flexors Ankle	Supine	On a stretcher. Hip flexion 0°, knee flexion 0°, and ankle in neutral position (0°) at the edge of the stretcher	Dorsal surface of the foot, proximal to the metatarsophalangeal joint	Lateral malleolus to HHD position
Plantar Flexors Ankle	Supine	On a stretcher. Hip flexion 0°, knee flexion 0°, and ankle in neutral position (0°) at the edge of the stretcher	Plantar surface of the foot, proximal to the metatarsophalangeal joint	Lateral malleolus to HHD position
Plantar Flexors Ankle	Supine	On a stretcher. Hip flexion 0°, knee flexion 0°, and ankle in neutral position (0°) at the edge of the stretcher	Plantar surface of the foot, proximal to the metatarsophalangeal joint	Lateral malleolus to HHD position

Source: Extracted from the Manual Maintenance Dynamometry protocol. HHD: Manual Maintenance Dynamometry, from the English Hand-Held Dynamometry; HGD: Grip Strength Dynamometry, from the English Hand Grip Dynamometer [14].

average measurement[25]. The following interpretation of the ICC was used: < 0.5 poor reliability; 0.51 to 0.75 moderate reliability; 0.76 to 0.90 good reliability; and > 0.90 excellent reliability[26]. To determine the measurement error across the evaluator's EA measurements (i.e., EA1 and EA2), the standard error of measurement (SEM), which is a measure of how much the scores observed are expected to vary due to measurement error, and the minimum detectable change (MDC), which is the minimum amount of change in an instrument score that must occur in an individual to be certain that the score change is not simply attributable to measurement error, were used[27] with the formula MDC = 1.96 SEm √2, where 1.96 is the Z value for a 95%CI and √2 is the square root of 2. This term is used because variability in two measurements (i.e., the initial measurement and the follow-up measurement) is considered.

Subsequently, inter- and intra-observer reliability and error measurements were performed on the subsamples grouped by maturity offset, resulting in two distinct maturity groups: pre-PHV group (maturity offset <-1) and circa/post-PHV group (maturity offset > -0.5). Participants with a maturity offset between -1 to -0.5 years were removed from the study due to an error in the prediction equation of approximately 6 months[28].

Additionally, the intra- and inter-rater reliability of isometric muscle torque was assessed by a scatter plot of two estimates based on the Bland-Altman method with a 95%CI of the limits of agreement.

Results

Seventy-two participants (females: n = 36; males: n = 36) were included in the analysis. Regarding the evaluation protocol, it was not necessary to adapt the instructions given, the positions, or the number of test attempts for a specific muscle group according to the age of the participants. There were also no reports of pain or discomfort during the procedures.

Table 2 shows the results of the inter- and intra-rater reliability analysis and SEM and MDC for each muscle group in a sample of participants. Overall, the results demonstrated good to excellent inter- (ICC = 0.85-

Table 2. Inter and intra-evaluator reliability analysis, standard measurement error, and minimum detectable change, for isometric muscle torque evaluation technique in each muscle group of the participants (n = 72)

	Reliability			
	Inter-rater	Intra-rater	Error*	
Muscle group	ICC (95% CI)	ICC (95% CI)	SEM	MDC
Shoulder Flexors	0.98 (0.98-0.99)	0.98 (0.97-0.99)	0.91	2.52
Shoulder Abductors	0.98 (0.97-0.99)	0.96 (0.94-0.97)	0.78	2.16
Medial Rotators of the Shoulder	0.98 (0.97-0.99)	0.98 (0.96-0.98)	1.08	2.99
Lateral Rotators of the Shoulder	0.97 (0.96-0.98)	0.97 (0.96-0.98)	0.83	2.30
Elbow Flexors	0.97 (0.96-0.98)	0.97 (0.95-0.98)	0.99	2.74
Elbow Extensors	0.97 (0.96-0.98)	0.98 (0.97-0.99)	0.78	2.16
Wrist Flexors	0.96 (0.94-0.98)	0.95 (0.92-0.97)	0.19	0.53
Wrist Extensors	0.95 (0.92-0.97)	0.97 (0.96-0.98)	0.18	0.50
Hand Grip Strength	0.97 (0.97-0.99)	0.97 (0.96-0.98)	0.41	1.14
Hip Flexors	0.98 (0.96-0.98)	0.98 (0.96-0.98)	1.41	3.91
Hip Extensors	0.85 (0.82-0.88)	0.91 (0.88-0.93)	2.10	5.82
Hip Abductors	0.88 (0.85-0.91)	0.95 (0.93-0.97)	0.78	2.16
Knee Flexors	0.98 (0.96-0.98)	0.98 (0.97-0.99)	1.67	4.63
Knee Extensors	0.97 (0.95-0.98)	0.97 (0.96-0.98)	1.87	5.18
Ankle Dorsiflexors	0.91 (0.84-0.95)	0.87 (0.77-0.92)	0.36	1.00
Plantar Flexors	0.94 (0.91-0.97)	0.96 (0.95-0.98)	0.63	1.75

Intraclass correlation coefficient (ICC), two-way random effects model, absolute agreement and average measures; CI: confidence interval; SEM, standard error of measurement; MDC, minimum detectable change. * The measurement error was estimated with the measurements of evaluator A (i.e., EA1 and EA2) using the standard error of measurement and the minimum detectable change in newton-meter (Nm).

0.98) and intra-rater reliability (ICC = 0.87-0.98) for the isometric torque evaluations across all muscle groups. In addition, SEM was low (0.18-2.10 Nm) and MDC ranged from 0.50 to 5.82 Nm. Two muscle groups, hip extensors and abductors, revealed good inter-rater reliability (ICC = 0.85 and ICC = 0.88, respectively); and one muscle group, ankle dorsiflexors, only showed good intra-rater reliability (ICC = 0.87).

Table 3 shows the results of inter- and intra-rater reliability and SEM and MDC for each muscle in the pre-PHV and circa/post-PHV groups. When this sample separation was performed according to maturity, participants in the circa/post-PHV group showed a decrease in inter- (ICC = 0.79) and intra-rater reliability (ICC = 0.88) in the hip extensors. In addition, the ICC presented a 95%CI lower limit of 0.65 and 0.75, respectively, obtaining a categorization as moderate reliability. Similarly, SEM (3.04 Nm) and MDC (8.43 Nm) increased in hip extensors. Lower intra-rater reliability was also observed in the wrist flexor (ICC = 0.86) and ankle dorsiflexor (ICC = 0.77) muscle groups with a 95% CI lower limit of 0.65 and 0.75, respectively.

Supplementary Tables 1, 2, and 3 (available in the online version) show the total number of participants, body mass, height, BMI, PHV, and maximal isometric torques of upper and lower limb muscles grouped by age and sex.

Figures 1 and 2 show the Bland-Altman plots for intra- and inter-rater reliability of the isometric muscle torque of the different muscle groups. From these plots, 100% presented at least 95.8% inter-rater (bias between -0.16 and 1.72 Nm) and intra-rater (bias between -0.68 and 2.32 Nm) agreement.

Discussion

In this investigation, we studied the intra- and inter-rater reliability of a hand-held dynamometry protocol to determine maximal isometric torque for various muscle groups in a pediatric population. Overall, the results demonstrated good to excellent inter- and intra-rater reliability for isometric torque evaluations using the *make* test, only two muscle groups, hip extensors and abductors, showed good inter-rater reliability; and one, ankle dorsiflexors, showed good intra-rater

Table 3. Inter and intra evaluator reliability for measurements with manual dynamometry. in the pre-PHV group (maximum height velocity) and in the circa/post PHV group

	Reliability pre PHV group				Reliability circa/post PHV group			
	Inter-rater	Intra- rater	Error*		Inter-rater	Intra- rater	Error*	
Muscle group	ICC (95% IC)	ICC (95% IC)	SEM	MDC	ICC (95% IC)	ICC (95% IC)	SEM	MDC
Shoulder Flexors	0.97 (0.94-0.98)	0.97 (0.95-0.98)	0.64	1.77	0.98 (0.96-0.99)	0.97 (0.94-0.98)	1.46	4.05
Shoulder Abductors	0.98 (0.96-0.99)	0.97 (0.94-0.98)	0.70	1.94	0.96 (0.93-0.98)	0.94 (0.86-0.97)	1.19	3.30
Medial Rotators of the Shoulder	0.98 (0.96-0.99)	0.98 (0.97-0.99)	0.98	2.72	0.97 (0.95-0.98)	0.96 (0.92-0.98)	1.71	4.74
Lateral Rotators of the Shoulder	0.97 (0.94-0.98)	0.95 (0.90-0.97)	0.67	1.86	0.93 (0.87-0.97)	0.95 (0.91-0.97)	1.14	3.16
Elbow Flexors	0.95 (0.91-0.97)	0.96 (0.92-0.98)	0.95	2.63	0.95 (0.91-0.98)	0.95 (0.89-0.97)	1.35	3.74
Elbow Extensors	0.97 (0.94-0.98)	0.97 (0.94-0.98)	0.78	2.16	0.95 (0.90-0.97)	0.97 (0.94-0.98)	1.04	2.88
Wrist Flexors	0.92 (0.85-0.96)	0.95 (0.91-0.97)	0.14	0.39	0.92 (0.83-0.96)	0.86 (0.71-0.93)	0.26	0.72
Wrist Extensors	0.92 (0.85-0.96)	0.94 (0.88-0.97)	0.15	0.42	0.92 (0.85-0.96)	0.96 (0.93-0.98)	0.29	0.80
Hand Grip Strength	0.96 (0.93-0.98)	0.91 (0.83-0.95)	0.28	0.78	0.98 (0.96-0.99)	0.97 (0.95-0.98)	0.79	2.19
Hip Flexors	0.98 (0.96-0.99)	0.98 (0.95-0.99)	1.53	4.24	0.93 (0.85-0.96)	0.94 (0.87-0.97)	1.65	4.57
Hip Extensors	0.98 (0.97-0.99)	0.99 (0.98-0.99)	2.37	6.57	0.79 (0.65-0.85)	0.88 (0.75-0.94)	3.04	8.43
Hip Abductors	0.96 (0.93-0.98)	0.94 (0.89-0.97)	1.99	5.52	0.94 (0.88-0.97)	0.93 (0.86-0.97)	2.77	7.68
Knee Flexors	0.97 (0.95-0.98)	0.98 (0.97-0.99)	1.71	4.74	0.96 (0.92-0.98)	0.96 (0.93-0.98)	2.35	6.51
Knee Extensors	0.95 (0.91-0.97)	0.98 (0.96-0.99)	2.03	5.63	0.94 (0.88-0.97)	0.95 (0.89-0.97)	2.52	6.99
Ankle Dorsiflexors	0.95 (0.90-0.97)	0.96 (0.92-0.98)	0.39	1.08	0.91 (0.83-0.96)	0.77 (0.53-0.89)	0.44	1.22
Plantar Flexors	0.97 (0.95-0.98)	0.97 (0.95-0.98)	0.62	1.72	0.96 (0.91-0.98)	0.90 (0.80-0.95)	0.75	2.08

Evaluation in pre-post PHV Groups (from English Peak Height Velocity); ICC. Intraclass correlation coefficient, two-way random effects model, absolute agreement and average measures; CI: confidence interval; SEM: standard error of measurement; MDC, minimum detectable change.
* The measurement error was estimated with the measurements of evaluator A (i.e., EA1 and EA2) using the standard error of measurement and the minimum detectable change in newton-meter (Nm).

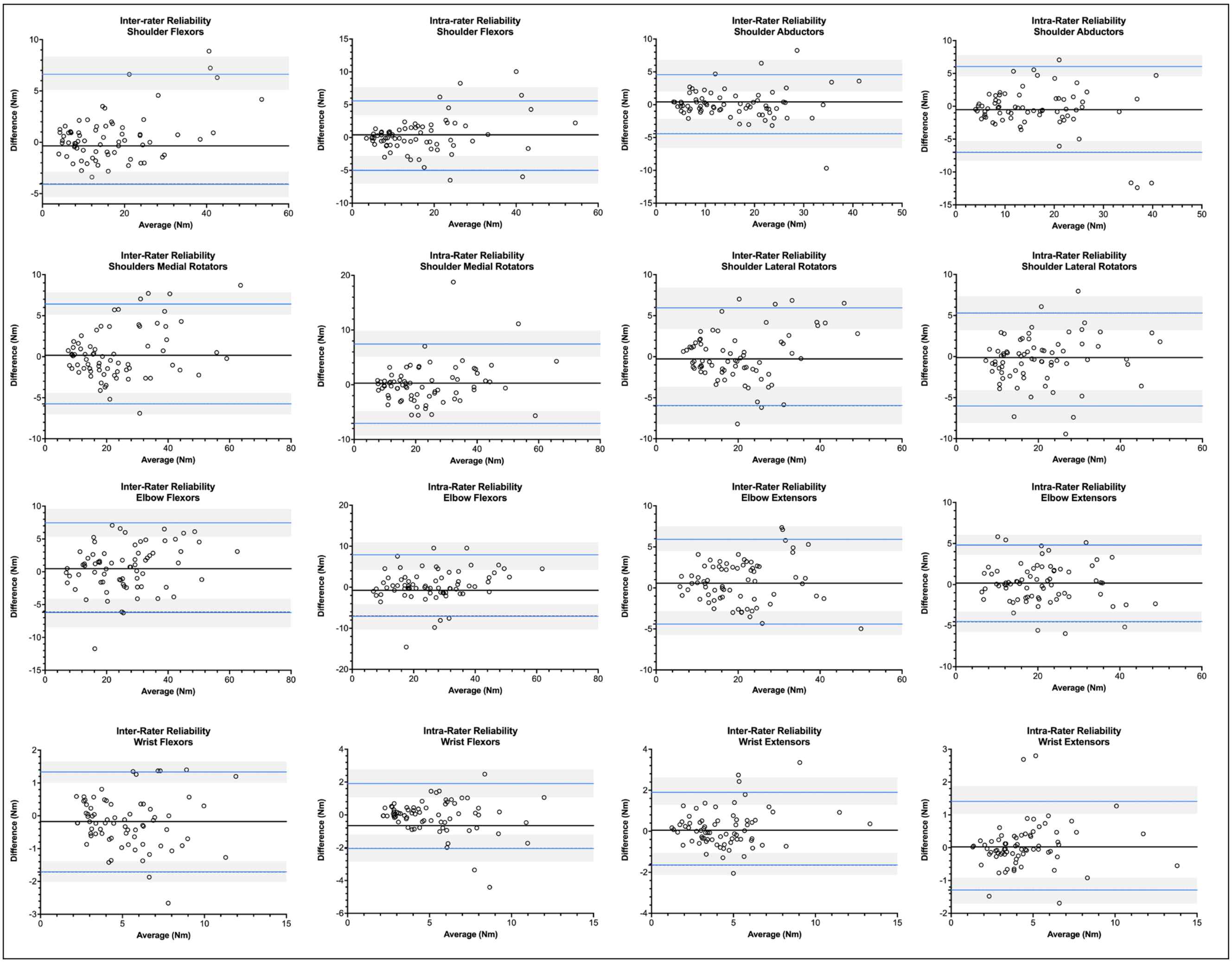

Figure 1. Bland-Altman plots for intra-evaluator and inter-evaluator reliability of isometric muscle torque of the upper limb muscle groups. At least 95.8% inter-evaluator agreement is observed (bias between -0.16 and 1.72 Nm) and intra-evaluator (bias between -0.68 and 2.32 Nm).

reliability. The results of this study corroborate those observed in populations from various latitudes (e.g., Brazil, Canada, and Western Europe), where the use of the *make* test has been recommended to determine reference values of maximal isometric force, showing high reliability and validity for the assessment of muscle strength of most clinically significant muscle groups[1,2,16]. In fact, hand-held dynamometry has shown reasonable (0.52) to excellent (0.86) concurrent validity with isokinetic dynamometry (Cybex) for most upper and lower limb muscle groups[14], as well as intra-rater reliability data (ICC = 0.67 to 0.99) and inter-rater reliability (ICC = 0.67 to 0.96), reported in various populations around the world[14,29-32].

In our study, isometric muscle torque data were determined from 15 muscle groups of the participants. These groups were selected because they are the main muscles evaluated and treated in the rehabilitation of the locomotor system in children, and their alteration may be associated with difficulties in functional activities such as speed of locomotion and daily living[3,29,33].

Also, maturity was considered in the participants, where the circa/post-PHV group revealed a decrease in inter- (ICC = 0.79) and intra-rater reliability (ICC = 0.88) in the hip extensors, obtaining a moderate reliability categorization. This could be explained by the characteristics of this muscle group and the growth rate of the participants, a situation that may influence the results of muscle torque since this has a close relationship with musculoskeletal development because the change in the distances from the center of the joint depends on the length of the limb of children who are in development, as well as the size and muscle composition[11,34].

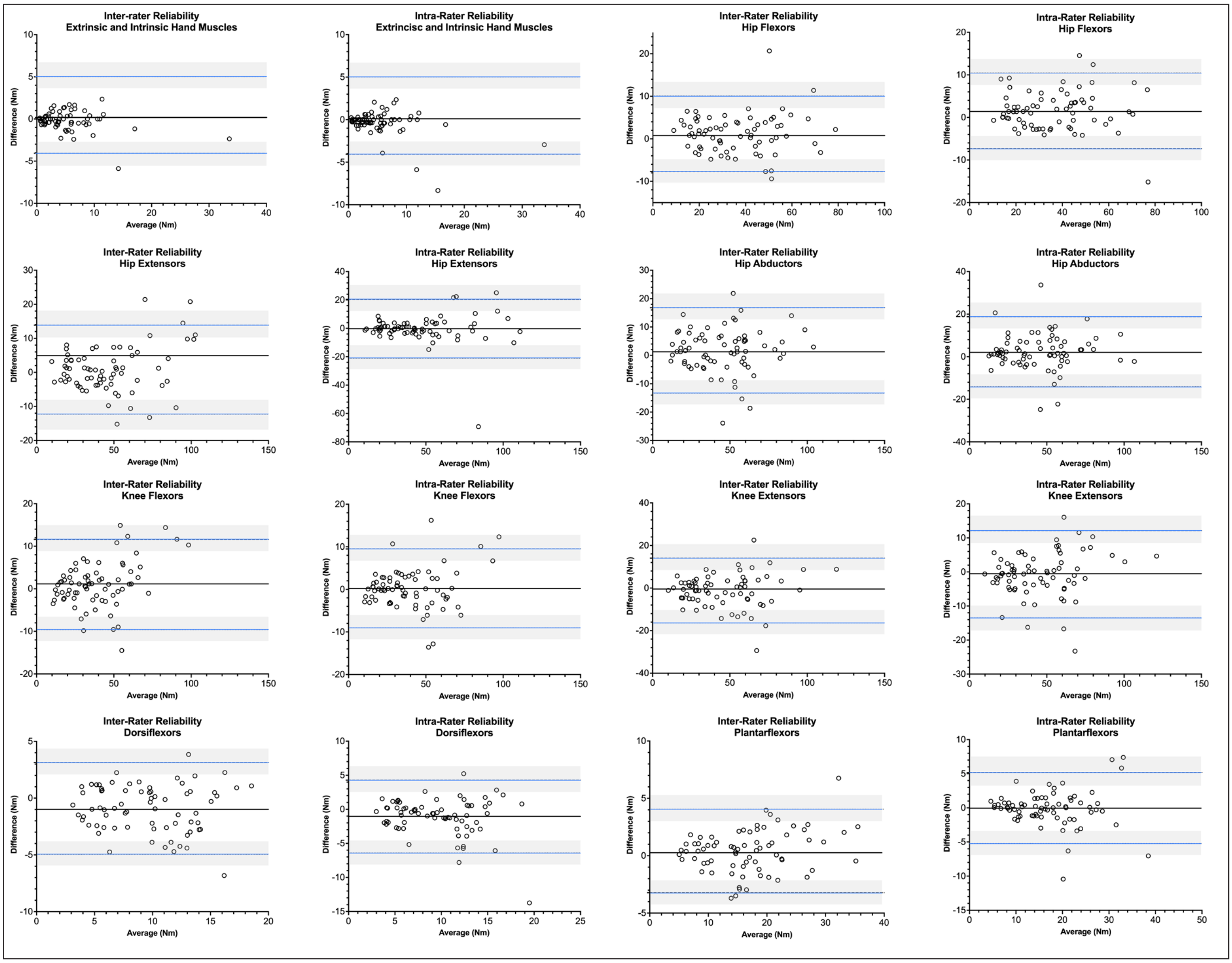

Figure 2. Bland-Altman plots for intra-evaluator and inter-evaluator reliability of isometric muscle torque of the hand muscle groups and the lower limb.At least 95.8% inter-evaluator agreement is observed (bias between -0.16 and 1.72 Nm) and intra-evaluator (bias between -0.68 and 2.32 Nm.

In relation to the hip muscles, specifically extensors, although the results maintain a good inter-evaluator correlation, some studies have mentioned that there may be differences in the results in their performance, which may be influenced by the evaluator's ability to produce force to counteract the ability of the evaluated individual, although they also support the use of the HHD technique in hip and elbow muscles, as it is a technique with a lower risk of generating musculoskeletal injuries[23,24].

On the other hand, a lower intra-rater reliability was also observed in the wrist flexor (ICC = 0.86) and ankle dorsiflexor (ICC = 0.77) muscle groups of the participants of the circa/post-PHV group, this could also be explained by different reasons since muscle performance, in addition to depending on body size and proportion, is associated with factors such as age, sex, sexual maturation, level of physical activity, height, BMI, and limb dominance, a situation that tends to differentiate between subjects older than 10 years and with greater notoriety even at 14-15 years of age[35]. Even so, the reliability obtained in this study is similar to data obtained from other studies, where the HHD is reliable in children and adults of different age groups, health status, disease, and/or comorbidities[14,17,35].

In addition, some results obtained in the maximal isometric torque in the wrist extensor muscle group, the extrinsic-intrinsic hand muscles, and hip extensors, caught our attention because they decreased their values between 13 to 14 years. We believe that these results may be due to changes related to the speed of growth, where in previous studies it has been observed that adolescents older than 11 years show a general progression of strength onwards, being males slightly stronger than females, however, the groups aged 11.5 to 12.9 years show more abrupt changes in strength, being this a threshold period compared to later periods[14]. In relation to the protocol of the HHD technique, several errors mentioned in the literature express that its results can be affected either by the lack of correct calibration of the device, lack of visual acuity in the operator, carelessness, fatigue, or excessive force when performing the measurements. These errors can be minimized with a well-defined protocol[10], which is why the reliability obtained in our results, with low measurement error values (SEM and MDC), allows us to determine that it is likely that the error has been minimized due to the standardization of the technique and training of the evaluators.

Regarding the limitations of the study, the children and adolescents were recruited through convenience sampling and only in Talca; therefore, in the future, the influence of other factors such as types of schools, socioeconomic level, or regional factors on muscle strength in the pediatric population should be investigated. Among the strengths is the use of a well-defined protocol and trained evaluators, which is reflected in the high reliability obtained and the low error values reported.

There is an increasing need for valid and reliable instruments for clinical measurements as well as for conducting future studies. The HHD with the *make* test and the HGD use lower-cost instruments and are easy to apply and reproducible, with a low risk of unwanted effects such as pain or discomfort. For this reason, we consider that in the future, we should advance in the development of a normative database of children and adolescents in the different regions of Chile with this technique and evaluate if there is more variability or influence of other factors.

In conclusion, the HHD evaluation of maximal isometric muscle torque in Chilean children and adolescents presents good to excellent inter- and intra-observer reliability. This makes it an evaluation procedure in rehabilitation, applicable to different conditions, and stages of growth. Pediatric professionals can use it reliably in their clinical practice.

Ethical Responsibilities

Human Beings and animals protection: Disclosure the authors state that the procedures were followed according to the Declaration of Helsinki and the World Medical Association regarding human experimentation developed for the medical community.

Data confidentiality: The authors state that they have followed the protocols of their Center and Local regulations on the publication of patient data.

Rights to privacy and informed consent: The authors have obtained the informed consent of the patients and/or subjects referred to in the article. This document is in the possession of the correspondence author.

Conflicts of Interest

Authors declare no conflict of interest regarding the present study.

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