Feasibility, Validity, and Reliability of the Plank Isometric Hold as a Field-Based Assessment of Torso Muscular Endurance for Children 8–12 Years of Age

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This project examined the feasibility, validity, and reliability of the plank isometric hold for children 8–12 years of age. 1502 children (52.5% female) performed partial curl-up and/or plank protocols to assess plank feasibility ($n = 823, 52.1\%$ girls), validity ($n = 641, 54.1\%$ girls) and reliability ($n = 111, 47.8\%$ girls). 12% ($n = 52/431$) of children could not perform a partial curl-up, but virtually all children ($n = 1066/1084$) could attain a nonzero score for the plank. Plank performance without time limit was influenced by small effects with age ($\beta = 6.86; p < .001, \eta^2 = 0.03$), flexibility ($\beta = 0.79; p < .001, \eta^2 = 0.03$), and medium effects with cardiovascular endurance ($\beta = 1.07; p < .001, \eta^2 = 0.08$), and waist circumference ($\beta = -0.92; p < .001, \eta^2 = 0.06$). Interrater (ICC = 0.62; CI = 0.50, 0.75), intra-
rater (ICC = 0.83; CI = 0.73, 0.90) and test-retest (ICC = 0.63; CI = 0.46, 0.75) reliability were acceptable for the plank without time limit. These data suggest the plank without time limit is a feasible, valid and reliable assessment of torso muscular endurance for children 8–12 years of age.

The fitness of children in developed countries has declined over recent decades (29,31), increasing their risk for health issues (4,7,10,24,26). Torso muscular endurance, a component of physical fitness, makes an important contribution to the efficient and effective use of the upper and lower extremities (23), injury prevention (5), and stability of the spinal column (2,17,18)—all of which contribute to optimal function in activities of daily living and engagement in a healthy, active lifestyle. Lower torso muscular endurance is associated with increased mortality risk in both men and women (11).

Valid and reliable assessment protocols are the cornerstone of our ability to identify and monitor children’s fitness (14). Partial curl-up protocols are recommended for monitoring torso muscular endurance (9), but these protocols are difficult to perform in children and result in substantial floor and ceiling effects (30,31). Variations of a plank protocol have been suggested as an alternative torso muscular endurance assessment, and have been shown to have acceptable validity (8,28) and reliability (32) in adults.

Our project examined the feasibility, validity, and reliability of the plank isometric hold as a measure of torso muscular endurance in children 8–12 years of age in a field-based setting. We hypothesized that a nonzero score would be more likely on the plank than the partial curl-up (i.e., reduced risk of floor effect); time required for plank administration would be similar to the partial curl-up; plank scores not adjusted for maturity would be higher for older children and males; plank scores would be positively correlated with health-related anthropometric and fitness measures; and the plank protocol would have acceptable interrater, intrarater, and test-retest reliability.

**Methods**

**Participants**

Study participants were a convenience sample of children attending rural, suburban, and inner-city schools or summer camps in southeastern Ontario, Canada, between 2009 and 2012. Study materials were provided in English or French, as requested by participants. Informed written parental consent and verbal child assent were obtained before enrollment. A written preactivity screening questionnaire determined risk for adverse events during maximal effort exercise. Parents could access their child’s results after data collection was complete. The study was approved by our institutional research ethics board and the research committees of participating school boards.

**Study Overview**

**Plank Protocol (Photo 1).** The plank protocol required participants to maintain a static prone position with only forearms and toes touching the ground. Proper
form required feet together with toes curled under the feet, elbows forearm distance apart, and hands clasped together against the floor mat. Participants maintained eye contact with their hands, a neutral spine, and a straight line from head to ankles. The child was given one 5-s practice trial, and the examiner instructed the child into the proper position, followed by a brief period of rest. The test began when the participant demonstrated the correct position. Participants were allowed to deviate from the correct position once and could continue the test if they immediately resumed the correct starting position. The test was terminated on the second deviation from the correct position or if the participant did not return to the correct position after the first warning. Throughout the development of the plank protocol, different maximum time limits were evaluated across three distinct cycles of testing. Different torso muscular endurance protocols were included for comparison during each phase of testing.

**Photo 1** — Picture of child performing the plank.

**Cycle 1.** During 2009–2010, 641 children (51.3% female) 8–12 years of age enrolled in eight rural and four urban elementary schools and five summer camps participated in either the Fitnessgram partial curl-up (34; n = 370) or the 90-s maximum time limit plank isometric hold (90-s plank; n = 271) to assess the feasibility of the 90-s plank. The Fitnessgram partial curl-up had participants slide their hands forward (7.6 cm for ages 5–9 and 11.4 cm for children 10 and older) to a maximum of 75 repetitions while maintaining a cadence of 20 partial curl-ups per minute (34).

**Cycle 2.** In 2011, 182 children (55.0% female) 8–12 years of age enrolled in summer camps participated in the feasibility of the 60-s maximum time limit plank isometric hold protocol (60 s plank). Sixty-one of these children performed both the 60-s plank and the Canadian Health Measures Survey (CHMS) partial curl-up protocol (31). The CHMS partial curl-up protocol requires participants to slide their hands forward 10 cm during the partial curl-up, regardless of age, to a maximum of 25 repetitions at a cadence of 25 partial curl-ups per minute (31).

**Cycle 3.** During the 2011–2012 academic school year, 631 children (54.7% female) enrolled in five rural and two urban elementary schools completed the
validity evaluation of the plank isometric hold with no predetermined time limit (unlimited plank). Validity was assessed by comparing the unlimited plank to flexibility (31), handgrip (31), cardiovascular endurance (15), waist circumference (31) and body mass index (BMI) percentile (21,31). A subsample of these participants (n = 73, 56.2% female) also completed the test-retest reliability assessment of the unlimited plank. In 2012, 38 children (31.6% female) enrolled in a summer camp completed the interrater and intrarater reliability evaluation of the unlimited plank. Ten participants (20% female) performed the plank test followed by a fatigued plank test on the same day.

Plank Feasibility

In Cycle 1, children completed either the Fitnessgram partial curl-up protocol (34) or the 90-s plank. In the summer of 2011 (Cycle 2), children completed both the CHMS partial curl-up protocol (31) and 60-s plank on the same day, with at least 15 min of rest between tests with the order of test administration randomly determined. In Cycle 3, only the unlimited plank was evaluated. Each protocol was explained and demonstrated before each trial. Feasibility was assessed by comparing all plank protocols (60-s, 90-s, and unlimited plank) with all partial curl-up protocols (Fitnessgram and CHMS) to compare nonzero scores (children unable to perform the protocol [i.e., floor effect]), interpretable scores (scores between zero and a maximum), and maximum scores (children reaching the cut-off point of each protocol [i.e., ceiling effect]). The time to complete all protocols was documented to compare the length of test administration time (in seconds) for each protocol.

Plank Validity

Sixty-one children performed both the CHMS partial curl-up and the 60-s plank on the same day to determine the extent of the association between these two tests. A subsample of children performed the unlimited plank followed by the 20-m shuttle run following the progressive aerobic cardiovascular endurance run (PACER) protocol and 20 partial curl-ups before being retested on the unlimited plank on the same day. Further unlimited plank validity testing was evaluated through comparisons of the unlimited plank protocol to standardized fitness assessments. Standing handgrip strength was measured with a handgrip dynamometer (Takei Model A5001, Japan). Total score was the sum of the highest score with each hand to the nearest 0.5 kg (31). Waist circumference was measured to the nearest 1 mm at the midpoint between the lowest floating rib and the top of the iliac crest, at the end of a normal expiration (31). Height was measured with a SECA portable stadiometer (Medical Scales and Measuring Systems, England). Weight was measured with an A&D Medical digital weight scale (A&D Engineering Inc, USA). The administration of height and weight followed CHMS protocols (31) and were used to calculate BMI (kg/m2) percentile (21). Cardiovascular endurance was assessed as the number of laps completed for a 20-m shuttle run using the PACER (15). Flexibility was assessed using an AcuFlex Sit and Reach box (Novel Products, USA); two measures were taken and the best score was recorded to the nearest 0.1 cm (31).
Plank Reliability

Reliability testing was completed during Cycle 3 using the unlimited plank protocol. To assess inter- and intrarater reliability, video recordings were created of children performing the isometric hold for as long as possible. In contrast to the unlimited plank protocol, for the reliability video recordings, children were continuously given corrections each time they deviated from the correct position. Video recording continued until the correct position was no longer attempted by the child. Subsequently, seven examiners independently reviewed the video-recordings using the established criteria for the plank protocol (test terminated when a second correction is required). Each examiner independently determined when the test would have been terminated for each video on 3 separate days at intervals of 2–4 days. The order in which the video recordings were reviewed was randomized between examiners, following similar published procedures (1). For test-retest reliability, a subsample of children performing the unlimited plank validity assessment completed the unlimited plank on 2 separate days with the protocol administered by the same examiner at an interval of 8 days.

Data Analyses

Descriptive statistics are reported as frequency or mean ± SD, as appropriate. All analyses were performed using IBM SPSS Statistics (Version 20). Statistical significance was set at \( p < .05 \).

**Plank Feasibility.** An independent unpaired t test was used to evaluate the difference in time to administer the 90-s plank and the Fitnessgram partial curl-up protocol. A linear regression model of plank time by age and sex evaluated plank feasibility across the 8–12 year age range for both males and females. Kappa statistics were calculated to determine agreement between the 60-s plank and the CHMS partial curl-up for the probability of a nonzero score and a nonzero/nonmaximal score. A paired t test was used to compare the time required for a child to complete the 60-s plank and the CHMS partial curl-up protocols.

**Plank Validity.** Spearman rank correlations assessed the relationship between CHMS partial curl-ups and the 60-s plank. This relationship was further tested in a multivariable linear regression model with age and sex as mandatory variables. A paired t test examined the difference between an unlimited plank score followed by a fatigued (after PACER and 20 partial curl-ups) unlimited plank score. Pearson correlation coefficients evaluated the association between the unlimited plank and standardized fitness measures (handgrip, waist circumference, BMI percentile, PACER, and flexibility). Fitness measures with a significant univariate correlation to the unlimited plank score were entered into a multivariable linear regression model. Backward variable selection was used to model the relationship between unlimited plank and standard fitness measures. The most insignificant variable was removed and this process continued until all variables were significant. Age and sex were mandatory variables whether significant or not. The same statistical procedures (univariate correlation followed by linear regression modeling) were used to analyze data from 61 children who performed the 60-s plank and the CHMS partial curl-up.
Plank Reliability. Interclass correlation coefficients (ICC, 2,1 [two-way, random single measures for absolute agreement]) with 95% confidence intervals (CI) evaluated inter- and intrarater and test-retest reliability.

Results

Participants

Children 8–12 years of age participated in either a school-based assessment (n = 1272; 53.0% female) or a summer-camp-based assessment (n = 230; 49.6% female). Overall recruitment rate during the school-based testing in 2011–2012 was 631 of 784 eligible children (80.5%). Recruitment rates for school based testing before 2011 and summer camps could not be determined, because the total number of families contacted to participate in those cycles of testing was known only to the school/camp.

Plank Feasibility

Performances of the Fitnessgram and CHMS partial curl-up protocols and the 60-s, 90-s, and unlimited plank protocols were categorized as zero, nonzero/nonmaximal, and maximal scores (Table 1). Different children performed either a plank protocol or a partial curl-up protocol and with their scores combined respectively, zero scores were recorded for 0.8% (9/1084) of children performing a plank protocol and 12.1% (52/431) performing a partial curl-up protocol. When 61 children (70.5% female) performed both the 60-s plank and the CHMS partial curl-up protocol, there was no agreement beyond that which would occur due to chance (kappa = 0.03; p = .74), for either zero or nonzero/nonmaximal scores. Of the 61 children who performed both the 60-s plank and the CHMS partial curl-up, a nonzero/nonmaximal score occurred in 71.1% (44/61) with the plank and 59.0% (36/61) with the CHMS partial curl-up.

No significant difference was found between time to complete either the Fitnessgram (29 s ± 28) or CHMS partial curl-up (36 s ± 21) protocols (p > .20). Mean time for the 90-s plank (52 s ± 25) was significantly higher (t = -10.4; p < .001) than the time required for the Fitnessgram partial curl-up. The CHMS partial curl-up protocol took significantly less time than the 60-s plank (41 s ± 16; p = .01). When the plank was administered with no time limit (56 s ± 40), 133 s was required to provide a nonzero/nonmaximal score for 95% of the participants (Table 2).

Plank Validity

A Spearman rank correlation between 60 s plank time and CHMS partial curl-ups was significant (r = .32, p = .01, n = 61). However, when the relationship was examined using a multivariable linear regression model adjusting for age and sex, neither age (p = .09), sex (p = .23) nor CHMS partial curl-ups (p = .24) were associated with 60 s plank. Forward variable selection during creation of the regression model indicated that the addition of age to the model eliminated the significant relationship between CHMS partial curl-ups and 60-s plank. The addition of sex to the model did not influence this relationship.
<table>
<thead>
<tr>
<th></th>
<th>8- to 10-Year-Old Children</th>
<th>11- to 12-Year-Old Children</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>zero scores n (%)</td>
<td>nonzero/nonmax scores n (%)</td>
</tr>
<tr>
<td>Fitnessgram curl-up(^a)</td>
<td>215 22 (10%)</td>
<td>193 (90%)</td>
</tr>
<tr>
<td>CHMS curl-up(^b)</td>
<td>47 6 (13%)</td>
<td>29 (62%)</td>
</tr>
<tr>
<td>60 s plank(^c)</td>
<td>113 1 (1%)</td>
<td>67 (59%)</td>
</tr>
<tr>
<td>90 s plank(^d)</td>
<td>156 0 (0%)</td>
<td>141 (90%)</td>
</tr>
<tr>
<td>Unlimited plank(^e)</td>
<td>403 5 (1%)</td>
<td>398 (99%)</td>
</tr>
</tbody>
</table>

\(^a\)Fitnessgram curl-up protocol does not limit the completion time but has a maximum of 75 repetitions.

\(^b\)Canadian Health Measures Survey (CHMS) curl-up protocol allows a maximum of 25 partial curl-ups during a 60-s assessment period.

\(^c\)Plank protocol had a predetermined time limit of 60 s.

\(^d\)Plank protocol had a predetermined time limit of 90 s.

\(^e\)Plank protocol did not have a predetermined time limit.
In a small subsample of participants \((n = 10, \ 20\% \ \text{female})\) who performed the unlimited plank test before and after performing the PACER protocol and 20 partial curl-ups, a paired t test demonstrated that initial unlimited plank scores were significantly better than the unlimited plank scores that could be obtained during the fatigued state. Mean difference was \(10 \text{ s}\ \pm \ 11 \ (t = 2.86, \ p = .02)\).

In a multivariable linear regression model with age and sex as mandatory variables, the unlimited plank was associated with increased cardiovascular endurance, increased flexibility, smaller waist circumference, and older age (Table 3), but did not differ by sex. 60 s plank scores were significantly correlated with older age \((p = .005, \ n = 182)\) but did not differ by sex \((p = .94, \ n = 182)\) or waist circumference \((p = .85, \ n = 61)\). In 271 children \((56.0\% \ \text{female})\), higher scores on the 90-s plank protocol were associated with older age \((p = .001)\) and male sex \((p = .02)\).

### Plank Reliability

Interrater reliability results were assessed across seven examiners on three separate trials. ICC’s for the 3 trials were: Trial 1 ICC = 0.65 (CI = 0.53, 0.77); Trial 2 ICC = 0.64 (CI = 0.52, 0.76); Trial 3 ICC = 0.58 (CI = 0.46, 0.72). ICC for intrarater reliability across 3 trials for the 7 examiners ranged from 0.73 to 0.92 (Table 4). In the test-retest analysis, the ICC between two plank performances completed at an interval of 8 days was 0.63 (CI = 0.46, 0.75).

### Discussion

Trends indicating a decline in the fitness of children and youth \((29,31)\) make the valid and reliable measurement of musculoskeletal fitness increasingly important. In children, there are feasibility challenges with partial curl-up protocols as floor and ceiling effects are common. This study demonstrated that the unlimited plank isometric hold is a feasible, valid, and reliable alternative assessment of torso muscular endurance. Our large convenience sample of 1,502 children was recruited from diverse environments, including 13 rural elementary schools; 6 urban elementary schools; and 8 summer camps. The size of the sample and access to the schools provided a uniquely broad range of participant fitness levels and testing environments.

### Plank Feasibility

The proportion of children 8–12 years of age who achieved nonzero/nonmaximal scores was greater with the unlimited plank protocol than either the Fitnessgram or CHMS partial curl-up protocols. These results suggest that the unlimited plank allows for better differentiation among participants who have lower levels of fitness and may be less influenced by skill, technique, or prior experience with the testing procedures. The simplicity of the isometric plank protocol \((28)\) and the ability of young children \((182 \ \text{grade 4 students})\) to perform the protocol correctly \((23)\) has been noted in previous research. Our results also support previous research indicating feasibility concerns with the administration of the CHMS partial curl-up protocol. We found that 12% of participants 8–12 years of age were unable to perform either the Fitnessgram or CHMS partial curl-up protocol.
Table 2  Percentile Scores for Time to Perform the Plank and Partial Curl-Up Protocols Among 8- to 12-Year-Old Children

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Fitnessgram Curl-Ups&lt;sup&gt;a&lt;/sup&gt; (time in sec)</th>
<th>CHMS Curl-Ups&lt;sup&gt;b&lt;/sup&gt; (time in sec)</th>
<th>60-s Plank&lt;sup&gt;c&lt;/sup&gt; (time in sec)</th>
<th>90-s Plank&lt;sup&gt;d&lt;/sup&gt; (time in sec)</th>
<th>Unlimited Plank&lt;sup&gt;e&lt;/sup&gt; (time in sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>370</td>
<td>61</td>
<td>182</td>
<td>271</td>
<td>631</td>
</tr>
<tr>
<td>Female</td>
<td>48%</td>
<td>71%</td>
<td>55%</td>
<td>56%</td>
<td>55%</td>
</tr>
<tr>
<td>Age&lt;sup&gt;f&lt;/sup&gt;</td>
<td>10.2 ± 1.2</td>
<td>9.7 ± 1.2</td>
<td>10.0 ± 1.2</td>
<td>10.2 ± 1.0</td>
<td>10.1 ± 1.0</td>
</tr>
<tr>
<td>5%</td>
<td>0.0</td>
<td>0.0</td>
<td>20.5</td>
<td>13.0</td>
<td>11.0</td>
</tr>
<tr>
<td>25%</td>
<td>9.0</td>
<td>20.4</td>
<td>36.3</td>
<td>32.0</td>
<td>29.2</td>
</tr>
<tr>
<td>50%</td>
<td>21.0</td>
<td>36.0</td>
<td>56.1</td>
<td>48.0</td>
<td>46.7</td>
</tr>
<tr>
<td>75%</td>
<td>42.0</td>
<td></td>
<td>73.0</td>
<td></td>
<td>70.6</td>
</tr>
<tr>
<td>95%</td>
<td>88.4</td>
<td></td>
<td></td>
<td></td>
<td>133.1</td>
</tr>
</tbody>
</table>

<sup>a</sup>Fitnessgram curl-up protocol does not limit the number of curl-ups or assessment period. 12% of children cannot perform test.

<sup>b</sup>Canadian Health Measures Survey (CHMS) curl-up protocol allows a maximum of 25 partial curl-ups during a 60 s assessment period. 5% of children cannot perform test. Only differentiates 70% of children.

<sup>c</sup>Plank protocol had a predetermined time limit of 60 s. Only differentiates 55% of children.

<sup>d</sup>Plank protocol had a predetermined time limit of 90 s. Only differentiates 86% of children.

<sup>e</sup>Plank protocol did not have a predetermined time limit.

<sup>f</sup>Participant age is mean ± 1 SD (in years).
Table 3  Association Between Unlimited Plank and Health-Related Fitness Measures in 8- to 12-Year-Old Children

<table>
<thead>
<tr>
<th>Higher plank score associated with:</th>
<th>n</th>
<th>Univariate correlation</th>
<th>Multivariable Model b</th>
<th>p-value</th>
<th>Effect sizee (Partial $\eta^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>male sexa</td>
<td>631</td>
<td>.10*</td>
<td>-5.37 (-11.36, 0.62)</td>
<td>0.08</td>
<td>no effect (.006)</td>
</tr>
<tr>
<td>older agea</td>
<td>631</td>
<td>.16*</td>
<td>6.86 (3.68, 10.05)</td>
<td>&lt; 0.001</td>
<td>small effect (.03)</td>
</tr>
<tr>
<td>increased flexibility</td>
<td>593</td>
<td>.22*</td>
<td>0.79 (0.44, 1.15)</td>
<td>&lt; 0.001</td>
<td>small effect (.03)</td>
</tr>
<tr>
<td>increased grip strength</td>
<td>591</td>
<td>.11*</td>
<td>N/S</td>
<td>N/S</td>
<td>N/A</td>
</tr>
<tr>
<td>higher PACERc shuttle run laps</td>
<td>591</td>
<td>.43*</td>
<td>1.07 (0.76, 1.36)</td>
<td>&lt; 0.001</td>
<td>medium effect (.08)</td>
</tr>
<tr>
<td>smaller waist circumference</td>
<td>582</td>
<td>-.28*</td>
<td>-0.92 (-1.23, -0.62)</td>
<td>&lt; 0.001</td>
<td>medium effect (.06)</td>
</tr>
<tr>
<td>lower BMI percentilef</td>
<td>575</td>
<td>-.28*</td>
<td>N/S</td>
<td>N/S</td>
<td>N/A</td>
</tr>
</tbody>
</table>

aAge and sex were mandatory variables in the multivariable model.
bMultivariate regression model accounted for 26% of the variance in plank performance.
cProgressive aerobic cardiovascular endurance run (PACER)
d95% Confidence limits of the parameter estimate
eEffect size is the partial $\eta^2$ based on (.01 small effect, .06 medium effect, .14 large effect; 19).
fBody mass index (kg/m2) percentile (21)

* Significant univariate correlation with plank score, $p < .01$ (2-tailed)
Tremblay et al. (2010) reported that the CHMS partial curl-up protocol resulted in zero scores among one quarter of children (Boys: 23–33%; Girls: 15–31%; 31), in a slightly younger sample of children 6–10 years of age.

Our results indicate that the plank protocol does not discriminate between children with above average levels of torso muscular endurance if a predetermined time limit is imposed (i.e., 60 and 90 s maximums). When the maximum plank time was 60 s, 45% of children remain undifferentiated. When the maximum time is extended to 90 s, the 90-s plank protocol successfully differentiates 86% of participants. To differentiate among 95% of children 8–12 years of age, a time limit of at least 133 s would be required. The mean length of time required for the unlimited plank protocol (56 s ± 40) is shorter in our study of children 8–12 years of age than for previous reports of mean plank time for adult participants. Mean plank times were reported for female professional dancers (120 s; 1), firefighters (118 s, mean age: 40 years; 16), young adults (94–116 s, mean age: 24 years; 5); and healthy adults (73 s, mean age: 34 years; 28).

While the unlimited plank provides the best differentiation, it takes significantly more time to administer in comparison with the Fitnessgram partial curl-up protocol. The increased time for test administration may limit the feasibility of its use in population surveillance studies involving a larger number of participants. Researchers in time limited or time sensitive environments (i.e., school based testing) may find the longer assessment duration of the plank protocol problematic. Researchers need to consider their assessment objectives, testing constraints and relative importance of floor versus ceiling effects when deciding on the maximum time allowed for performance of the plank isometric hold. Unlimited plank scores have been shown to be higher in children with better cardiovascular fitness, increased flexibility, smaller waist circumferences, and older age, so progressive time limits may be beneficial based on the results from this study population.

Table 4 Intrarater Reliability of the Plank Protocol Among 8- to 12-Year-Old Children

<table>
<thead>
<tr>
<th>Examiner</th>
<th>Interclass Correlation Coefficient</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.79</td>
<td>0.66, 0.88</td>
</tr>
<tr>
<td>2</td>
<td>.92</td>
<td>0.87, 0.95</td>
</tr>
<tr>
<td>3</td>
<td>.80</td>
<td>0.69, 0.88</td>
</tr>
<tr>
<td>4</td>
<td>.92</td>
<td>0.86, 0.95</td>
</tr>
<tr>
<td>5</td>
<td>.88</td>
<td>0.80, 0.93</td>
</tr>
<tr>
<td>6</td>
<td>.79</td>
<td>0.67, 0.88</td>
</tr>
<tr>
<td>7</td>
<td>.73</td>
<td>0.59, 0.84</td>
</tr>
</tbody>
</table>

Note. n = 38, 31% female.

aEach examiner independently determined when the test would have been terminated for each video for three separate trials, with the interval between trials ranging from 2 to 4 days.

bICC (2,1); two-way, random single measures for absolute agreement.
Plank Validity

All plank protocols demonstrated a significant age effect with older children performing better. These age patterns were expected based on previous research, showing that older children perform better on tests of muscular endurance (6,31), and support the validity of the plank isometric hold as an assessment of torso muscular endurance.

Determining the validity of field tests of torso muscular endurance is difficult because of the lack of a “gold standard” reference procedure. Indeed, our pilot work demonstrated that after controlling for age and sex, 60-s plank scores were not significantly related to CHMS partial curl-up performances. The 60-s plank and the CHMS partial curl-up have been shown to have feasibility issues (Table 2), which may have influenced the lack of correlation between these test protocols in our results. The results from our subsample of children who performed the unlimited plank protocol without and then with cardiovascular and abdominal muscle fatigue support the validity of the unlimited plank protocol as an assessment of torso muscular endurance.

Using defined effect sizes for partial eta squared (\(\eta^2\); 0.01 small effect, 0.06 medium effect, 0.14 large effect; 19), our multivariable linear regression model indicated that higher scores on the unlimited plank protocol were associated with medium-sized effects for increased cardiovascular endurance and smaller waist circumference, and by small-sized effects for increased flexibility, and older age. These associations are similar to previous reports for adults, which found that torso muscular endurance was related to cardiovascular endurance (27), lower-body function (20,22,25), and anthropometric measures (3,12). Few studies have been performed in children, but they are also supportive of our results. Plank-type exercises performed twice per week for 6 months have been shown to significantly improve 1-min sit-up performance in 182 Grade 4 children (23). Smaller waist circumference was related to increased sit-up performance in 1,140 children in Grades 1, 2, and 4 (3), and children above the 80th percentile for BMI were less likely to pass a test of abdominal strength (12). The consistent findings between our unlimited plank protocol and previous research examining fitness variables supports the validity of the unlimited plank protocol as a measure of torso muscular endurance. Our study examines a larger range of fitness variables than previous reports, providing a more comprehensive evaluation of the relationships between torso muscular endurance and other fitness measures in children.

Plank Reliability

Using published criteria for the strength of ICC values (moderate = 0.4; substantial = 0.6; and excellent = 0.8 [13]), two out of the three interrater reliability analyses across seven examiners were substantial. The moderate finding during the third interrater reliability trial may reflect examiner fatigue from reviewing the same video recordings for a third time. Some examiners were more familiar with the unlimited plank test than others; however, the interrater reliability between all examiners was substantial. Our examiners received relatively little training (reading the assessment procedure and 1 hr of group practice trials), and yet they were able to accurately conduct a reliable assessment.
Intrarater reliability across three trials was substantial to excellent for all our seven examiners. These results are comparable to previous reports showing good reliability of an unlimited plank protocol among adults (28). In contrast to the substantial intrarater reliability for unlimited timed plank trials found in our study, scoring systems that categorized a 10-s timed plank performance based on a four-score criteria (excellent, good, moderate, poor) had only fair reliability (intrarater ICC = 0.21, CI = 0.07, 0.35; interrater ICC = 0.36, CI = 0.22, 0.53) among adults (33).

We found substantial test-retest agreement on plank performance among 73 children who repeated the unlimited plank test over an 8-day interval. Similar results have been obtained with adults. Significant Pearson correlation coefficients \( r = 0.78, p < .05 \) were found between repeated unlimited plank performances on the same day in 43 adults (mean age: 34) with no history of back pain (28). Substantial reliability for the unlimited plank was demonstrated during three assessments over 9 days in 8 adults (mean age: 24 years; 7 days between sessions 1 and 2; 2 days between sessions 2 and 3; ICC = 0.85, CI = 0.61, 0.97; 5).

To our knowledge, no other study has conducted reliability evaluations of a timed plank protocol with children. Our results are promising and suggest that the unlimited plank protocol can be reliably administered to children 8–12 years of age in a field-based setting.

**Study Limitations**

Schools had the option to opt-in to the project after being contacted by their school board research ethics committee. This convenience sample of schools introduces a potential inclusion bias as the schools that volunteered to participate may have had a more positive approach to physical activity and fitness. However, the impact of the potential selection bias would not be expected to impact our comparison of children performing either the partial curl-up or plank protocols sampled using the same procedures, and our large sample did include children who demonstrated a wide range of fitness levels. The sample of children assessed via summer-camp programs was limited by the relatively narrow range of fitness levels among participating children. Since most, but not all, of the summer-camp programs were focused on specific sport (i.e., tennis camp, hockey camp), the campers may have been more active or fit than the general population. The influence of children who do not attend summer camps on the feasibility and reliability of the plank protocol remains uncertain.

In all cycles of testing, chronological age was used instead of maturational age. We recognize that fitness performance, particularly in the peri-pubertal years from 8-12 years of age, can be affected by growth and maturation, which is not accounted for in our study.

**Conclusion**

Administration of a partial curl-up protocol to assess torso muscular endurance has limited feasibility in children. In contrast, our unlimited isometric plank hold protocol is feasible for virtually all children 8–12 years of age. The unlimited plank protocol more often provided a nonzero/nonmaximal score than either a time-limited
plank protocol or a partial curl-up protocol. The unlimited plank appears to be valid, as it correlates with other measures of health-related fitness and varies as expected by age. Measures of intra- and interrater reliability were substantial and test-retest reliability scores are consistent over an interval of 8 days.

Future research is recommended to identify the predetermined time limits for the plank protocol that would be associated with decreased health risks. Shorter time limits would increase the feasibility of administering the plank protocol in population-based studies and time restricted environments. The development of normative data by age and sex would assist with interpretation of the plank-protocol results and enable the assessment of torso muscular endurance in relation to health and performance outcomes of interest.

Acknowledgments

This study was partially funded by a grant from the Canadian Institutes of Health Research awarded to Dr. Meghann Lloyd and Dr. Mark Tremblay (IHD 94356). TJS is supported by Doctoral Research Awards from the Canadian Institutes of Health Research and the Canadian Diabetes Association as well as an Excellence Scholarship from the University of Ottawa. The authors wish to thank Joel Barnes, Claire Francis, Priscilla Bélanger, David Thivel, Weimo Zhu, Elena Boiariskaia, and Nick Barrowman for their assistance with various aspects of data collection and analysis.

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