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# Tandem Gait Test-Retest Reliability Among Healthy Child and Adolescent Athletes

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***Context:*** The tandem gait test is a method for assessing dynamic postural control and part of the Sport Concussion Assessment Tool, versions 3 and 5. However, its reliability among child and adolescent athletes has yet to be established.

***Objective:*** To examine the test-retest reliability of the single-task and dual-task tandem gait test among healthy child and adolescent athletes.

***Design:*** Descriptive laboratory study.

***Setting:*** Sports injury-prevention center.

***Patients or Other Participants:*** Uninjured and healthy athletes between the ages of 9 and 18 years.

***Intervention(s):*** Tandem gait measures repeated 3 times across the period of approximately 1 month.

***Main Outcome Measure(s):*** Participants completed the tandem gait test under single-task and dual-task (ie, while simultaneously executing a cognitive task) conditions. Our primary outcome measure was completion time during the single-task and dual-task conditions. We also assessed cognitive accuracy and response rate while participants completed the dual-task tandem gait test.

***Results:*** Thirty-two child and adolescent athletes completed the study (mean age = 14.3 ± 2.4 years; females = 16). Single-task tandem gait times were similar across the 3 testing sessions (14.4 ± 4.8, 13.5 ± 4.2, and 13.8 ± 4.8 seconds; $P = .45$). Dual-task tandem gait times steadily improved across the test timeline (18.6 ± 6.9, 16.6 ± 4.5, and 15.8 ± 4.7 seconds; $P = .02$). Bivariate correlations indicated moderately high to high agreement from test 1 to test 2 (single-task $r = .627$; dual-task $r = 0.655$) and from test 2 to test 3 (single-task $r = 0.852$; dual-task $r = 0.775$). Both the single-task (intraclass correlation coefficient; ICC [3,1] = 0.86; 95% confidence interval [CI] = 0.73, 0.93) and dual-task (ICC [3,1] = 0.84; 95% CI = 0.69, 0.92) conditions demonstrated high reliability across testing sessions.

***Conclusions:*** Tandem gait outcome measures demonstrated high test-retest reliability in both the single- and dual-task conditions. The overall reliability was within the acceptable range for clinical practice, but improvements across tests suggested a moderate practice effect. Tandem gait represents a reliable, dynamic, postural-control test that requires minimal space, cost, and time.

***Key Words:*** postural balance, concussions, mild traumatic brain injury, assessment, sports

**Key Points**

- Performances on the single-task and dual-task forms of the tandem gait test demonstrated high test-retest reliability.
- Reliability was higher for the single-task tandem gait test than for the dual-task condition.
- Both the single-task and dual-task forms of the tandem gait test appeared to demonstrate suitable levels of test-retest reliability for clinical assessment.

Concussion, defined as a traumatic brain injury induced by biomechanical forces,[1] can be a challenging injury for clinicians to diagnose and monitor. As several domains are affected by the injury, patients can present in heterogeneous and diverse manners.[2] Therefore, multifaceted assessments are recommended.[1]

Although many concussion assessments are firmly established in the clinical armamentarium, recent evidence[3] indicated that the tests routinely used by clinicians may possess a less-than-optimal level of reliability. Because postural-control impairments are common after concussion, the Sport Concussion Assessment Tool (SCAT; versions 3 [SCAT3] and 5 [SCAT5]) includes 2 methods of assessing postural control: the modified Balance Error Scoring System (mBESS) and the tandem gait test.[4] Use of the mBESS in clinical practice is an accepted[5] and consistent postural-stability measure after concussion,[6–8] yet recent findings[9] suggested that the tandem gait test may be a more useful method for detecting postconcussion postural-control impairments. Despite the test's potential utility as an objective outcome measure for concussion,[9,10] few authors have examined its characteristics, such as test-retest reliability, particularly among child and adolescent athletes.

The tandem gait test may be reliable across repeat testing sessions,[11] but further investigation in the child and adolescent athlete population is needed. Among a group of healthy young adults, although performance steadily improved (ie, faster time to completion) across sequential trials, the overall reliability was high (intraclass correlation coefficient [ICC] = 0.98).[11] Furthermore, Sullivan et al[12] reported high reliability for neurologists or physiotherapists assessing tandem gait test completion time among healthy participants and patients who had brain lesions, suggesting the potential ubiquity of this test across different medical specialties. However, other than these studies, few researchers have explored the reliability of the tandem gait test, particularly among children under the age of 18 years. In 1 study,[13] children with concussions walked more slowly and spent more time in double stance during the tandem gait test compared with a group of uninjured children. Adding a cognitive task during the test (dual task) to the single-task form of the tandem gait test (ie, completing the test with undivided attention) may result in more apparent and long-lasting postural-control impairments.[10] The simultaneous execution of both a cognitive and a motor task represents a more realistic demand for athletes than single tasks that may result in longer lasting impairments,[14] but investigators have used instrumented gait methods that are not typically feasible in the clinic setting. Thus, a dual-task tandem gait test may provide clinicians with a suitable method for objectively assessing performance on a complex and objective motor-cognitive task.

Therefore, the purpose of our investigation was to examine the test-retest reliability of the single-task and dual-task tandem gait test among healthy young athletes, tested at time intervals similar to those typically used to monitor recovery from concussion. We hypothesized that performance would improve slightly across testing sessions but that both single-task and dual-task completion times would demonstrate high reliability.

## METHODS

### Study Design and Participants

We assessed the test-retest reliability of a single-task and dual-task tandem gait test among uninjured and healthy young athletes using a prospective, repeated-measures design. All participants were tested 3 times during approximately 1 month, a time frame in which most sport-related concussions in this age group resolve.[15,16] We recruited healthy athletes aged 9 to 18 years from a sports injury-prevention center. Participants were included if they reported active engagement in an organized sport. Exclusion criteria were a diagnosed concussion in the year before testing, a significant sensory deficit (eg, deafness or blindness), a psychiatric disorder, a self-reported history of migraine, or use of a medication that affects the central nervous system within the 3 months before testing. Before the first visit, we obtained parental and participant consent and assent, respectively. The institutional review board approved the study protocol.

### Testing Timeline

After enrollment, participants completed their initial test. They returned for repeat testing approximately 2 and 4 weeks later. We selected this timeline based on a typical testing timeline of individuals receiving care at a sport concussion clinic, beginning initially after injury and continuing until they are cleared for return to full athletic participation.[17] In addition, this time frame was consistent with the time frames in other concussion test-retest studies.[17–19]

### Outcome Measures

All testing was conducted in a hallway free of distracting visual or auditory stimuli, where participants completed the tandem gait test protocol. Consistent with procedures used in previous studies,[10,20,21] participants completed single-task and dual-task tandem gait test batteries. During both conditions, participants completed the tandem gait test following standardized instructions,[4] walking without shoes using an alternate heel-to-toe gait along a 3-m length of sports tape. Participants completed a practice trial, followed by 3 timed trials in each condition. During the test, the administrator gave instructions to approximate the heel and toe, walk beyond the end of the 3-m line, make a 180° turn, and return to the starting point while walking in the same heel-to-toe fashion. One test administrator recorded each trial to the nearest hundredth of a second using a standard stopwatch or smartphone. The primary outcome variable was the time required to complete the test, averaged across 3 trials completed in each condition and was selected based on previous research.[9,10,20–23] This outcome is consistent with the SCAT3 test, whereas the SCAT5 uses a pass/fail criterion. No participants *failed* a trial (defined as an overt separation of the heel and toe, stepping off the tape, or touching the test administrator), so using a pass/fail criterion as a primary outcome measure would not have yielded meaningful results among our sample.

Participants were asked to simultaneously and continuously complete 1 of 3 cognitive test forms during each dual-task trial. To ensure that a dual-task effect was being elicited throughout the test, they were given continuous cues so that they were completing a cognitive task throughout each trial. They were given a cognitive task to complete before the trial; once that was completed, a new task was provided until they completed the tandem gait test. In addition to completing the cognitive forms during the tandem gait test, they also completed the forms while standing still. During each quiet-stance trial, they continually responded to verbal cues for 30 seconds.

The cognitive test forms required participants to spell a 5-letter word backward, serially subtract by 6s or 7s from a randomly presented 2-digit number, and recite the months in reverse order starting from a randomly selected month, as described previously.[10,20,21] Before each dual-task trial, the administrator described the task and instructed the participant to begin doing both tasks simultaneously and continue them throughout the gait trial. Consistent with prior studies,[10,20,21] each participant was assigned a different test form during each trial so that we could assess cognitive function across multiple domains. The specific cognitive test for each trial was randomly selected from a predetermined list, and no repeat cues were given during a testing session or across the 3 separate testing sessions. Thus, although the test forms were consistent throughout the study, participants did not receive the same cognitive cues at any time during the study (eg, subtract by 7s from 98 at test session 1, subtract by 7s from 86 at test session 2, subtract by 7s from 78 at test session 3). Secondary cognitive outcomes were analyzed in both single-task (quiet standing) and dual-task (during the tandem gait test) conditions and consisted of the number of correct answers, number of total responses, and overall accuracy across trials.

**Table 1. Participant Characteristics**

| Variable | Mean ± SD or n (%) | Range |
|---|---|---|
| Age, y | 14.3 ± 2.4 | 9.7–18.3 |
| Children (9–12 y) | 11 (35%) | |
| Middle adolescents (13–18 y) | 21 (65%) | |
| Female sex | 16 (50%) | |
| Height, cm | 160.3 ± 13.3 | 132–185 |
| Mass, kg | 53.2 ± 15.1 | 27–87 |
| Prior history of concussion >1 y before enrollment | 5 (16%) | |
| Test 2 time (days after test 1) | 11 (7) | 6–32 |
| Test 3 time (days after test 1) | 26 (12) | 14–45 |

## Statistical Analysis

Data normality for all outcome variables was checked using the Shapiro-Wilk test. Means and standard deviations are presented for the continuous variables, and the number and corresponding percentage are presented for categorical variables. To examine the mean difference in performance across the 3 testing sessions, we used 1-way repeated-measures analyses of variance with Greenhouse-Geisser correction as needed and follow-up pairwise comparisons adjusted with the Bonferroni method.

To evaluate the relationship between test performances during study visits, we used the bivariate Pearson (normally distributed) or Spearman (nonnormally distributed) correlation for each outcome measure between tests 1 and 2, 2 and 3, and 1 and 3. To interpret the correlations, we used the following values: <0.39 as *low*, 0.4 to 0.59 as *moderate*, 0.60 to 0.79 as *moderately high*, and ≥0.80 as *high*.[24] To determine the reliability of measures across the 3 testing sessions, intraclass correlation (ICC) estimates and their 95% confidence intervals (CI) were calculated based on a consistency, 2-way mixed-effects model with a single rater per measurement (ICC [3,1]).[25] We also calculated the ICC (3,1) intrarater reliability measurements for the 3 trials completed during the first testing session using the same analysis. For ICC (3,1) values, we used the following ranges to interpret the clinical value of our results: >0.9 as *very high*, 0.80 to 0.89 as *high*, 0.70 to 0.79 as *adequate*, 0.60 to 0.69 as *marginal*, and ≤0.59 as *low*.[26] For each outcome variable, we also calculated the 95% reliable change index (RCI) to describe the estimated measurement error surrounding test-retest differences.[27] Finally, to assess differences between the single-task and dual-task conditions, we compared tandem gait times at each time point using a 2 × 3 repeated-measures analysis of variance, where task (single, dual) and time (test 1, 2, 3) were the independent variables.

Statistical significance was set at $\alpha$ <.05 and all tests were 2 sided. If an interaction or main effect reached statistical significance, pairwise follow-up comparisons were conducted and adjusted using the Bonferroni procedure to control familywise type I error. Statistical analyses were performed using SPSS (version 25.0; IBM Corp, Armonk, NY).

## RESULTS

A total of 32 young athletes participated in the study. Females and males were evenly distributed, and their ages ranged from 9 to 18 years (Table 1). Mean tandem gait test times were similar across all 3 testing sessions during the single-task conditions, but participants completed the dual-task tandem gait test significantly faster at test 3 relative to test 1, indicating a practice effect (Table 2). Mean dual-task cognitive performance did not differ across the testing timeline (Table 2). However, during single-task quiet stance, participants had fewer total and correct cognitive responses at tests 2 and 3 compared with test 1 (Table 2).

Correlations were high between tests 2 and 3 for the single-task tandem gait time and between tests 1 and 2 for quiet-stance cognitive test correct and total answers (Table 3). Moderately high correlations were found between tests 1 and 2 for single-task tandem gait time, dual-task tandem gait time, and correct and total cognitive test answers (Table 3). Except for cognitive test accuracy, each outcome measure demonstrated high reliability across the 3 testing sessions (Table 4). The intrarater reliability among trials completed during the first testing session was high for single-task (ICC [3,1] = 0.95, 95% CI = 0.90, 0.97) and dual-task (ICC [3,1] = 0.98, 95% CI = 0.95, 0.99) conditions.

The RCI yielded values of 5.3 and 8.5 seconds for the single-task and dual-task conditions of the tandem gait test, respectively (Table 4). A significant task-by-time interaction was present for tandem gait time ($P$ = .003; $\eta_p^2$ = 0.24). Follow-up pairwise tests indicated that participants completed the single-task tandem gait test faster than the

**Table 2. Tandem Gait and Symptom Outcome Measures at Each Testing Point**

| Variable | Time, Mean ± SD | | | *P* Value |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Single task | | | | |
| Single-task tandem gait time, s | 14.4 ± 4.8 | 13.5 ± 4.2 | 13.8 ± 4.8 | .45 |
| Cognitive test correct answers during quiet stance, No. | 39.8 ± 14.8 | 49.3 ± 16.0 | 51.5 ± 19.6 | <.001[a] |
| Cognitive test total responses during quiet stance, No. | 41.5 ± 14.7 | 51.1 ± 15.3 | 53.0 ± 19.3 | <.001[a] |
| Cognitive test accuracy during quiet stance, % correct | 95.7 ± 6.3 | 95.9 ± 5.7 | 95.3 ± 9.1 | .86 |
| Dual task | | | | |
| Dual-task tandem gait time, s | 18.6 ± 6.9 | 16.6 ± 4.5 | 15.8 ± 4.7 | .018[b] |
| Cognitive test correct answers during tandem gait, No. | 20.9 ± 6.6 | 21.9 ± 6.5 | 21.2 ± 6.8 | .60 |
| Cognitive test total responses during tandem gait, No. | 22.2 ± 6.3 | 23.2 ± 7.4 | 21.8 ± 6.9 | .54 |
| Cognitive test accuracy during tandem gait, % correct | 93.1 ± 7.8 | 94.7 ± 6.6 | 97.0 ± 3.3 | .08 |

[a] Pairwise follow-up testing indicated fewer correct and total responses at test 1 compared with test 2 ($P$ < .001) and test 3 ($P$ < .001).
[b] Pairwise follow-up testing indicated a slower time for test 1 compared with test 3 ($P$ = .011).

Table 3. **Bivariate Correlations Between Testing Sessions for Each Outcome Measure**

| Variable | Test 1 | | Test 2 | |
|---|---|---|---|---|
| | Correlation | *P* Value | Correlation | *P* Value |
| Single-task tandem gait time, s | | | | |
| Test 2 | 0.627[a] | <.001 | | |
| Test 3 | 0.565 | .002 | 0.852[b] | <.001 |
| Quiet-stance cognitive test correct answers | | | | |
| Test 2 | 0.859[b] | <.001 | | |
| Test 3 | 0.759[a] | <.001 | 0.792[a] | <.001 |
| Quiet-stance cognitive test total responses | | | | |
| Test 2 | 0.842[b] | <.001 | | |
| Test 3 | 0.714[a] | <.001 | 0.766 | <.001 |
| Quiet-stance cognitive test accuracy, % correct | | | | |
| Test 2 | 0.630[a] | <.001 | | |
| Test 3 | 0.724[a] | <.001 | 0.879[b] | <.001 |
| Dual-task tandem gait time, s | | | | |
| Test 2 | 0.655[a] | <.001 | | |
| Test 3 | 0.644[a] | <.001 | 0.775[a] | <.001 |
| Tandem gait cognitive test correct answers | | | | |
| Test 2 | 0.745[a] | <.001 | | |
| Test 3 | 0.522 | .007 | 0.779[a] | <.001 |
| Tandem gait cognitive test total responses | | | | |
| Test 2 | 0.732[a] | <.001 | | |
| Test 3 | 0.415 | .04 | 0.634[a] | .001 |
| Tandem gait cognitive test accuracy, % correct | | | | |
| Test 2 | 0.316 | .12 | | |
| Test 3 | 0.226 | .28 | 0.122 | .57 |

[a] Moderately high correlation (0.60–0.79).
[b] High correlation (≥0.80).

dual-task tandem gait test at all 3 time points ($P < .001$; Table 2).

## DISCUSSION

Outcome measures for the single-task and dual-task forms of the tandem gait test demonstrated high test-retest reliability. Although the overall reliability of single-task and dual-task tandem gait test times was within the acceptable range for clinical practice (>0.75),[25] the correlations between individual testing time points suggested a moderate practice effect. Specifically, correlations were stronger between tests 2 and 3 than between tests 1 and 2. Therefore, when determining the course of recovery after a concussion, clinicians should consider improvements in tandem gait performance among child and adolescent athletes in the context of potential improvements due to both practice and recovery from injury. Given that we did not assess participants who were diagnosed with concussion, we cannot determine how improvements after a concussion should be interpreted. Furthermore, the relative consistency of performance between tests 2 and 3 suggests a ceiling effect due to repeated exposure, particularly during the single-task condition.

Practice effects have been noted for other postural-control assessments. For example, researchers[28] observed that the total number of errors committed on the BESS decreased across serial testing sessions within a 5-day period. In addition, Schneiders et al[11] reported very high test-retest reliability on the tandem gait test (ICC = 0.98). However, to our knowledge, no authors have directly compared the reliability of the BESS and the tandem gait test. We did not find improvements on the single-task version of the tandem gait test across time, yet the stronger correlation between times 2 and 3 versus times 1 and 2 indicated that a slight practice effect may have occurred initially but plateaued as a result of repeat testing. This may have been due to the younger ages of our participants relative to those in the Schneiders et al investigation (mean age = 21 years).[11] Furthermore, our test intervals were somewhat longer than those in previous studies. We selected this time frame to increase ecological validity by mimicking the typical serial-assessment pattern used clinically for many concussion patients, but the longer intervals may have led to lower test-retest reliability. In addition, the mean single-task test completion time among our cohort of participants was approximately 14 seconds. Although 14 seconds was the recommended pass/fail criterion in the SCAT3,[29] our results align with those of Santo et al,[23] who observed that this threshold resulted in a high false-positive rate and that this time should not be used for all adolescent athletes.

Reliability was higher during the single-task tandem gait test than the dual-task tandem gait test. This may be due to the novelty and complexity imposed by the addition of a concurrent cognitive task to a motor task. Although this increased complexity has been noted to augment the ability to detect subtle, yet persistent, deficits after concussion,[14] it may also reduce the reliability of the test. During a dual-task reaction time test, researchers[30] also noted improved motor performance across time among healthy athletes. In contrast, the reliability of the cognitive test performance in our study was poor. This may be due to a task-prioritization effect, similar to previous dual-task gait observations of an association between motor, but not cognitive, performances on a dual task with subsequent sport-related injuries.[31] Thus, the motor performance aspect of a cognitive-motor

Table 4. **Reliability and Reliable Change Index for Each Outcome Measure Across the 3 Testing Sessions**

| Variable | Intraclass Correlation Coefficient (3,1) | 95% Confidence Interval | *P* Value | Reliability Rating | Reliable Change Index |
|---|---|---|---|---|---|
| Single-task tandem gait time | 0.86 | 0.73, 0.93 | <.001 | High | 5.3 s |
| Quiet-stance cognitive test correct answers | 0.91 | 0.83, 0.96 | <.001 | High | 12.3 responses |
| Quiet-stance cognitive test total responses | 0.90 | 0.80, 0.95 | <.001 | High | 12.8 responses |
| Quiet-stance cognitive test accuracy | 0.88 | 0.77, 0.94 | <.001 | High | 6% correct |
| Dual-task tandem gait time | 0.84 | 0.69, 0.92 | <.001 | High | 8.5 s |
| Tandem gait cognitive test correct answers | 0.86 | 0.73, 0.94 | <.001 | High | 6.6 responses |
| Tandem gait cognitive test total responses | 0.82 | 0.64, 0.91 | <.001 | High | 7.4 responses |
| Tandem gait cognitive test accuracy | 0.26 | 0.00, 0.66 | .19 | Poor | 18% correct |

dual-task tandem gait test appears to have an adequate level of reliability for serial testing, yet cognitive performance should be interpreted cautiously, particularly among child and adolescent athletes.

Relative to other established concussion assessments, the single-task and dual-task forms of the tandem gait test appeared to demonstrate sufficient reliability for clinical purposes. Both had high reliability, extending the findings of previous studies using instrumented gait methods among healthy adolescent and young adult athletes.[32] However, the advantage of the tandem gait paradigm is the ability to assess motor function objectively without the technological requirements needed for instrumented gait assessments. Furthermore, our results suggest that reliability of the tandem gait test exceeded that of other objective tests that have been used in concussion evaluations (eg, eye tracking[17] or Trail Making Test performance).[19] Thus, even though several assessments are available for use in the multifaceted evaluation of concussion, the high test-retest reliability and objective nature of the tandem gait test indicate it may be a worthwhile and useful addition for clinical decision making and may complement existing tests such as the BESS.

Our findings should be interpreted in light of the study limitations. Our relatively small sample of child and adolescent athletes may not provide findings generalizable to other age groups. In addition to the small sample size, the use of 3 cognitive tests during dual-task tandem gait may have led to less reliability across tests. Age, which was not assessed in this investigation, should be considered a possible modifying factor in tandem gait performance. Future studies with larger samples across different age groups should be conducted to better establish the characteristics of the tandem gait test. Also, because only 1 rater administered the tandem gait tests, we could not calculate interrater reliability measures. Future researchers should establish these values. Furthermore, additional investigation into the reliability and recovery trajectories of athletes with concussions must be conducted to properly identify the role of the tandem gait test in clinical settings. Our study was designed to mimic a serial postconcussion testing timeline rather than a preinjury baseline-to-post-injury test timeline. Given that many practitioners use a baseline-to-postinjury comparison clinically, our findings should not be extended to longer times between tests than we selected.

## CONCLUSIONS

Performance on the single-task and dual-task tandem gait tests was adequately reliable among a group of uninjured young athletes. These findings extend previous work and suggest that the tandem gait test in both single-task and dual-task forms may reliably measure concurrent motor and cognitive function across time among children and early to middle adolescents.

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