Songklanakarin J. Sci. Technol.
47 (5), 381–387, Sep. – Oct. 2025

http://www.sjst.psu.ac.th

Original Article

Assessment of ankle functional performance in children with chronic ankle instability using functional performance tests and walking speed tests

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Received: 20 September 2024; Revised: 12 December 2024; Accepted: 16 July 2025

Abstract

This study aimed to evaluate the effectiveness of functional performance tests for children (FPTs ^{children}) in assessing ankle function in children with and without CAI and to correlate these tests with the Cumberland Ankle Instability Tool - Thai version (CAITY-T). Seventy-six children with and without CAI aged 7-12 years were recruited. Participants were assessed using the CAITY-T, six-meter crossover hop test (6MCHT), single leg stance test (SLST), Y-balance test (YBT), and ten-meter walk test (10MWT). Children with CAI demonstrated significantly poorer performance in 6MCHT and SLST with eyes open on both floor and foam and fast walking speed in 10MWT compared to controls ($p<0.05$). A positive correlation was found between YBT anterior scores and CAITY scores in children with CAI ($p<0.05$). FPTs ^{children} effectively differentiates children with CAI from healthy controls. The positive correlation between YBT and CAITY suggests the importance of dynamic balance assessments. These findings support using objective FPTs ^{children} measures and subjective self-assessments in clinical practice.

Keywords: children, chronic ankle instability, ankle functional performance, walking speed, Cumberland ankle instability tool–youth

1. Introduction

Lateral ankle sprains are common musculoskeletal injuries in children, particularly those who engage in high levels of physical activity (Mandarakas, Pourkazemi, Sman, Burns, & Hiller, 2014). A significant proportion of children with a history of lateral ankle sprains develop chronic ankle instability (CAI), with reported prevalence rates ranging from 18% to 47% (Mandarakas *et al.*, 2014). CAI is characterized by mechanical instability (MI), perceived instability (PI), and recurrent sprains (RS), which often coexist and contribute to long-term functional deficits (Hertel, 2002; Hertel, & Corbett, 2019; Hiller, Kilbreath, & Refshauge, 2011). Recent research has shown that the prevalence of CAI among children aged 7

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to 12 years is approximately 36.6%, with rates of MI, PI, and RS reported as 11.6%, 35.3%, and 27.3%, respectively (Kadli, Lekskulchai, Jalayondeja, & Hiller, 2020).

Children with CAI often exhibit structural and functional ankle impairments, such as ligamentous laxity, proprioceptive deficits, and reduced physical activity, which affect balance, strength, agility, and overall lower limb function, increasing future injury risk (Lin, Houtenbos, Lu, Mayer, & Wippert, 2021; Suphasubtrakul, Lekskulchai, & Jalayondeja, 2024). Functional performance deficits in CAI are prevalent and can harm long-term health (Augustsson, & Sjöstedt, 2023). As neuromuscular control, postural stability, and proprioception are still maturing in children, they are more vulnerable to CAI-related impairments, which can delay motor skill acquisition and functional independence, emphasizing the need for early detection and intervention (Fatoye, Palmer, Macmillan, Rowe, & van der Linden, 2009; Nagymáté, Takács, & Kiss, 2018). Functional Performance Tests (FPTs) have been widely used in clinical and research settings to assess lower limb function and predict injury risk in populations with ankle instability (Buchanan, Docherty, & Schrader, 2008; Caffrey, Docherty, Schrader, & Klossner, 2009; Rosen, Needle, & Ko, 2019; Sharma, Sharma, & Singh Sandhu, 2011). These tests offer an inexpensive and effective alternative to instrumented measures. Previous studies have demonstrated the utility of FPTs in identifying functional deficits associated with ankle instability. For example, Caffrey *et al.* (2009) found that four single-limb hopping tests (figure-of-8 hop, side hop, six-meter crossover hop, and square hop) effectively identified functional deficits in individuals with functional ankle instability.

While FPTs are well-established for assessing CAI in adults, evidence for their use in children remains limited. Recent studies highlight their value in identifying pediatric CAI-related deficits, with tools like the Cumberland Ankle Instability Tool-Youth Thai version (CAITY-T). For instance, thresholds such as a CAITY-T score ≤25 have been used to classify functional instability in children, providing a basis for incorporating objective FPTs as complementary assessments (Kadli *et al.,* 2020). Furthermore, validation revealed strong concurrent validity (Spearman's rank correlation coefficient = 0.762 and 0.731 for the right and left ankles, respectively) and good internal consistency (Cronbach's alpha = 0.837). Test-retest reliability was excellent with ICC (2,1) of 0.945 (95% CI = 0.93–0.96). The ROC curve and Youden's index were used to produce a cut-off score of ≤ 25 that distinguished between participants with and without CAI (the likelihood ratios were 0.03 negative, 17.5 positive, 97.2% sensitivity, and 94.4% specificity) (Yingyongsaksri, Hiller, Thara wadeepimuk, & Nanbancha, 2023). However, more research is needed to confirm their predictive validity in children. Currently, FPTs are best viewed as “potential predictors” or “useful screening tools” rather than definitive diagnostic measures.

For this study, we designed an assessment using FPTs for children (FPTs ^{children}) by including the six-meter crossover hop test (6MCHT) and the single-leg stance test (SLST) to assess ankle instability, the Y-balance test (YBT) to assess balance, and the ten-meter walk test (10MWT) to assess walking comfortable and speed. The selected tests are supported by additional literature demonstrating their reliability and suitability for children in this age range. For instance, hopping tasks like the 6MCHT effectively assess power, strength, and agility in pediatric populations (Yalfani, Gandomi, & Kohboomi, 2017), while the 10MWT evaluates speed and gait characteristics crucial for daily activities (de Baptista *et al.,* 2020).

This study aimed to examine the effectiveness of a battery of FPTs ^{children} including 6MCHT, SLST, YBT, and 10MWT in assessing ankle functional performance in children aged 7-12 years with and without CAI. By correlating these tests with the CAITY, we sought to determine whether FPTs could reliably indicate functional deficits and dynamic balance in this population. Our findings aim to provide clinicians with practical, evidence-based tools for early identification and targeted intervention in children with CAI.

2. Materials and Methods

2.1 Participants and sample size

Sample size calculations were performed using G*Power 3.1.9.2, based on effect size data from Ko, Rosen, & Brown (2018), which reported a Cohen’s f effect size of 0.8 (large effect size) using the Star Excursion Balance Test (SEBT) to assess functional performance deficits in adolescent athletes with a history of lateral ankle sprains. Using this effect size, an alpha of 0.05, and a power of 0.8, it was determined that a minimum sample size of 38 participants per group was required.

This study conducted and recruited participants at schools surrounding Mae Fah Luang University. A total of 76 healthy children aged 7 to 12 years were recruited and stratified equally into two groups based on the presence or absence of CAI: children with CAI (CAI) and children without CAI (non-CAI). Stratification was conducted to ensure equal representation of participants across age and gender in both groups. Inclusion criteria for both groups included a normal body mass index (BMI) between the 5th and 85th percentile on the Centers for Disease Control and Prevention (CDC) BMI-for-age growth charts (Hales, Freedman, Akinbami, Wei, & Ogden, 2022), and ankle pain ≤5/10 on a visual analog scale (VAS) (Cho, Kim, Lee, Woo, & Lee, 2021). Additional inclusion criteria for the CAI group were a history of unilateral ankle sprains occurring at least 1 year before study enrollment, recurrent ankle sprains more than 3 months before enrollment, a feeling of giving way at least twice a year (Gribble *et al.,* 2013), and a Cumberland Ankle Instability Tool-Youth (CAITY) score ≤25 (Kadli *et al.,* 2020).

Exclusion criteria for both groups included physical anomalies, bilateral ankle instability, previous surgery to the lower extremities, lower extremity fractures within 3 months before participation, uncontrolled seizures, severe epilepsy or asthma, severe heart disease, hearing problems, uncorrectable visual problems, or current participation in other ankle joint rehabilitation programs (Gribble *et al.,* 2013).

Ethical approval was obtained from the Mae Fah Luang University Ethics Committee on Human Research (EC22149-25), and informed consent and assent were obtained from parents or guardians and participants, respectively.

2.2 The tests

2.2.1 The Cumberland ankle instability tool-Thai version (CAITY-T)

The CAITY-T is a 9-item, 30-point scale that measures the severity of functional ankle instability in children. Ankles are classified as stable or unstable based on the numerical score. A score of 0 indicates severe functional ankle instability, while a score of 30 indicates a stable ankle. Each participant with CAI selects the option that best describes their ankles for each question (Kadli *et al.,* 2020).

2.2.2 The combining of FPTs for children (FPTs ^{children})

The FPTs ^{children} comprise the single-leg stance test (SLST), the Y-balance test (YBT), the ten-meter walk test (10MWT), and the six-meter crossover hop test (6MCHT). The tests were conducted in a standardized order—starting with the SLST, followed by the YBT, the 10MWT, and finally 6MCHT —to minimize fatigue, as the SLST and YBT require less physical exertion compared to the 10MWT and 6MCHT. Participants were provided with a 2-minute rest period between tests to ensure recovery and minimize fatigue.

1) Single-leg stance test (SLST)

The SLST is used to assess static balance. Participants were instructed to stand on their injured side without shoes for up to 30 seconds with their hands on their hips and their non-weight-bearing limb's hip and knee flexed to 90 degrees. Each participant was assessed under four conditions: standing with eyes open on a stable surface (EO-floor), standing with eyes open on a foam surface (EO-foam), standing with eyes closed on a stable surface (EC-floor), and standing with eyes closed on a foam surface (EC-foam). The test started when the foot was lifted off the ground and stopped when any of the following occurred: reaching 30 seconds, changes in the position of the weight-bearing foot, any body part except the weight-bearing foot touching the floor or opening the eyes during the eyes-closed condition (Condon & Cremin, 2014). The test-retest reliability was evaluated, revealing an Intraclass Correlation Coefficient (ICC (3,1)) of 0.76-0.95.

2) Y-balance test (YBT)

The YBT assesses dynamic balance. Participants stood on one foot and reached as far as possible with the opposite limb in three directions: anterior, posteromedial, and posterolateral. After three practice trials, participants completed three measured trials on the affected limb in each direction, with a 5-minute rest period between trials. Trials were discarded and repeated if the hands were removed from the hips, the reaching limb was used for weight-bearing, the stance limb was displaced, or there was a loss of balance. Reach distances were normalized to the participant's leg length (Gribble, Hertel, & Plisky, 2012). The test-retest reliability revealed an ICC (3,1) of 0.71-0.95.

3) Ten-meter walk test (10MWT)

The 10MWT evaluates walking speed over a straight 10-meter distance. After a 2-meter distance for acceleration and deceleration at the beginning and end, the walking time was measured over a 6-meter distance. Participants were instructed to walk at both comfortable and fast speeds (de Baptista *et al.,* 2020). The test-retest reliability revealed an ICC (3,1) of 0.91-0.93.

4) Six-meter crossover hop test (6MCHT)

The 6MCHT assesses a combination of lower limb power, strength, and agility. Participants hopped diagonally over a 15-cm-wide line, alternating sides for the entire 6 meters as fast as possible. Trials were discarded and repeated if the contralateral foot touched the ground, the participant fell, missed the stopwatch pad, or did not clear the line width completely (Yalfani *et al.,* 2017). The test-retest reliability revealed an ICC (3,1) of 0.91-0.93.

2.3 Procedure

Participants attended a single laboratory session where demographic information, medical history, and leg length were recorded, along with the completion of the CAITY-T questionnaire. Participants with a CAITY score ≤25 were identified as having CAI.

The testing order was standardized: SLST, YBT, 6MCHT, and 10MWT, chosen to minimize fatigue, as the SLST and YBT require less exertion. Participants completed three trials of each task under standardized conditions, with the average of the three used for analysis. A 2-minute rest period was provided between SLST, YBT, the 6MCHT, and the10MWT trials.

Reliability testing was conducted on a sample of 10 participants (5 children with CAI and 5 children without CAI), who completed the FPTs under identical conditions on two separate occasions, one week apart. Intraclass Correlation Coefficients (ICCs) were calculated for test-retest reliability. All tests were conducted and scored by a licensed physical therapist with over 5 years of experience in pediatric functional assessment. Sensitivity and specificity analyses were conducted to assess the diagnostic accuracy of the FPTs ^{children} in identifying CAI, using the CAITY-T score ≤25 as the gold standard (Yingyongsaksri *et al.,* 2023). In addition, the interpretation of the ICC was as follows: values between 0.75 and 1.00 indicate excellent reliability, values between 0.50 and 0.74 indicate moderate reliability, and values below 0.50 indicate poor reliability (Koo & Li, 2016).

2.4 Statistical analysis

All statistical analyses were performed using SPSS Statistics software version 23.0. The distribution of the data was assessed using the Kolmogorov-Smirnov test, and all data were found to be suitable for parametric analysis. Descriptive statistics, including means and standard deviations (SD), were reported for continuous variables. Independent sample t-tests were utilized for comparisons between the two groups for tests with only one condition. Cohen's d was calculated to determine the effect size for significant group differences, with values of 0.2, 0.5, and 0.8 considered as small, medium, and large effect sizes, respectively. Correlation analysis was performed to assess the relationship between the FPTs [children] measures and the CAITY scores in children with CAI. Pearson's correlation coefficient (r) was calculated, with a significance level set at $p < 0.05$ for all analyses.

3. Results

The baseline demographic characteristics of the participants are summarized in Table 1. No significant differences were observed between the two groups in terms of age, gender distribution, or other baseline demographic variables ($p > 0.05$).

Comparison of the FPTs for children between those with and without chronic ankle instability revealed significant differences in several measures. Specifically, significant differences were found between the two groups in the SLST with eyes open on both floor ($p = 0.010$, Cohen's d = 0.60, medium effect size) and foam ($p = 0.002$, Cohen's d = 0.71, medium to large effect size) conditions, the 6MCHT ($p = 0.003$, Cohen's d = -0.70, large effect size), and in the fast speed condition of the 10MWT ($p = 0.044$, Cohen's d = -0.47, medium effect size), as shown in Table 2. These effect sizes reflect moderate to large differences between the groups, suggesting meaningful functional impairments in children with CAI.

Furthermore, the correlation between the FPT plus walking test and CAITY scores in children with CAI was examined (Table 3). The results indicate a positive correlation between the YBT in the anterior direction and CAITY scores ($r = 0.331$, $p=0.043$). However, no significant correlations were found between other functional tests and CAITY scores ($p > 0.05$).

4. Discussion

The findings of this study contribute to our understanding of the effectiveness of using FPTs [children] for measuring ankle functional performance in children aged 7–12 years with and without CAI. Results showed that the FPTs [children] could differentiate children with and without CAI by demonstrating significantly poorer single-leg stance performance with eyes open on both surfaces, reduced hop test performance, and slower 10-meter walking at comfortable and fast speeds compared to healthy controls. A positive correlation was observed between YBT scores in the anterior direction and the CAITY scores in children with CAI, with no significant correlations in other ankle functional performance tests.

The results indicate that children with CAI exhibit measurable deficits in various aspects of ankle function, which can be effectively identified using FPTs [children]. Notably, the significantly poorer performance in the SLST with eyes open on both floor and foam surfaces suggests that static balance is particularly compromised in children with CAI. This is consistent with previous research indicating that static balance deficits are a hallmark of CAI and may be due to impaired proprioception and neuromuscular control (Zhang, Lu, Cai, Fan, & Jiang, 2020). Interestingly, no significant differences were found in the SLST with eyes closed on either the floor or foam surfaces. This lack of difference may indicate that children with CAI experience greater difficulty maintaining static balance under less challenging conditions (eyes open) but can compensate when visual input is removed (eyes closed), possibly through reliance on alternative sensory systems such as proprioception or vestibular input (Zhang *et al.*, 2020). The absence of significant differences in SLST with eyes closed may further support the hypothesis that children with CAI rely on compensatory mechanisms, particularly in challenging balance scenarios.

Moreover, the reduced performance in the 6MCHT highlights deficits in lower limb power, strength, and agility in children with CAI. This test requires rapid, coordinated movements and substantial lower limb strength, which are often impaired in individuals with ankle instability. Our findings align with previous studies that have reported similar deficits in dynamic tasks among individuals with CAI (Son, Kim, Seeley, & Hopkins, 2019).

Interestingly, while significant differences were found in the SLST with eyes open on both surfaces and 6MCHT, no significant differences were observed in the YBT or the 10MWT at comfortable speeds. This discrepancy can be attributed to the unique demands of each task. Unlike the YBT, which primarily assesses dynamic balance and allows for compensatory strategies such as shifting weight or using upper body movements, the 6MCHT integrates rapid changes in direction and speed, which require both dynamic balance and adequate lower limb strength and power. Children with CAI may struggle to compensate during the 6MCHT because the task simultaneously challenges multiple functional components, including agility, coordination, and neuromuscular control. These impairments are less easily compensated for, compared to balance-focused tasks like the YBT (Doherty *et al.*, 2016). Similarly, the lack of significant differences in the 10MWT at comfortable speeds might be

Table 1. Baseline demographics of child groups with chronic ankle instability (CAI) and without CAI (non-CAI)

Variable	CAI (n= 38)	Non-CAI (n= 38)	P-value
Gender (Boys: Girls)	17:21	19:19	0.646
Age (years)[a]	9.53 ± 1.69	9.63 ± 1.62	0.789
Weight (kg)[a]	33.22 ± 10.96	33.92 ± 14.29	0.812
Height (cm)[a]	137.48 ± 13.37	135.63 ± 14.33	0.562
Side of CAI (Right: Left)	25:13	-	-
CAITY score (scores)	18.34 ± 4.38	-	-

Note: CAITY: the Cumberland ankle instability tool-youth
[a]: Data analysis comparing between the groups by using the independent samples t-test

Table 2. The combining of FPTs for children (FPTs [children]) included the single-leg stance test (SLST), Y-balance test (YBT), six-meter crossover hop test (6MCHT), and ten-meter walk test (10MWT) for child groups with chronic ankle instability (CAI) and without CAI (non-CAI)

FPTs [children]	Non-CAI (n= 38)	CAI (n= 38)	P-value
SLST (condition)			
Eyes open on floor (s)	28.35±2.76	25.74±5.43	0.010*
Eyes closed on floor (s)	12.06±5.96	9.67±5.25	0.067
Eyes open on foam (s)	25.78±4.94	20.63±8.90	0.002*
Eyes closed on foam (s)	4.48±2.55	3.72±2.29	0.173
YBT (direction)			
Anterior (%)	70.41±9.16	72.82±9.53	0.264
Posteromedial (%)	67.59±9.73	69.87±11.16	0.347
Posterolateral (%)	60.51±12.15	58.04±11.60	0.368
6MCHT (s)	5.18±1.50	8.09±5.72	0.003*
10MWT (speed)			
Comfortable (m/s)	4.93±0.68	5.09±0.69	0.305
Fast (m/s)	3.43±0.38	3.61±0.38	0.044*

Note: s for seconds, m for meters
*Significant difference between groups called at $p<0.05$

Table 3. The correlation between combining FPTs for children (FPTs children) including the single-leg stance test (SLST), Y-balance test (YBT), six-meter crossover hop test (6MCHT), and ten-meter walk test (10MWT) and scores of self-reported functions using Cumberland Ankle Instability Tool - Youth (CAITY) in children with chronic ankle instability (CAI)

FPT [children]	CAITY score	
	Pearson Correlation (r)	P-value
SLST (condition)		
Eyes open on floor (s)	0.086	0.607
Eyes closed on floor (s)	-0.180	0.519
Eyes open on foam (s)	-0.133	0.428
Eyes closed on foam (s)	0.119	0.476
YBT (direction)		
Anterior (%)	0.331	0.043*
Posteromedial (%)	0.155	0.354
Posterolateral (%)	0.220	0.185
6MCHT (s)	-0.060	0.720
10MWT (speed)		
Comfortable Speed (m/s)	-0.046	0.786
Fast Speed (m/s)	-0.009	0.957

Note: Data analysis using Pearson's product-moment correlation coefficient
*Significant level at $p<0.05$

because this test is less demanding than the fast speed condition, where differences became apparent (Bohannon, 1997). Therefore, children with CAI may compensate for deficits in certain aspects of ankle function by utilizing alternative strategies during more dynamic tasks. In addition, participants with unilateral CAI experienced greater feelings of instability in the involved limb while performing unilateral hopping tests, despite the lack of functional deficits (Madsen, Hall, & Docherty, 2018).

The positive correlation between YBT scores in the anterior direction and CAITY scores suggests that dynamic balance ability is related to self-reported ankle function in children with CAI. However, the observed correlation ($r = 0.331$) is relatively weak, indicating that while dynamic balance may influence self-reported ankle stability, it is likely not the sole determinant. Other factors, such as proprioception, neuromuscular control, and psychological influences like perceived instability or fear of reinjury, may also contribute to CAITY scores. These findings highlight the need for cautious interpretation and suggest that multiple assessments are required for a comprehensive evaluation of ankle function in children with CAI. This finding supports the inclusion of dynamic balance assessments, such as the YBT, in clinical evaluations of CAI, as they provide valuable insights into the functional impact of the condition (Song, Jang, Nolte, & Wikstrom, 2022). Clinically, these findings underscore the importance of incorporating a comprehensive battery of FPTs [children] in the assessment of children with CAI. By identifying specific deficits in balance, strength, and agility, clinicians can tailor interventions to address these impairments. Strategies to enhance proprioception, neuromuscular control, and lower limb strength should be prioritized to improve overall ankle function and reduce the risk of future injuries.

Despite the valuable insights provided by this study, several limitations should be acknowledged. The cross-sectional design limits our ability to establish causality or determine long-term outcomes of ankle functional performance in children with CAI. Additionally, the relatively small sample size and homogeneous participant population may limit the generalizability of the findings. Future research should employ longitudinal designs with larger, more diverse samples to further elucidate the relationship between ankle function and CAI in children. Additionally, sensitivity and specificity analyses were not conducted, as the necessary data were not collected during the study. Future research should incorporate these analyses to better assess the diagnostic accuracy of FPTs [children] in identifying CAI.

5. Conclusions

Functional performance tests for children (FPTs [children]) effectively differentiate children with CAI from healthy controls, highlighting significant deficits in balance, strength, and walking speed. The positive correlation between YBT anterior scores and CAITY suggests the importance of dynamic balance assessments. These findings support using both objective FPTs $^{\text{children}}$ measures and subjective self-assessments in clinical practice. Therefore, FPTs $^{\text{children}}$ combined with walking speed tests are reliable for assessing ankle function in children with CAI, aiding in identifying deficits and informing rehabilitation strategies.

In summary, FPTs $^{\text{children}}$ are specifically adapted to account for the developmental, physical, and cognitive differences in pediatric populations. These adaptations include simplified instructions and procedures, such as conducting the 6MCHT with smaller hopping distances and more frequent rest intervals to accommodate children's lower endurance and ensure feasibility. In contrast, general FPTs are often conducted with minimal modifications and may require higher levels of coordination, strength, and attention, which can be challenging for children to complete reliably. Additionally, FPTs $^{\text{children}}$ emphasize monitoring for fatigue, distraction, and proper form due to children's developing neuromuscular control. For example, during the YBT, children are closely supervised to maintain proper alignment and avoid compensatory movements that could lead to injury. In contrast, adults can typically tolerate more intense or complex tests, with precautions focusing primarily on pre-existing conditions or injuries.

6. Clinical Implications

- Clinicians should incorporate a battery of FPTs $^{\text{children}}$, such as the SLST to assess balance, the 6MCHT to evaluate lower limb power, strength, and agility, and the 10MWT to measure walking ability and speed, to identify specific deficits in children with suspected CAI.

- The positive correlation between YBT scores and CAITY scores underscores the importance of dynamic balance assessments. Including the YBT can provide valuable insights into the functional impact of ankle instability.

- Tailored rehabilitation programs focusing on improving proprioception, neuromuscular control, and lower limb strength should be designed based on identified deficits.

- Regular re-assessment using FPTs $^{\text{children}}$ can monitor the effectiveness of interventions and track progress, indicating successful rehabilitation or the need for adjusted strategies.

- Early identification and intervention for CAI can reduce the risk of recurrent ankle injuries by addressing functional impairments and enhancing ankle stability.

- Combining objective FPT measures with subjective self-assessment tools like the CAITY provides a comprehensive understanding of ankle instability, ensuring that both physical and perceived aspects are considered in clinical decisions.

Acknowledgements

The authors would like to thank all participants for participating in this study.

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