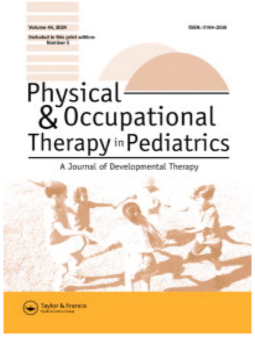

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Looking Beyond the Number of Repetitions: An Observational Cross-Sectional Study on Calf Raise Test Outcomes in Children Aged 10–17 Years

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ABSTRACT

Aims: The calf raise test (CRT) assesses plantarflexor strength and endurance, but normative data for children are scarce. Furthermore, contradictions exist on which factors are associated with total repetitions, with repetitions being the only metric considered. We quantified three of the main CRT outcomes (repetitions, total work, and peak height) in children 10–17 years and explored their relationship with various factors.

Methods: Healthy children ($n = 165$, 50.3% female) completed single-legged calf raises on a 10° incline, once on each leg. Test outcomes were extracted using the valid and reliable Calf Raise application.

Results: CRT outcomes were not significantly different between legs ($p \geq .19$). The only covariates significantly associated with outcomes based on stepwise quantile regressions were body mass index centile for repetitions, meeting physical activity recommendations for total work and peak height, and age for total work. Outcomes did not significantly differ based on sex or maturation. Median values were around 26 for repetitions, 640–1460 J for total work (age dependent), and 10.1 cm for peak height for children meeting physical activity recommendations.

Conclusion: Children who were older, had lower body mass indices, and were more active exhibited superior CRT outcomes. Meeting physical activity recommendations appears beneficial for plantarflexor function and should continue to be prioritized in children.

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Ankle; endurance; minors; muscle strength; triceps surae; youth

Healthcare professionals and researchers use the calf raise test (CRT) to assess the triceps surae muscle-tendon unit (Hébert-Losier, Newsham-West, et al., 2009). The test involves repetitive concentric–eccentric contractions of the plantarflexors in unipedal stance to volitional cessation and is typically quantified using the number of repetitions

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completed. In simpler terms, individuals go "up" and "down" on their toes as many times as possible, standing on one leg. The CRT is typically viewed as an endurance test, although it rather reflects triceps surae muscle-tendon unit performance (Hébert-Losier, Schneiders, et al., 2009). CRT outcomes have been linked to functional performance in several populations, including 10-m sprint performance in national rugby players (Hébert-Losier et al., 2023), walking speed and ankle power in patients surgically treated for a chronic Achilles tendon rupture (Nordenholm et al., 2022), function based on the Senior Fitness Test battery in older adults (André et al., 2018), and locomotor capacity in children (Ferland et al., 2012). Despite practitioners using this test in children (Ferland et al., 2012; Maurer et al., 2007; Yocum et al., 2010), normative values for children (here defined as individuals below 18 years of age) (United Nations Treaty Collection, 1989) are scarce. Such normative values would be clinically invaluable to inform practice given that outcomes from adults might not generalize to children.

In 2017, Hébert-Losier et al. (2017) provided updated normative values for the number of CRT repetitions in healthy adults aged 20–81 years (median: 24 right, 23 left), reporting that age, physical activity levels, body mass index (BMI), and sex were associated with outcomes. In contrast, Maurer et al. (2007) reported no significant effect of age, physical activity levels, height, body mass, and sex on CRT repetitions in children 7–9 years (mean: 36 dominant leg). Yet, when examining a broader age range, age alone accounted for 41% of the variation in CRT repetitions in typically developing children aged 5–12 years (mean: 19 dominant leg) (Yocum et al., 2010), with older children outperforming younger ones (mean: 32 vs. 13). More recently in a larger sample of children aged 8–12 years (mean: 21 right, 20 left) (Mishra et al., 2023), the opposite relationship was observed, where age was negatively correlated to repetitions (i.e. decline in performance with age). In addition, calf muscle girth and body mass were positively related to outcomes in these children (Mishra et al., 2023). The disagreement regarding which factors influence repetitions might stem from differences in CRT procedures, sample sizes, and maturation status. Maturation status can influence muscle energetics (Tonson et al., 2010), force generation abilities (Tonson et al., 2008), and the neuromuscular system (Radnor et al., 2018). In young individuals, there is a mismatch between the linear progression of chronological age and the nonlinear progression of biological maturation (Lloyd et al., 2014). Maturation status has not been considered when establishing normative CRT outcomes in children. Pubertal onset varies considerably between individuals, with typical onsets of 8–13 years in females (Eckert-Lind et al., 2020; Parent et al., 2003) and 9–14 years in males (Parent et al., 2003).

Furthermore, whilst counting repetitions is easy to implement in clinic, total positive work and peak height during the CRT are regarded as important outcomes. For instance, these outcomes are more sensitive than repetitions completed for detecting side-to-side differences in the presence of Achilles tendinopathy (Silbernagel et al., 2010) and post-Achilles tendon ruptures (Olsson et al., 2011). Since work accounts for the positive displacement of each repetition and the mass of individuals, this measure is considered a more empirically rigorous measure of triceps surae muscle-tendon unit function than repetitions completed (Byrne et al., 2017), and is proposed to reflect muscular contractile properties and endurance metabolism (Svensson et al., 2019). In contrast, CRT peak height is moreover linked with muscle fascicle and tendon lengths (Silbernagel et al., 2012). Together, these studies highlight how work and peak height during the CRT are important clinical outcomes that should also be measured alongside repetitions.

Hence, we aimed to quantify three of the main CRT outcomes (repetitions, peak height, and work) in a sample of healthy children aged 10–17 years to establish normative data. We also explored the association of sex, chronological age, maturation status, BMI, physical activity participation, and lower-extremity dominance with these outcomes. We anticipated children who were male, older, post-pubertal, more physically active, or had a lower BMI percentile would outperform children who were female, younger, pre-pubertal, less physically active, or had a greater BMI percentile. We anticipated similar outcomes between dominant and non-dominant legs (Hébert-Losier et al., 2017; Mishra et al., 2023).

Methods

Participants

Males and females in intermediate and secondary schools in Aotearoa New Zealand aged 10–17 years were invited to participate in this cross-sectional study with repeated measures. A minimum sample of 10 individuals per sex (two sexes) and age group (eight groups) was targeted (Hébert-Losier et al., 2017), leading to a minimum targeted sample of 160 individuals. Prior research report no significant differences in total repetitions between sides, with median or average differences of 1–2 repetitions in cohorts completing between 20 and 32 repetitions (Hébert-Losier et al., 2022, 2017; Mishra et al., 2023; Svantesson et al., 1998). Therefore, it is reasonable to assume similar performances between sides. Based on G*Power 3.1.9.7 computations, this sample size of 160 was sufficient to detect a small effect size (Cohen's $f = 0.16$, number of groups $= 16$) accounting for two repeated measures (dominant, non-dominant, correlation between measures at 0.60 based on pilot data collected within our laboratory, sphericity assumed) using repeated measures analysis of variance (within-between interactions) at a 5% probability level and 80% power.

Individuals and schools in the Canterbury region of Aotearoa New Zealand were invited to participate through word-of-mouth and e-mail after ethical approval (Human Research Ethics Committee of the University of Waikato, 2020#11). All participants and their parents or legal guardians were provided with an information sheet that outlined the aims, procedures, and risks involved (e.g. delayed onset muscle soreness). Participants and their parents or legal guardians were required to sign a consent form prior to participating in line with New Zealand's Health Research Council guidelines relating to research involving children (Health Research Council, 2017) and UNICEF's principles guiding ethical research involving children (Graham et al., 2013). Males and females aged 10–17 years with no current lower-extremity or spine injury were eligible. Those with a current or recent lower-extremity or spine injury (less than 3 months) were excluded, as were those with previous Achilles tendon ruptures. All participants were recruited and data were collected within a 1-month period in 2021.

Procedures

Participants' baseline characteristics were collected prior to experimentation. Data collected via survey included date of birth, sex (male or female), ethnicity, leg dominance (foot used to kick a ball), and the International Physical Activity Questionnaire-Short Form (IPAQ-SF) (Craig et al., 2003). Standing and sitting heights were recorded to the nearest 0.1 cm using a stadiometer (seca model 0123), and mass to the nearest 0.1 kg using an electronic scale (seca model ESE813).

Before testing, each participant performed 10 bilateral standing calf raises barefoot from the floor as warm-up. Participants then completed three single-leg calf raises barefoot once on each leg on a 10° incline following a 60 beats per minute metronome to familiarize themselves with the experimental task, raising up as high as possible in one beat and lowering down to the incline in one beat. Corrective feedback (e.g. lift the heel as high as possible, do not lean forward, follow the beat, etc.) was required in less than 10% of participants during familiarization. Following warm-up and familiarization, a 2-min rest was given. The testing order (dominant vs. non-dominant) was randomized to limit order bias, and a 2-min rest period was taken between sides.

The experimental task required participants to perform a maximal number of single-legged calf raise repetitions on a 10° incline once on each leg barefoot following previously described protocols (Fernandez et al., 2023; Hébert-Losier et al., 2017; Svantesson et al., 1998). To assist balance, individuals were permitted to apply fingertip support at shoulder height on a wall in front of them. Calf raise cadence was controlled at 30 raises per minute, where participants were asked to lift and lower their heel following a 60 beats per minute metronome. The non-tested leg was held behind participants (knee at approximately 90°). Participants were instructed to lift their heel of the tested leg as high as possible for each repetition and perform as many repetitions as possible, keeping the knee of the test leg and their trunk straight. The precise instructions are provided in supplement (S1). The test was terminated when participants could no longer: (1) lift the stance heel from the incline or repeat a complete repetition; (2) maintain the set pace, test leg knee angle, or trunk position; (3) rely on fingertip support only for balance and used the wall to assist performance; or (4) use their calf muscles to complete the action (i.e. compensatory strategy, typically from the hip). Participants were given one chance verbally to reestablish a correct calf raise repetition before termination. During the test, the tester provided the following standardized verbal encouragement at regular intervals: "keep going as high as possible." A single tester assessed all participants. The tester was a trained physiotherapist and sport scientist who had been trained by an expert with years of experience in the use of the CRT and Calf Raise application. Furthermore, the fidelity and reliability of methods were confirmed through internal pilot testing. Experimentation was performed in a well-light environment on hard floors, either at a biomechanics university laboratory or in the gymnasium of schools. All participants were able to follow the test instructions and complete the procedures.

Data Collection

A circular black marker of 14 or 24 mm in diameter depending on age ($<$12 years or $\geq$12 years) and foot size was affixed to the skin of individuals on a flat area below the lateral malleolus in-line with the calcaneus to track CRT outcomes using the Calf Raise application (Fernandez et al., 2023; Hébert-Losier & Balsalobre-Fernandez, 2020;

Hébert-Losier et al., 2022). The black markers were centered in larger white ones of 24 and 32 mm in diameter to ensure color contrast. During testing, an iPhone X (Apple Inc., Cupertino, CA) running iOS 13.7 was positioned on a stand 30 cm from and perpendicular to the foot of participants in a manner that allowed the entire foot to be visible throughout the CRT (Fernandez et al., 2023). The recording device was moved to 50 cm for longer feet (Hébert-Losier et al., 2022). The Calf Raise application v.1.5.1 was used to record videos of the experimental trials at 60 frames per second, and then used for data extraction.

Data Extraction and Measures

Data from the IPAQ-SF questionnaire was used to define those meeting minimal aerobic physical activity recommendations of an average of 60 min per day of moderate-to-vigorous physical activity (MVPA) in the past week (Bull et al., 2020). In children, MVPA (min/day) and total activities (metabolic equivalent min/day) show moderate correlations to accelerometry data in 13–14-years-old boys ($r = 0.31$, $p < .001$) (Rääsk et al., 2017) and 12–18-years-old children ($\rho = 0.31$) (Wang et al., 2013). The IPAQ-SF also demonstrates acceptable stability over 12-months ($\alpha = 0.63$) (Gråstén & Watt, 2016) and moderate-to-high one-week test–retest reliability for activity-related measures (intraclass correlation (ICC) = 0.53–0.79) (Wang et al., 2013) in children.

The anthropometric measurements collected were used to calculate BMI (kg/m^2) from body mass and standing height measures. Raw BMI units were converted to age-and-sex specific BMI centiles using the 2007 World Health Organization 5–19 years growth charts and the World Health Organization AnthroPlus software (World Health Organization, 2009). Anthropometric data were also used to derive maturational status based on peak height velocity (PHV) using standard equations (Mirwald et al., 2002). Participants were subsequently categorized as pre-pubertal, mid-pubertal, and post-pubertal when less than −1 year, from −1 to 1 year, and when 1 year or more from the calculated PHV, respectively (Rumpf et al., 2015).

The Calf Raise application tracks the vertical displacement of a circular marker placed on the foot using computer-vision algorithms and image-processing features applied to CRT videos (Fernandez et al., 2023; Hébert-Losier & Balsalobre-Fernandez, 2020; Hébert-Losier et al., 2022). Based on intraclass correlation coefficients (ICCs) and standard error of measurements (SEMs), the intra-rater (ICC = 0.99–1.00, SEM = 0.0–0.6), inter-rater (ICC = 0.99–1.00, SEM = 0.1–0.3), and test–retest (ICC = 0.91–0.96, SEM = 2.2–2.6) reliability of repetitions completed during the CRT are excellent in children and adults (Fernandez et al., 2023; Hébert-Losier et al., 2017; Maurer et al., 2007; Yocum et al., 2010). Furthermore, the three main CRT outcomes (repetitions, peak height, and work) extracted using the application show excellent concurrent validity compared to laboratory-based 3D motion capture and force plate data (intraclass correlation, $ICC_{3,1} = 0.96–1.00$; coefficient of variation, CV = 0–6.9%) (Fernandez et al., 2023; Hébert-Losier et al., 2022). The intra-rater ($ICC_{3,1} = 0.99–1.00$; CV = 0–1.3%) and inter-rater ($ICC_{2,1} = 0.97–1.00$; CV = 0.4–1.9%) reliability of application use is also excellent (Fernandez et al., 2023). Hence, the application is considered valid and reliable for measuring CRT outcomes in healthy individuals (Fernandez et al., 2023; Hébert-Losier et al., 2022).

To calibrate the videos, the tester adjusts the size of a scalable circle displayed on screen over the black marker of known diameter (i.e. either 14 or 24 mm) in the first frame of a CRT video. This initial marker position defines a zero vertical position. Following computer-vision tracking of the marker, the tester then identifies the start of the first repetition, end of the last repetition, first peak, last peak, and number of repetitions (*n*) from the outputted vertical displacement curve. From these inputs, the total positive (vertical) displacement (*d*, in m) is calculated and used to compute the total positive work (*J*) as:

$$Work = F_g \times d$$

where F_g is the product of body mass (measured on the day) and gravitational acceleration constant ($g = 9.81$ m/s^2). The peak vertical displacement reached during the CRT (where the initial position of the marker is zero) is extracted and used as peak height measure (in cm).

Data Analysis

Descriptive statistics were calculated for all dependent and independent variables, which included means with standard deviations (mean ± SD) and counts. The CRT outcomes were not normally distributed for both dominant and non-dominant legs upon visual inspections and based on Kolmogorov–Smirnov's normality testing ($p < .004$) except for non-dominant leg total work ($p = .08$); hence, non-parametric analytical approaches were used.

Wilcoxon's signed ranks tests were applied to explore differences between dominant and non-dominant legs for all CRT outcomes and Spearman's rank correlations (ρ) extracted to explore the strength of the association of outcomes between sides. Data were stratified for subsequent analyses in presence of a significant difference between legs; otherwise, non-dominant and dominant data were averaged. Like a previous study (Hébert-Losier et al., 2017), quantile regressions were then used to estimate medians and percentiles, which make no assumptions regarding data distribution. Multiple quantile regression models were built for each CRT variable that considered the five covariates of interest (sex, chronological age, maturation status, BMI centile, and meeting physical activity recommendations). In stepwise regression, non-significant covariates were sequentially removed until only significant covariates remained. Coefficients and their 95% confidence limits [lower, upper] were extracted to provide estimates of the impact of each covariate on performance for the median (50th) percentile. Furthermore, estimates of the lower (25th), median (50th), and upper (75th) percentiles for each CRT outcome were extracted accounting for the significant covariates. Data were analyzed using IBM® SPSS® Statistics version 29.0.1.0 (IBM Corporation, Armonk, NY) with significance level set at $p \leq .05$. All available data were analyzed (i.e. pairwise deletion) in presence of missing data.

Table 1. Demographic characteristics of participants (n = 165) by sex and age group.

Variable	Age (years)	Height (cm)	Mass (kg)	BMI (kg/m^2)	BMI centile	Leg[a] (R:L)	MVPA[b] (Y:N)	PHV[c] (pre:mid:post)	Ethnicity (NZ:M:A:O)
Female (n = 83)	14.0 ± 2.3	157.5 ± 8.3	50.1 ± 10.5	20.0 ± 3.0	0.54 ± 0.28	68:15	38:45	9:25:49	59:2:9:13
10 years (n = 10)	10.5 ± 0.3	145.2 ± 5.0	36.6 ± 5.3	17.3 ± 2.0	0.52 ± 0.28	9:1	3:7	9:1:0	7:0:3:0
11 years (n = 11)	11.7 ± 0.2	150.0 ± 7.3	41.5 ± 9.0	18.3 ± 2.9	0.51 ± 0.37	10:1	3:8	0:11:0	9:0:1:1
12 years (n = 12)	12.6 ± 0.3	155.7 ± 5.4	45.7 ± 6.3	18.8 ± 2.1	0.51 ± 0.23	7:5	4:8	0:10:2	12:0:0:0
13 years (n = 10)	13.6 ± 0.4	159.3 ± 3.9	52.1 ± 5.9	20.6 ± 2.7	0.61 ± 0.27	8:2	5:5	0:3:7	7:0:0:3
14 years (n = 10)	14.6 ± 0.3	160.2 ± 6.2	50.2 ± 7.0	19.7 ± 3.3	0.42 ± 0.34	7:3	6:4	0:0:10	3:1:4:2
15 years (n = 10)	15.5 ± 0.3	160.6 ± 3.2	57.2 ± 5.3	22.2 ± 1.8	0.68 ± 0.20	8:2	7:3	0:0:10	7:1:2
16 years (n = 10)	16.6 ± 0.3	166.7 ± 4.9	62.4 ± 9.6	22.4 ± 2.8	0.61 ± 0.22	10:0	3:7	0:0:10	7:0:0:3
17 years (n = 10)	17.5 ± 0.4	163.6 ± 4.4	56.7 ± 6.3	21.2 ± 2.1	0.49 ± 0.26	9:1	7:3	0:0:10	7:0:1:2
Male (n = 82)	14.1 ± 2.3	164.1 ± 13.7	56.8 ± 17.5	20.6 ± 4.1	0.61 ± 0.27	67:15[3]	45:34[3]	31:25:26	55:9:7:9[2]
10 years (n = 10)	10.5 ± 0.3	143.4 ± 6.1	38.5 ± 9.0	18.8 ± 5.0	0.66 ± 0.28	8:2	4:6	10:0:0	8:0:0:1[1]
11 years (n = 10)	11.4 ± 0.3	149.5 ± 5.1	40.5 ± 7.6	18.0 ± 2.6	0.55 ± 0.27	10:0	2:6[2]	10:0:0	8:1:0:1
12 years (n = 10)	12.6 ± 0.3	155.7 ± 5.4	44.9 ± 7.0	18.4 ± 1.9	0.53 ± 0.27	8:2	7:2[1]	7:3:0	8:0:1:1
13 years (n = 10)	13.6 ± 0.3	165.7 ± 5.6	53.4 ± 3.3	19.5 ± 2.0	0.57 ± 0.24	8:2	6:4	2:8:0	7:1:1:1
14 years (n = 11)	14.6 ± 0.2	166.0 ± 5.8	55.7 ± 6.7	20.2 ± 1.7	0.57 ± 0.22	10:1	9:2	2:8:1	8:1:1:1
15 years (n = 11)	15.6 ± 0.4	175.0 ± 6.7	72.2 ± 8.1	23.6 ± 2.3	0.80 ± 0.17	9:2	5:6	0:3:8	4:5:0:2
16 years (n = 10)	16.6 ± 0.3	178.6 ± 7.4	76.0 ± 22.0	23.5 ± 5.3	0.62 ± 0.35	8:2	5:5	0:2:8	7:1:1:1
17 years (n = 10)	17.6 ± 0.3	177.7 ± 6.9	71.8 ± 12.2	23.0 ± 5.2	0.54 ± 0.33	6:4	7:3	0:1:9	5:0:3:1[1]

A: Asian; BMI: body mass index; L: left; M: Māori; MVPA: moderate-to-vigorous physical activity; NZ: New Zealand European; O: other; PHV: peak height velocity; R: right.
Data are means ± standard deviations and counts.
[1,2,3]Missing data from 1, 2, and 3 participants, respectively.
[a]Leg used to kick a ball.
[b]Met minimum aerobic physical activity recommendations of an average of 60 min per day of moderate-to-vigorous physical activity (MVPA) in the past week.
[c]Pre, mid, and post PHV when less than −1 year, from −1 to 1 year, and when 1 year or more from calculated PHV.

Results

Participants

Characteristics of the 165 participants (50.3% female) who completed this study are reported in Table 1. Most participants were right-side dominant (81.8%), with half (51.2%) meeting minimum physical activity recommendations. There was a greater representation of post-puberal (45.5%) than mid-pubertal (30.3%) and pre-pubertal (24.2%) participants.

Calf Raise Test Outcomes

Participants completed an average of 26.1 ± 5.5 repetitions, reached 9.8 ± 2.0 cm in peak height, and performed 1087.5 ± 473.8 J of work during the CRT. There were no significant differences between dominant and non-dominant sides for repetitions ($p = .77$), peak height ($p = .71$), and work ($p = .19$); hence, data were averaged between sides for further analyses. Outcomes were significantly correlated between sides ($\rho = 0.70$, 0.65, and 0.83 for repetitions, peak height, and work; all $p < .001$). Descriptive statistics of these data are presented in Table 2.

Quantile Regression Models

The only covariates found to have a significant association with CRT outcomes after stepwise regression were BMI centile for repetitions, age and meeting minimum physical activity recommendations for work, and meeting minimum physical activity recommendations for peak height (Table 3). Specifically, lower repetitions were associated with higher BMI centile; greater total work was associated with increase in age, and higher total work and peak height were associated with meeting physical activity recommendations. Estimated lower, median, and upper quartiles are shown in Table 4. CRT outcomes did not differ significantly based on sex or maturational status.

Table 2. Calf raise test outcomes of participants ($n = 165$) by sex and age group.

Variable	Repetitions (n)	Total work (J)	Peak height (cm)
Female ($n = 83$)	26.0 ± 5.2	1049.1 ± 404.5	9.9 ± 2.5
10 years ($n = 10$)	26.2 ± 8.2	618.4 ± 165.2	8.7 ± 0.9
11 years ($n = 11$)	25.9 ± 4.6	656.2 ± 179.3	8.2 ± 2.1
12 years ($n = 12$)	27.7 ± 5.2	1340.1 ± 549.2	13.2 ± 3.7
13 years ($n = 10$)	25.5 ± 4.2	997.9 ± 251.7	9.0 ± 1.5
14 years ($n = 10$)	25.9 ± 3.5	1133.4 ± 180.4	10.4 ± 1.4
15 years ($n = 10$)	24.2 ± 3.4	1089.6 ± 176.2	9.7 ± 1.3
16 years ($n = 10$)	28.1 ± 5.0	1408.4 ± 346.5	9.5 ± 2.0
17 years ($n = 10$)	24.6 ± 6.0	1130.0 ± 375.2	10.1 ± 1.6
Male ($n = 82$)	26.1 ± 5.8	1126.3 ± 534.6	9.6 ± 1.5
10 years ($n = 10$)	24.6 ± 4.5	583.1 ± 138.5	8.9 ± 1.5
11 years ($n = 10$)	22.5 ± 7.0	625.7 ± 243.6	9.3 ± 1.2
12 years ($n = 10$)	28.1 ± 5.7	941.1 ± 282.5	10.3 ± 1.0
13 years ($n = 10$)	26.7 ± 6.7	1074.1 ± 339.5	9.6 ± 2.1
14 years ($n = 11$)	25.3 ± 2.4	1096.8 ± 157.5	10.0 ± 1.4
15 years ($n = 11$)	25.6 ± 7.7	1444.3 ± 532.3	10.1 ± 1.4
16 years ($n = 10$)	27.6 ± 5.2	1596.5 ± 633.8	9.3 ± 2.1
17 years ($n = 10$)	28.7 ± 5.4	1619.8 ± 516.2	9.6 ± 0.8

Data are means ± standard deviations.

Table 3. Estimates with 95% confidence intervals [lower, upper] from the multiple quantile regression models for each calf raise test outcome.

Variable	Coefficient	*p* Value
Repetitions (*n*)		
Intercept	28.6 [26.2, 31.0]	<.001
BMI centile	−4.8 [−8.5, −1.0]	.014
Total work (J)		
Intercept	−678.0 [−1092.6, −263.4]	.002
Age (years)	117.5 [87.9, 147.1]	<.001
MVPA[a]	144.5 [8.4, 280.7]	.038
Peak height (cm)		
Intercept	9.4 [8.9, 9.8]	<.001
MVPA[a]	0.8 [0.2, 1.4]	.007

BMI: body mass index; MVPA: moderate-to-vigorous physical activity.
[a]Met minimum aerobic physical activity recommendations of an average of 60 min per day of moderate-to-vigorous physical activity (MVPA) in the past week.

Table 4. Estimates of the median (50th), lower (25th), and upper (75th) percentiles for each calf raise test outcome accounting for significant covariates from the multiple regression models.

Variable	25th	50th	75th
Repetitions (*n*)			
25th BMI centile	24.1	27.5	30.8
50th BMI centile	22.8	26.3	29.6
75th BMI centile	21.5	25.1	28.3
Total work (J)			
10 years – MVPA[a] yes (no)	556.4 (414.2)	641.2 (496.7)	870.7 (605.2)
11 years – MVPA[a] yes (no)	644.0 (501.7)	758.7 (614.1)	1002.7 (737.2)
12 years – MVPA[a] yes (no)	731.5 (589.2)	876.1 (731.6)	1134.8 (869.3)
13 years – MVPA[a] yes (no)	819.0 (676.7)	993.6 (849.1)	1266.8 (1001.3)
14 years – MVPA[a] yes (no)	906.5 (764.3)	1111.0 (966.5)	1398.8 (1133.4)
15 years – MVPA[a] yes (no)	994.0 (851.8)	1228.5 (1084)	1530.9 (1265.4)
16 years – MVPA[a] yes (no)	1081.5 (939.3)	1346.0 (1201.4)	1662.9 (1397.4)
17 years – MVPA[a] yes (no)	1169 (1026.8)	1463.4 (1318.9)	1795.0 (1529.5)
Peak height (cm)			
MVPA[a] yes (no)	9.3 (8.2)	10.1 (9.4)	10.9 (10.7)

BMI: body mass index; MVPA: moderate-to-vigorous physical activity.
[a]Met minimum aerobic physical activity recommendations of an average of 60 min per day of moderate-to-vigorous physical activity (MVPA) in the past week.

Discussion

We quantified three of the main CRT outcomes in a sample of healthy children aged 10–17 years, looking beyond the number of repetitions and quantifying total work and peak height in addition to repetitions. With respect to CRT repetitions, we found an inverse association between BMI centile and repetitions. This finding diverges from those reported elsewhere where BMI showed no association (Maurer et al., 2007) and body mass exhibited a positive association (Mishra et al., 2023) with CRT repetitions in children. The apparent divergence in the identified associations between BMI-related metrics and CRT repetitions may be due to numerous factors, including differences in CRT procedures, the decision to use BMI centiles as opposed to raw BMI or body mass values, and/or variations in age ranges. In our study, the negative association suggests that the muscular endurance is poorer for children with greater rather than lower body mass for their height relative to their age and sex versus their peers of similar age and sex. These results align with a prior study in adults that also reported CRT repetitions were inversely associated with BMI (Hébert-Losier et al., 2017). It is arguable, however, whether the change in repetitions with BMI and BMI centile is clinically meaningful (i.e. approximately five repetitions per 1.0 centile). Given the SEM for the CRT is 2.2 repetitions based on test–retest data (Hébert-Losier et al., 2017), the minimal detectable change is around six repetitions (i.e. SEM $\times$ 1.96 $\times$ $\sqrt{2}$). The absence of an association between CRT repetitions and age adds to the mixed findings regarding the association between these two variables in previous research conducted in children (Maurer et al., 2007; Mishra et al., 2023). It could be that differences in the age of the sampled groups and sample sizes of studies contribute to these diverging results. Overall, our median values indicate that completing around 25 repetitions is "typical" for children aged 10–17 years, which aligns with the long-standing criterion for normal in adults recommended by Lunsford and Perry (1995).

We anticipated CRT repetitions would differ based on sex and maturational status. In the adult literature, sex differences in fatigue are strongly muscle dependent (Behrens et al., 2023). Females are often weaker than males, although less fatigable at slow-to-moderate contractile velocities at a given intensity (Ha et al., 2021). For the plantarflexors, minimal sex differences in muscle function and peripheral fatigue metrics after a dynamic fatiguing task have been reported in young adults (Ha et al., 2022), consistent with our observations in children. It has been proposed that the similarities in fiber type of the plantarflexors between sexes contribute to these minimal sex disparities (Ha et al., 2022). With regards to maturation, muscle mass and strength increase as individuals mature, but resistance to fatigue contrastingly declines (Ratel et al., 2004; Tonson et al., 2010). The CRT involves repetitive submaximal contractions to volitional cessation, lifting and lowering one's body mass. The enhanced strength post-puberty may counterbalance the decreased resistance to fatigue reported for this population. It could be that differences in energetics at a muscle level take place during the CRT across maturation despite achieving comparable repetitions, with a greater oxidative and reduced phosphocreatine breakdown contributing to task performance pre-puberty (Tonson et al., 2010).

Our study expands on findings from prior research by providing insight into CRT work and peak height metrics, not only repetitions. We found that work was positively associated with age and meeting physical activity recommendations, such that total work was greater among older children and children who were more active. As work is the product of total displacement and mass, that older children generated more work is not entirely surprising. Adults typically achieve 2000 J of work during the CRT (Hébert-Losier et al., 2022; Silbernagel et al., 2006; Svensson et al., 2019), which is close to the average seen in our older children. The association between meeting physical activity recommendations and both greater work and peak height are likely attributable to children engaging in more regular physical activity having greater muscular strength and endurance abilities. Our findings reinforce the importance of physical activity for the development and wellbeing of young people, and highlight the need to promote physical activity among young people in Aotearoa New Zealand where many children and youth participate in physical activity, but considerable inequities exist (Wilson et al., 2023).

Although we identified large significant correlations and no significant differences between sides in CRT metrics, the contralateral side cannot always be used as a reference to normal when injury or deficiencies are present (Barbosa et al., 2023; O'Neill et al., 2019); hence, access to normative data becomes important to implement evidence-based practice. Clinicians can therefore use the values reported here for repetitions, peak height, and work as guidelines of normal CRT performance to inform rehabilitation progress in presence of injury, for example. Prospective studies are still needed to establish whether these normative thresholds are suitable indicators of resilience to injury incidence or readiness to return-to-play post Achilles or calf muscle injuries in young athletes. The number of repetitions alone does not consider the quantity or quality of the movement and can mask limitations in heel rise height and true triceps surae muscle-tendon unit function. For example, 10-m sprint times in athletes show large and moderate correlations to CRT work and peak height, respectively; but no significant relation to repetitions (Hébert-Losier et al., 2023). The clinical quantification of peak height and work is therefore recommended. Numerous devices are available for assessing CRT metrics (Fernandez & Hébert-Losier, 2023), with linear position transducers (Andreasen et al., 2021; Byrne et al., 2017) and the free-to-use Calf Raise App (Fernandez et al., 2023; Hébert-Losier et al., 2022) enabling the valid and reliable calculations of the three main CRT metrics of repetitions, peak height, and total work. These two devices are perceived to offer the best compromise for clinicians seeking research-grade outcomes for the CRT at a modest cost (Fernandez & Hébert-Losier, 2023).

Limitations

This study is not without limitations. Though adequately powered to detect small effect sizes, a larger sample would have been beneficial to allow other factors, such as ethnicity, to be included in analyses. It would also enable the extraction of extreme centiles (i.e. 2.5th and 97.5th) to establish normative ranges rather than focusing on central percentiles (Ialongo, 2019). In addition, the physical activity measure was self-reported, meaning it is subject to bias. There are no childhood physical activity questionnaires with strong evidence of both acceptable validity and reliability (Hidding et al., 2018). As it was not feasible to instrument children with accelerometers or perform doubly labeled water technique (the gold standard) to assess physical activity levels and energy expenditure, the IPAQ-SF was used as an indicator of physical activity. As the IPAQ-SF has been reported to both overestimate (Wang et al., 2013) and underestimate (Rääsk et al., 2017) physical activity compared to accelerometry in children, a more accurate quantification of physical activity might have shown different levels of association with CRT outcomes. Also, the normative data apply to the performance of the test on a 10° incline following a 60 beats per minute metronome, and should not be directly translated to CRT performances when test parameters are changed (Hébert-Losier et al., 2024).

Conclusion

In summary, we are the first to our knowledge to document CRT performance in children aged 10–17 years; focusing not only on repetitions, but also peak height and total work. Our findings indicate that completing around 26 repetitions and reaching a peak height of around 10 cm represent "normal" when performed on a 10° incline in children, like adults, with no differences between sexes, maturation, or age. Achieving 640 J of work is normal for a 10-year-old child and should increase by approximately 118 J annually until the age of 17 years. Meeting minimum physical activity recommendations appears beneficial for plantarflexor function and should continue to be a national and international priority for the wellbeing of children. Future research may use the values we report as normative data for comparing outcomes of individuals with an injury or pathology.

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Author contributions

Conceptualization and methodology: KHL. Data curation: KHL and YP. Formal analysis: KHL, YP, OW, and JC. Investigation: KHL, YP, and JC. Project administration: KHL and JC. Resources: KHL and JC. Supervision: KHL, OW, and JC. Visualization: KHL and OW. Writing – original draft preparation, review and editing: KHL, YP, OW, and JC.

Ethical approval

This study was approved by The Human Research Ethics Committee of the University of Waikato (2020#11).

Consent form

Participants and their parents or legal guardians gave written informed consent before data collection began.

Disclosure statement

One of the authors (KHL) developed the free-to-use Calf Raise application. The data from the application were obtained from an independent researcher (YP) not related to the development of the application.

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