[Physical Therapy]

Test-Retest Reliability of Isokinetic Knee Strength Measurements in Children Aged 8 to 10 Years

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Background: Isokinetic dynamometry is a useful tool to objectively assess muscle strength of children and adults in athletic and rehabilitative settings. This study examined test-retest reliability of isokinetic knee strength measurements in children aged 8 to 10 years and defined limits for the minimum difference (MD) in strength that indicates a clinically important change.

Hypothesis: Isokinetic knee strength measurements (using the Biodex System 4) in children will provide reliable results.

Study Design: Descriptive laboratory study.

Methods: In 22 healthy children, 5 maximal concentric (CON) knee extensor (KE) and knee flexor (KF) contractions at 2 angular velocities (60 deg/s and 180 deg/s) and 5 maximal eccentric (ECC) KE/KF contractions at 60 deg/s were assessed 7 days apart. The intraclass correlation coefficient ($ICC_{2.1}$) was used to examine relative reliability, and the MD was calculated on the basis of standard error of measurement.

Results: ICCs for CON KE/KF peak torque measurements were fair to excellent (range, 0.49-0.81). The MD% values for CON KE and KF ranged from 31% to 37% at 60 deg/s and from 34% to 39% at 180 deg/s. ICCs in the ECC mode were good (range, 0.60-0.70), but associated MD% values were high (>50%). There was no systematic error for CON KE/KF and ECC KE strength measurements at 60 deg/s, but systematic error was found for all other measurements.

Conclusion: The dynamometer provides a reliable analysis of isokinetic CON knee strength measurements at 60 deg/s in children aged 8 to 10 years. Measurements at 180 deg/s and in the ECC mode were not reliable, indicating a need for more familiarization prior to testing.

Clinical Relevance: The MD values may help clinicians to determine whether a change in knee strength is due to error or intervention.

Keywords: child; reproducibility of results; knee joint; strength testing; dynamometry

Resistance training for children has become a popular and accepted method to promote health, fitness, and performance enhancement.[4,9,18,28] Children refers to girls and boys up to the age of 11 and 13 years, respectively, who have not developed secondary sex characteristics.[18] Following the safety standards and prescription recommendations for children, this training is safe and effective[10,14,18] and may reduce the risk of sports-related injuries.[18,27] However, to evaluate the changes in muscular fitness after a resistance training program and to allow appropriate prescription, there is a need for equipment and methods that provide reliable measurements.

Several isokinetic reliability studies have focused on knee extensor (KE) and knee flexor (KF) strength measurements in adults and have shown that this method is highly reliable.[2,7] The KE and KF are commonly measured as they have a key role in many functional and daily activities. Moreover, the high incidence of knee injuries in young athletes has encouraged clinicians and researchers to study KE and KF strength.[19] However, the reliability

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The authors report no potential conflicts of interest in the development and publication of this article.

DOI: 10.1177/1941738116632506

Table 1. Participant characteristics[a]

	All Children (n = 22)	Boys (n = 10)	Girls (n = 12)
Age, y	8.8 ± 0.5 (8-10)	8.8 ± 0.5 (8-10)	8.8 ± 0.5 (8-10)
Weight, kg	30.5 ± 6.3 (23.5-43.6)	31.6 ± 7.1 (23.5-43.6)	29.6 ± 5.7 (23.5-40.9)
Height, cm	134 ± 8 (122-150)	136 ± 9 (124-150)	132 ± 8 (122-150)
Body mass index, kg/m^2	16.8 ± 2.2 (14.2-22.7)	16.9 ± 2.6 (14.2-22.7)	16.8 ± 1.9 (14.5-21.8)

[a]Data presented as mean ± SD (range).

of isokinetic knee strength measurements in children has not been fully examined. In previous studies, the *relative* reliability of isokinetic KE/KF strength measurements in this age group was moderate to high in the concentric (CON)[6,15,16,20,21,25] and eccentric (ECC) mode,[6,15,16,21] with intraclass correlation coefficients (ICCs) ≥0.41. In several studies, the ICCs were greater for KE than KF.[6,15,16,20] However, the *absolute* reliability of isokinetic knee strength measurements in children has not yet been determined in detail; therefore, the smallest change necessary to indicate a clinically important change for an individual is unknown.

Previous reliability studies that included children younger than 10 years had small sample sizes (n = 10-12).[6,20] Children this age may not be motivated to cooperate in isokinetic testing, and there may be difficulties in properly strapping them in the dynamometer because of smaller body size.[26] To get a precise estimate of the reliability, studies should include a minimum of 15 to 20 subjects.[11] Also, many different commercial dynamometers have been used to assess the reliability of knee strength measurements in children: the Biodex System 3,[6] KinCom,[15] Lido Active,[20] and Cybex,[22] with no previous study using the Biodex System 4. Existing studies have used a wide range of angular velocities to assess the reliability of CON and ECC KE/KF strength measurements in children with conflicting results.[6,15,16,20,21,25]

The aims of this study were to assess test-retest reliability of isokinetic CON and ECC KE/KF strength measurements in children aged 8 to 10 years and to examine a comprehensive set of statistical analyses for the interpretation of reliability.

METHODS

Participants

A sample of healthy boys (n = 10) and girls (n = 12) aged 8 to 10 years was recruited from a primary school in the south of Sweden. Inclusion criteria were (1) no musculoskeletal dysfunction in the tested leg within the past 6 months and (2) no other reported medical conditions such as acute infection or neurological or cardiovascular disease (Table 1). The children were average in height and weight compared with similar controls.[12]

An information letter was sent to the principal, who gave written consent for the children to participate during school hours. Written informed consent was given by all children and their parents or legal guardians before participation. A baseline questionnaire was completed to describe the type and level of physical activity of the subjects. Twenty children participated in 1 or more organized moderate to high-intensity activities per week, for example, swimming, soccer, gymnastics, and martial arts. The subjects were not familiar with isokinetic testing and had never been tested before. This study followed the World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects, and the study was approved by the Advisory Committee for Research Ethics in Health Education, Lund University.

Procedures

All tests were performed using the same dynamometer (Biodex Multi-Joint System 4; Biodex Medical Systems, Inc). The standard knee unit attachment was used. Before testing each subject, the system was calibrated according to the manufacturer's guidelines. All tests were performed on the dominant leg. Leg dominance was determined by asking the subjects to kick a ball placed in front of them. Subjects were tested at the same time of day on 2 separate occasions, 7 days apart. The test procedure on both test sessions started with standardized verbal instructions. Thereafter, the subjects performed a low-resistance (25 W) warm-up for 5 minutes on a bicycle.

Each subject was seated in the adjustable chair (Figure 1), and standard procedures were employed.[25] To account for the influence of gravity on torque data, each subject's leg was weighed and a gravity correction was made. The total range of motion (ROM) was 90°, set from 100° of leg flexion to 10° of leg flexion (0° being full extension). To warm-up and be accustomed to the movements of the lever arm, each subject performed 3 submaximal CON KE/KF contractions at 60 deg/s. After a 30-second rest, each subject performed 5 maximal continuous CON/CON cycles of KE/KF contractions at 60 deg/s. After a 1-minute rest, 3 submaximal CON KE/KF contractions were performed at 180 deg/s, followed by a 30-second rest. Thereafter, the testing continued with 5 maximal continuous CON/CON cycles of KE/KF contractions at 180 deg/s. The highest peak torque of the 5 maximal contractions at each angular velocity and for each muscle group was obtained from the comprehensive data sheet and used as the criterion score.

Figure 1. Setup and positioning of the participants.

After a 2-minute rest, the subjects were given careful instructions on how to perform ECC contractions by using manual guidance of the movement. Then, the subjects performed 3 submaximal ECC KE/KF contractions at 60 deg/s. After a 1-minute rest, the subjects performed 5 maximal continuous ECC/ECC cycles of KE/KF contractions at 60 deg/s. The highest peak torque of the 5 maximal ECC contractions for each muscle group was used as the criterion score.

The subjects were allowed to follow the torque curves on the computer screen for visual feedback. In addition, they were given standardized verbal encouragement during the maximal contractions.

Statistical Analyses

Descriptive statistics (means ± SD) were calculated for the individual characteristics and the peak torque measurements. Statistical significance was accepted at $P < 0.05$. The relative consistency between measurements was assessed by the intraclass correlation coefficient, $ICC_{2,1}$.[29] A 2-way analysis of variance (ANOVA) random effects model, absolute agreement, was used, and the 95% CI for $ICC_{2,1}$ was obtained from the ANOVA tables. ICC values in the range of 0.40 to 0.75 were interpreted as fair to good reliability, and those greater than 0.75 represented excellent reliability.[11]

The standard error of measurements (SEM), that is, the absolute reliability, was estimated as the square root of the within-subjects mean square error term from the ANOVA.[24] The SEM% was defined as: SEM/mean of all measurements from both test sessions × 100. This value is independent of the units of measurement, and by calculating SEM%, the values are more easily interpreted and can be compared with data from other reliability studies.

The SEM was then used to determine the minimum difference (MD) to be considered clinically important for a single subject.[3,13,29] The MD was calculated as: 1.96 × SEM × √2. The value 1.96 is the z score associated with the 95% CI and √2 is used to account for the variance of 2 test sessions. The MD was also expressed as a percentage value (in analogy with SEM%). Systematic error was assessed by evaluating the F ratios from the repeated-measures ANOVA.

RESULTS

There was no systematic error for CON KE/KF and ECC KE at 60 deg/s, but systematic error was found for all other measurements (Table 2).

The ICC value for CON KE at 60 deg/s was excellent (>0.75), while the ICC values for CON KF at 60 deg/s, CON KE/KF at 180 deg/s, and both ECC strength measurements were fair to good (0.49-0.70).[11] The 95% CI for ICC was acceptable for all measurements but wide for CON KF at 180 deg/s (0.03-0.77) (Table 3).

For CON peak torque measurements, SEM ranged from 4.5 to 5.5 N·m for KE and 3.1 to 3.5 N·m for KF. SEM% was lower for KE at both 60 deg/s and 180 deg/s (11.1% and 12.4%, respectively) compared with KF (13.1% and 13.9%, respectively). For ECC peak torque measurements, SEM ranged from 9.8 to 11.5 N·m, and SEM% values were higher than CON peak torque measurements (18.0% and 21.5%).

The MD values ranged from 8.5 to 15.3 N·m for CON measurements and 27.3 to 31.8 N·m for ECC measurements. The MD% values for CON KE/KF measurements at 60 deg/s and 180 deg/s were between 30.9% and 38.5%, respectively. For ECC measurements, the MD% values were higher (49.7% and 59.6%, respectively).

DISCUSSION

The results from this study suggest that CON KE/KF strength measurements at 60 deg/s are reliable in children aged 8 to 10 years and can be used to detect clinically important changes in knee strength as the result of an intervention. However, CON knee strength measurements at 180 deg/s and in the ECC mode were not considered reliable because of systematic bias and high lower limits for clinically important changes.

Reliability Statistics

Concentric Mode

Several studies have shown that high ICC values do not necessarily imply that a test is suitable for clinical use.[17,23] In this study, we also calculated the measurement error in absolute and relative terms. These values are important for clinicians and researchers since they

Table 2. Isokinetic concentric (CON) and eccentric (ECC) knee extensor (KE) and knee flexor (KF) strength measurements (n = 22)[a]

	Test session 1	Test session 2	*P* value[b]
KE CON 60 deg/s, N·m	47.8 ± 13.1	51.0 ± 13.0	0.076
KF CON 60 deg/s, N·m	26.0 ± 5.5	27.7 ± 6.2	0.117
KE CON 180 deg/s, N·m	34.5 ± 9.6	38.4 ± 7.9	0.009
KF CON 180 deg/s, N·m	20.4 ± 4.3	23.9 ± 5.4	0.001
KE ECC 60 deg/s, N·m	64.3 ± 23.0	63.3 ± 17.8	0.781
KF ECC 60 deg/s, N·m	49.2 ± 19.6	42.2 ± 12.0	0.028

[a]Data presented as mean ± SD.
[b]Repeated-measures analysis of variance.

Table 3. Reliability of isokinetic concentric (CON) and eccentric (ECC) knee extensor (KE) and knee flexor (KF) strength measurements (n = 22)

Test	$ICC_{2,1}$ (95% CI)	SEM	SEM%	MD	MD%
KE CON 60 deg/s	0.81 (0.58-0.92)	5.5	11.1	15.3	30.9
KF CON 60 deg/s	0.62 (0.28-0.82)	3.5	13.1	9.8	36,5
KE CON 180 deg/s	0.68 (0.30-0.86)	4.5	12.4	12.6	34.4
KF CON 180 deg/s	0.49 (0.03-0.77)	3.1	13.9	8.5	38.5
KE ECC 60 deg/s	0.70 (0.40-0.86)	11.5	18.0	31.8	49.7
KF ECC 60 deg/s	0.60 (0.22-0.81)	9.8	21.5	27.3	59.6

$ICC_{2,1}$, intraclass correlation coefficient; MD, minimum difference to be considered clinically important at a 95% CI; MD%, relative minimum difference at a 95% CI; SEM, standard error of measurement; SEM%, relative standard error of measurement.

can be used to evaluate the effectiveness of a resistance training program.[13,17,29] The SEM% values indicated acceptable within-subject variation and ranged from 11.1% to 12.4% for CON KE measurements and from 13.1% to 13.9% for CON KF measurements. These estimates are similar or slightly greater than those measurement errors reported in previous studies.[6,21,25]

To detect a real change for a single individual, we estimated MD%, which is independent of the units of measurement and therefore more easily interpreted. For the present study, the size of the relative change (MD%) should exceed 31% (KE CON at 60 deg/s) up to 39% (KF CON at 180 deg/s) to indicate a clinically important change in isokinetic CON knee strength for an individual. Strength gains of approximately 30% to 50% are commonly observed after short-term (8-20 weeks) youth resistance-training programs.[4,8] Therefore, the MD% values reported in this study are acceptable and sufficiently small to detect clinically important changes in CON KE/KF strength.

In the present study, the relative reliability was lower at 180 deg/s compared with 60 deg/s for both KE and KF (Table 3). This finding is in accordance with a previous reliability study including children aged 13 years.[16] An explanation for the lower reliability at the higher velocity may be that children have difficulties in attaining high movement velocities due to an immature neuromuscular system.[5]

Eccentric Mode

Few studies have examined the reliability of ECC knee strength measurements in children. There is, however, no reason to expect greater muscle injury with ECC actions in children compared with adults, provided the children are given proper warm-up and habituation.[5] To reduce the risk of injury, ECC testing was limited to 1 test velocity. No pain or discomfort was reported during the ECC testing.

ICCs are considered good and comparable based on a reliability study including 9- to 12-year-old girls (KE, 0.79; KF, 0.48).[15] The lower reliability of the ECC tests compared with CON tests could be explained by difficulties to perform ECC contractions during isokinetic testing. In addition, children may struggle to understand the technique of ECC contractions and not have the required motor coordination for proper movements.[1]

SEM% and MD% values in the ECC mode were high (>18% and >50%, respectively). Thus, the high MD% values assume that a single subject needs to improve substantially in ECC strength if the change should represent a clinically important improvement. This clearly illustrates the need to include both relative and absolute reliability statistics to fully assess a measurement method.

Systematic Error

The utilized protocol was sufficient to eliminate any systematic error between test sessions for isokinetic CON knee strength measurements at 60 deg/s. The subjects performed significantly better on the second test for CON KE/KF strength measurements at 180 deg/s. A possible reason could be learning. Learning effects are problematic when assessing knee muscle strength over time, since improvements may be due to learning rather than intervention. The opposite was shown for the ECC measurements where results indicated lower ECC KF strength at test session 2. Muscle strength testing using isokinetic dynamometry is a complex procedure, and the younger the child, the greater the need for simple instructions.[1]

CONCLUSION

Isokinetic CON KE/KF strength measurements at 60 deg/s demonstrated good to excellent relative and absolute reliability with no systematic error between test sessions and can favorably be used for evaluating knee strength in children aged 8 to 10 years. The minimum differences (MD%) in KE and KF strength to be considered clinically important, for example, before and after an intervention, are 31% and 37%, respectively. These values may help clinicians to determine whether a change in knee strength is due to error or intervention. However, isokinetic knee strength measurements at 180 deg/s and in the ECC mode were not considered reliable for this age group, indicating a need for additional practice and familiarization with the testing procedures.

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