

Normative Tandem Gait in Collegiate Student-Athletes: Implications for Clinical Concussion Assessment

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Background: Impaired balance is common after concussion. The third edition of the Sport Concussion Assessment Tool (SCAT-3) recommends the Balance Error Scoring System (BESS) and/or tandem gait for postconcussion balance assessment. The limitations of the BESS are well documented; however, tandem gait has received little attention throughout concussion literature. The purpose of this study was to provide normative data for tandem gait in collegiate student-athletes based on sport type, concussion history, and gender.

Hypothesis: Tandem gait will be influenced by concussion history, sport, and gender.

Study Design: Cohort study.

Level of Evidence: Level 3.

Methods: Four hundred collegiate student-athletes from both collision/contact ($n = 200$) and limited contact/noncontact ($n = 200$) sports performed 4 tandem gait trials, consistent with SCAT-3 guidelines. The dependent variables included the best of the 4 trials (BEST), the mean of the 4 trials (MEAN), and the mean of each of the trials individually (ORDER). Separate multivariate analyses of variance were performed for each of the independent variables to determine effect on BEST and MEAN trial times. Significant main effects were followed up with a 1-way analysis of variance (ANOVA). A separate 1-way ANOVA was used to assess ORDER differences.

Results: The mean BEST was 10.37 ± 1.76 seconds, and the MEAN was 11.32 ± 0.70 seconds. There were no significant differences in BEST or MEAN tandem gait times, respectively, between those with and without concussion history ($P = 0.41$ and $P = 0.69$, respectively), sport type ($P = 0.57$ and $P = 0.42$, respectively), or gender ($P = 0.73$ and $P = 0.49$, respectively). There were significant differences ($P < 0.05$) between ORDER of the 4 tandem gait trials across the population, with improved times at each trial.

Conclusion: The results of this study provide a normative data set for tandem gait in healthy collegiate student-athletes and suggest that common determinants of balance, including concussion history, collision sport participation, and gender do not appear to influence performance, but ORDER could have significant clinical implications.

Clinical Relevance: Clinicians may use these data to distinguish important determinants of tandem gait performance and improve awareness when returning an individual to play after a concussion.

Keywords: brain; mild traumatic brain injury; balance; postural control

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There are an estimated 1.6 to 3.8 million sport-related concussions that occur annually in the United States, with over 10,000 concussions annually among National Collegiate Athletic Association (NCAA) student-athletes.^{20,40} Impaired balance is a cardinal symptom after concussion.²⁴ The third edition of the Sport Concussion Assessment Tool (SCAT-3) recommends the use of either the modified Balance Error Scoring System (mBESS) and/or tandem gait for postconcussion balance assessment, with the BESS being the most commonly used.^{18,24} The BESS is a clinically feasible assessment; however, there are substantial limitations including low interrater (0.57) and intrarater (0.74) reliability, as well as low sensitivity (0.34), both at time of injury and throughout recovery.^{7,23} Furthermore, the high interrater (9.4) and intrarater (7.3) minimum detectable change scores, which exceed the normal BESS change acutely postconcussion, as well as the practice effect secondary to repeat administration, both further limit the test efficacy.^{3,7,37} Finally, the BESS is negatively influenced by ankle instability, acute fatigue after exertional activities, and testing environment.^{6,8,29} Given the BESS limitations, it is surprising that the alternative test, tandem gait, has received limited attention in the literature.^{9,17,32,33}

Tandem gait is a clinically feasible and highly reliable (intraclass correlation coefficient: 0.97) assessment tool used to evaluate dynamic balance, speed, and coordination, all domains commonly impaired after a concussion.^{9,17,32} The tandem gait task was initially developed to assess balance in individuals with cerebellar ataxia and has also been utilized to identify impairments in essential tremor and aging populations.^{9,16,36} The cerebellum is a critical structure involved in controlling posture and balance, particularly during the coordination of movements^{11,38}; thus, if the cerebellum is affected by a concussive injury, a task requiring coordination, such as gait, could elucidate impairments. Instrumented tasks, including both gait and gait termination, have both successfully identified alterations in balance after concussion and well beyond clinical recovery (eg, symptom resolution, cognitive test results).^{1,14,15,25,26} Indeed, Buckley et al¹ observed lingering alterations in gait termination 10 days postconcussion, despite full recovery on BESS and all standard clinical assessments. However, the implementation of instrumented balance measures in clinical settings is cost-prohibitive because of the requirement of full biomechanics laboratory motion analysis systems and trained personnel. Thus, tandem gait may be a more appropriate and clinically feasible task that can be performed without the use expensive motion analysis systems.

Tandem gait is a recommended balance component of the SCAT-3; however, limited data exists involving healthy collegiate student-athletes, and common determinants have not been fully explored. Normative reference values for the SCAT-3, including tandem gait, have been reported in both a sample of professional male hockey players and healthy adults^{12,32}; however, the ages ranged from 16 to 40 years, which is not representative of a true collegiate population.^{12,32} Impaired tandem gait performance has been noted in pediatric subjects with prolonged concussion recovery; however, healthy

normative data has not been established.⁵ Additionally, neither concussion history nor sport type has demonstrated a negative effect on tandem gait¹² or mBESS.³⁹ Participants in collision and high-contact sports are more susceptible to subconcussive impacts, which have been speculated to be a possible cause of differences in gait parameters between athletes and nonathletes.²⁷ Furthermore, gender differences in gait characteristics (eg, shorter steps, faster cadences) are well established,²⁸ but their effect on tandem gait in athletes is unknown. Finally, persons with a history of concussion demonstrate a conservative strategy during both single- and dual-task instrumented gait trials, but it is unknown if these differences carry over to tandem gait.^{2,21} Therefore, the purpose of this study was to provide normative data on a clinically feasible tandem gait task in collegiate student-athletes with consideration of sport type (collision/contact versus noncontact), gender, and concussion history. The results of this study can provide clinicians with important determinants of tandem gait performance. Consistent with previous gait literature, it was hypothesized that tandem gait would be influenced by sport type, concussion history, and gender.

METHODS

Participants

Four hundred NCAA Division I student-athletes were recruited from both collision/contact and noncontact sports at a single institution (Table 1). Each participant provided oral and written informed consent in accordance with the university's institutional review board. Participants were included in the study if they were active members of an NCAA team at the institution and medically cleared for athletic participation. The exclusion criteria included any self-reported neurological disorder, current lower extremity orthopaedic injury, and metabolic, vestibular, vision disorders, or other conditions that would impair gait performance.

Procedure

Tandem gait was collected barefoot and in accordance with SCAT-3 guidelines.³¹ The participants were instructed to stand behind the starting line with feet together and, in response to a verbal cue, they walked with alternating heel-to-toe gait, in a forward direction, along a 3-m long, 38-mm wide, line of sports tape as quickly as possible. Once the participants reached the end of the line, they completed a 180° turn and returned to the starting line with the same heel-to-toe gait pattern (Figure 1). To be considered a successful trial, the participants were required to complete the trial in ≤14 seconds without stepping off the line or separating the heel and toe. While the SCAT-3 recommends that unsuccessful trials be repeated, if possible,³¹ because of the time constraints associated with large testing sessions, unsuccessful trials were not repeated. All participants had at least 3 successful trials, which matched previous literature, and no practice trials were performed.³² Each trial was timed using a handheld stopwatch (Champion Sports).

Table 1. Group demographics (mean \pm SD)

Variable	Collision/Contact Sports (n = 200)	Limited Contact/Noncontact Sports (n = 200)
Age, y	20.1 \pm 1.2	19.6 \pm 1.3
Height, cm	181.4 \pm 11.2	172.9 \pm 10.9
Weight, kg ^a	86.6 \pm 21.9	70.4 \pm 14.2
Concussion history, ^a no. of concussions	30% (60/200) 0.4 \pm 0.7 (range, 0-4)	14% (28/200) 0.2 \pm 0.4 (range, 0-2)
Sport breakdown, ^b male/female	Football: 82/0 Soccer: 21/21 Basketball: 15/15 Field hockey: 0/25 Lacrosse: 14/4 Diving: 1/2	Rowing: 0/41 Swimming: 23/19 Baseball: 33/0 Track & field: 0/19 Volleyball: 0/16 Cross country: 0/12 Golf: 3/5 Tennis: 4/3 Softball: 0/5

^aCollision/contact sport participants were significantly heavier ($P < 0.001$) and had a greater prior concussion history ($P < 0.001$) than limited contact/non-contact sport participants.

^bSport classifications adapted from Rice.³⁰

Data and Statistical Analysis

The independent variables included sport type (collision/contact or limited contact/noncontact),³⁰ gender (male/female), and self-reported diagnosed concussion history (yes/no) (Table 1). The dependent variables measured from the tandem gait trials included each participant's best time (BEST) and mean time of the 4 trials (MEAN). Additionally, the mean of each trial (ORDER) (eg, trial 1 across all participants, trial 2 across all participants, etc) was also included as a dependent variable.

The lower and upper quartiles of performance were determined for the overall BEST and MEAN tandem gait times. Separate multivariate analyses of covariance were performed for each of the independent variables to determine their effect on BEST and MEAN trial times (Table 2). Significant main effects were followed up with a 1-way analysis of variance (ANOVA). Separately, a 1-way ANOVA was used to assess differences between ORDER, and follow-up comparisons utilized Tukey post hoc testing. Cohen's *d* effect sizes were calculated for all significant post hoc tests, where 0.2 corresponds to a small effect size, 0.5 a medium effect size, and 0.8 a large effect size.⁴ All statistical significance was set at $P < 0.05$. All statistical analyses were performed with SPSS (version 22, IBM Inc).

RESULTS

All participants completed all trials without falls or other incidents. As expected, the contact sports athletes were

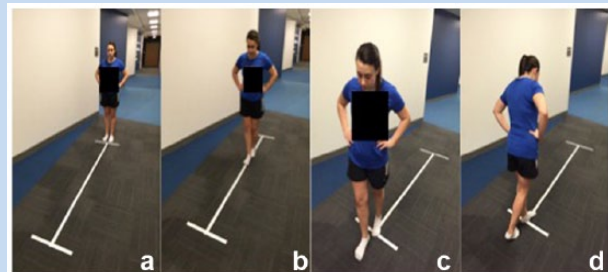


Figure 1. Tandem gait progression: (a) starting position, (b) progression, (c) turn initiation, and (d) turn completion.

significantly heavier ($P < 0.001$) and had more self-reported concussions ($P < 0.001$) than limited contact/noncontact athletes (Table 1). Fifty-nine participants (14.8%) had 1 unsuccessful trial, but all included participants had at least 3 successful trials. Overall, the mean BEST trial time for all participants was 10.37 \pm 1.76 seconds (range, 5.61-13.85 seconds) and the group MEAN for the 4 trials was 11.32 \pm 0.70 seconds. The upper and lower quartiles of performance can be seen in Table 3.

There were no significant differences in tandem gait BEST trial times between those with and without a history of concussion ($P = 0.41$), collision/contact sport participants versus limited contact/noncontact sport participants ($P = 0.57$), or male and female participants ($P = 0.73$) (Table 3). Similarly, there were no

Table 2. 95% confidence intervals and effect sizes for concussion history, sport type, and gender

	BEST (s) 95% CI	MEAN (s) 95% CI
Concussion history		
Yes	10.14-10.88	11.02-11.83
No	10.14-10.53	11.12-11.55
Cohen's <i>d</i>	-0.104	-0.047
Sport type		
Collision/contact	10.08-10.56	11.01-11.54
Limited contact/noncontact	10.18-10.67	11.16-11.70
Cohen's <i>d</i>	-0.057	-0.078
Gender		
Male	10.15-10.65	11.02-11.56
Female	10.10-10.58	11.15-11.68
Cohen's <i>d</i>	-0.034	0.068

Table 3. Multivariate analysis of variance results for concussion history, sport type, and gender

	BEST (s) Mean ± SD	MEAN (s) Mean ± SD
Overall	10.37 ± 1.76	11.32 ± 0.70
Quartiles		
25th	9.20	10.16
75th	11.63	12.65
Concussion history		
Yes (n = 88)	10.51 ± 1.70	11.42 ± 1.95
No (n = 312)	10.33 ± 1.77 <i>P</i> = 0.41	11.33 ± 1.91 <i>P</i> = 0.69
Sport type		
Collision/contact (n = 200)	10.32 ± 1.88	11.28 ± 2.05
Limited contact/noncontact (n = 200)	10.42 ± 1.63 <i>P</i> = 0.57	11.43 ± 1.78 <i>P</i> = 0.42
Gender		
Male (n = 196)	10.40 ± 1.83	11.29 ± 1.89
Female (n = 204)	10.34 ± 1.69 <i>P</i> = 0.73	11.42 ± 1.94 <i>P</i> = 0.49

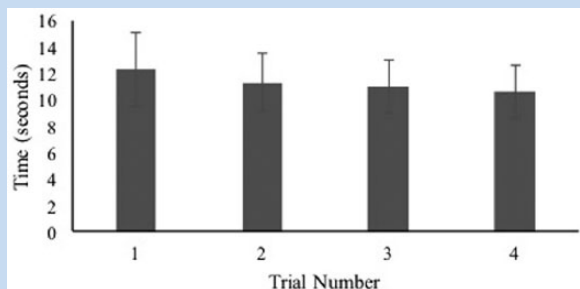


Figure 2. Mean tandem gait times across the 4 trials. There was a significant difference ($P < 0.001$) between all the trials, compared with each other. The effect sizes between trials ranged from 0.15 to 0.67, with the largest 2 being between trial 1 and trial 4 ($d = 0.67$) and trial 1 and trial 3 ($d = 0.53$), and the smallest being between trial 2 and trial 3 ($d = 0.15$).

significant differences in tandem gait MEAN trial time between those with and without a history of concussion ($P = 0.69$), collision/contact sport participants versus limited contact/noncontact sport participants ($P = 0.42$), or male and female participants ($P = 0.49$) (Table 3).

There were significant differences ($P < 0.001$) between the ORDER ($F = 107.76$, $P < 0.000$) trials, compared with each other, across the entire population (trial 1, 12.29 ± 2.81 seconds; trial 2, 11.32 ± 2.19 seconds; trial 3, 11.01 ± 1.99 seconds; trial 4, 10.65 ± 2.01 seconds) (Figure 2). All pairwise post hoc comparisons reached statistical significance. There were small to moderate effect sizes, ranging from $d = 0.15$ between trials 2 and 3 to $d = 0.67$ between trials 1 and 4.

DISCUSSION

This is the first study to identify normative values for a tandem gait assessment in a healthy, collegiate student-athlete population, a critical demographic for concussion assessment. The participants completed the trials without difficulty, supporting the suggestion that this is a clinically feasible balance assessment. The main finding of this study was that no significant differences in BEST or MEAN tandem gait times were observed between those with or without concussion history, different sport types (collision/contact vs limited contact/noncontact), or gender. Thus, common confounding determinants of performance or neurological health do not appear to influence tandem gait outcomes. There were, however, significant differences in the ORDER trials, which is important for the use of tandem gait in a clinical setting. These results suggest that tandem gait is a stable task that is not influenced by common determinants of performance.

The overall mean for our participants' BEST tandem gait trial was 10.37 ± 1.76 seconds, whereas the MEAN of the trials was 11.32 ± 0.70 seconds. In professional hockey players, the mean

of the best tandem gait trials was 10.8 ± 1.8 seconds,¹² and Schneiders et al³² reported the mean of 3 tandem gait trials in healthy adults was 11.2 ± 1.2 seconds, both of which are similar to our results. The SCAT-3 concussion assessment tool, likely widely utilized by sports medicine clinicians,¹⁸ recommends 4 trials rather than the 3 assessed by Schneiders et al.³² To more closely compare the findings, we calculated the mean of the first 3 trials in our population, which was 11.5 ± 0.7 seconds.³² Furthermore, we identified a significant improvement (less time) in ORDER tandem gait time from trial 1 to trial 4, which is consistent with Schneiders et al,³² who noted improvements across 3 trials. Thus, the SCAT-3 recommendation of recording the best trial may be a more representative measure of tandem gait, compared with the mean, as it is not influenced by the order effect. The presence of a practice effect cannot be ruled out; nonetheless, clinicians need to assure they are consistent with the number of trials performed between baseline and postconcussion to minimize this potential confounding variable. The effect size decreased between trials as they progressed; however, there was still a significant difference in time between the third and fourth trials. Future research should address the time change between trials to determine how many trials are necessary to represent a true picture of normative tandem gait.

Alterations in balance, both a conservative gait strategy and altered postural dynamics, have been observed in individuals with a history of at least 1 concussion.^{2,21,35} Recently, Buckley et al² demonstrated a conservative gait strategy in collegiate student-athletes with any history of concussion, regardless of the number of concussions, as compared with concussion-free student-athletes during standard gait trials. Herein, using a binary grouping for concussion history (ie, yes or no), there were no group differences in BEST or MEAN tandem gait times. Concussion history was also not a factor in the tandem gait normative values of professional ice hockey players,¹² or mBESS performance during the SCAT-2 in collegiate athletes.³⁹ Although we classified concussion history using a binary grouping, the majority of the student-athletes (78%) who self-reported a prior concussion history reported 1 concussion only. Tandem gait may not be sensitive enough to detect residual impairments from a single concussion or participants may have sufficiently recovered or adapted prior to testing. The addition of a cognitive challenge or dual task is a potential modification that would likely increase task difficulty and may identify differences in individuals with a history a prior concussion.²⁶

Differences in instrumented single- and dual-task gait parameters between athletes and nonathletes have been observed, which have been speculated to result from repeated head impacts common in collision sports.²⁷ Herein, we identified no differences in tandem gait performance between individuals involved in collision/contact versus limited contact/noncontact sports. Axonal disruption throughout the critical neural networking centers of the brain (ie, the cerebellum) has been proposed as the cause of instability in postural performance after concussion,¹³ as well as impaired sensory integration, which would suggest that recently concussed

individuals are unable to accurately exchange and integrate information from the visual, vestibular, and somatosensory systems.¹⁰ It is possible that the accumulation of repetitive head impacts in a college-aged person is not enough to reach the threshold of axonal injury, or somatosensory impairment, where alterations in balance testing are visible. Similarly, there were no differences observed between noncontact and contact/limited contact sport collegiate athletes in the mBESS component of the SCAT-2.³⁹ Thus, it would appear that, although the mechanisms behind balance control differ between the mBESS and tandem gait (ie, somatosensory control compared with supraspinal control), repetitive head impacts do not appear to adversely affect these clinical balance screening tools.³⁴

Similar to the normative data in healthy adults presented by Schneiders et al,³² we found no gender effect associated with BEST or MEAN time to complete tandem gait. This finding contradicts an earlier finding that women were significantly slower than men during tandem gait after a moderate-intensity exercise protocol.³³ Additionally, there were no gender differences in mBESS scores of collegiate athletes,³⁹ demonstrating that gender does not appear to be a significant determinant in the differences observed in static and dynamic balance. Men tend to have a faster velocity during normal gait, likely because of a longer stride length (1.46 m compared with 1.28 m in women), while women often display a greater cadence (117 steps/minute compared with 111 steps/minute in men).²⁸ Because of the nature of the tandem gait task (ie, heel-to-toe walking), stride length likely has little influence as a potential confounding variable. Cadence, however, could play a role in the time of tandem gait completion, as an individual with faster cadence would presumably complete a tandem gait task more quickly. Future research is needed to identify additional determinants that could influence tandem gait times.

The nature of the tandem gait task suggests that foot size could be a confounding variable in performance, but this was not measured in this study, and therefore this is a potential limitation. However, clinically, tandem gait would be a within-subjects test; therefore, most anthropometric data would likely be consistent across time for collegiate student-athletes. Consistent with SCAT-3 recommendations, the tandem gait task was recorded using a handheld stopwatch; however, the difference between hand-timing and electronic timing ranges has been found to be 0.19 ± 0.14 seconds.²² Concussion history was of self-reported diagnosed concussions only, and unreported and undiagnosed concussion were not included. This approach is common in the literature and has moderate reliability, but should also be considered when extrapolating the results of the study.^{19,21,35} No a priori power analysis was conducted in this investigation; thus, it should be acknowledged that our sample size may be inadequate. However, 400 participants constitute a large clinical sample and exceeds the sample size of other tandem gait publications.

Despite being recommended as a balance assessment in the SCAT-3, tandem gait has received little attention in the collegiate student-athlete population despite the numerous BESS

shortcomings. The results of this study provide a normative data set for tandem gait in healthy collegiate student-athletes and suggest that common determinants of performance and neurological health—including gender, concussion history, and collision sport participation—do not appear to influence BEST or MEAN tandem gait time. However, repeat administration of the tandem gait task does appear to elicit improvements, and future investigations are needed to assess the amount of trials required for the time to stabilize, as well as establish test-retest reliability, in healthy collegiate student-athletes. Future studies are also required to investigate the acute, subacute, and chronic concussion effects on tandem gait performance, particularly in comparison with both standard clinical tests as well as instrumented measures of balance to further elucidate the test sensitivity. Nonetheless, the results of this study suggest that tandem gait is a clinically feasible assessment that can be performed at little to no cost by a single clinician, and thus has considerable potential implications for concussion management.

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