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Original Research

Clinical Assessment of Spatiotemporal Parameters of Gait when Performing a Visuospatial Cognitive Task

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Background

It is unknown if differences exist for normalized velocity (m/s) and step length (m) when measured using clinically accessible tools, such as the 10-Meter Walk Test (10MWT) and a timed gait analysis (TGA), and costly equipment, such as the GAITRite® electronic walkway system, in healthy adolescent athletes.

Purpose

The purpose of this study was to compare normalized velocity and step length data using low- and high-tech equipment during single- and dual-task gait. The investigators hypothesized that there would be no significant differences between data collected using the 10MWT, TGA, and GAITRite®.

Study Design

Cross-sectional, repeated-measures study design.

Methods

A convenience sample of healthy male (n=23) and female (n=20) adolescent athletes aged 14-18 years were recruited from a local high school. A three-way mixed analysis of variance analyzed normalized velocity (m/s) and step length (m) data measured with the 10MWT, TGA, and GAITRite® while participants walked at a self-selected speed with and without a visuospatial cognitive task. All data were collected in the participants' school setting. A three-way mixed ANOVA was used to analyze data.

Results

No significant interactions between assessment tool, walk condition, or sex were found. A main effect of walk condition ($p<0.0001$) and sex ($p<0.0004$) was found for normalized velocity (i.e., females walked faster than males). Normalized velocity was also significantly decreased when measured with the 10MWT compared to the GAITRite® ($p<0.007$) and the TGA ($p<0.03$).

Conclusions

Normalized velocity may be generalizable between the TGA and GAITRite®, but not the 10MWT. Therefore, the TGA may be a viable adjunct to current multimodal assessments of gait following concussion in the absence of costly equipment.

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Level of Evidence

Level 2

INTRODUCTION

Comprehensive assessment of adolescents with sport-related concussion (SRC) has shown to be complex, time consuming, and partially dependent on costly, clinically inaccessible computerized equipment when measuring spatiotemporal parameters of gait, such as velocity and step length.[1-4] Until recently, the widely accepted model for concussion assessment was comprised mainly of neurocognitive testing, symptoms checklists, and a neurological exam.[1,2] Specifically, standardized assessments such as the Sport Concussion Assessment Tool, 5th Edition (SCAT5) were held as the "mainstay"[3] of concussion evaluations due partially to their low-tech (i.e., no costly electronic devices required) and sideline friendly nature.[1-3] While cognition, oculomotor function, gross sensorimotor coordination, gait, vestibular function, and balance are all important components of the neurological assessment, these single-task tests featured in tools like the SCAT5 may not fully capture changes in functional movement, such as the ability to simultaneously perform gait and cognitive/visuospatial activities, that is typical during return to everyday activities.[4,5] Changes in functional movement may include altered neuromechanical responsiveness, perception-action coupling, and decreased processing speed when ambulating while performing an additional task rather than performing tasks individually.[5-7] Furthermore, changes in such functional gait activities could be exacerbated by the cognitive and motor demands of athletic participation.[5,6] To that end, dual-task models that combine cognitive and motor demands may be an important form of assessment to help identify post-concussion deficits, such as decreased gait speed, changes in cadence, and altered single or dual-limb stance times, that manifest during daily life as well as athletic play.[4-9] To utilize these models, clinical comparison values must be available to clinicians who are working with concussed athletes.

Investigators have examined and reported dual-task data for gait in adolescents using auditory, visuospatial, and cognitive tasks in both healthy[4] and concussed athletes.[5-9] Additionally, normative spatiotemporal gait data for adolescent athletes with concussion have been published.[9] Preliminary reference values specific to the adolescent population for the dual-task cost (DTC) associated with walking while completing a visuospatial memory task with altered visual attention have been published.[4] These data may more closely resemble the everyday tasks that involve manipulation of an object with visual attention on the object rather than the broader environment experienced in both daily activity and in athletic play; and, many of these data were generated using expensive computerized equipment that may not be available in clinical or sideline settings.[4-10]

In recognition of increasingly available dual-task data, the 6th International Conference on Concussion in Sports, held in Amsterdam on October 2022, updated the SCAT5 to incorporate optional timed dual gait tasks within the newer Sport Concussion Assessment Tool, 6th Edition (SCAT6) using the clinically feasible Tandem Gait Test (TGT).[11] Moderate practice effects have been identified among healthy adolescents[12] and young adults[13] as well as pediatric athletes with concussion[14] when performing the TGT. Additionally, literature has reported inconsistent administration protocols for the TGT,[13] and the authors of the present study are not aware of any studies comparing the TGT against validated computerized technology to assess important spatiotemporal parameters of gait. Indeed, many assessments used to derive spatiotemporal data in literature have been completed using an expensive piece of equipment not readily available to most clinicians which may create a significant barrier to utility of these clinical comparison values. Data generated through more traditional or clinically feasible tools could be helpful in providing useful information to more clinicians in a variety of settings.

Similar to the TGT, the 10-Meter Walk Test (10MWT) is a well-established and standardized measure of gait speed[15] with high test-retest reliability when measuring comfortable and fast gait speed (ICC = 0.95-0.96) and step length (ICC = 0.91-0.98) in adolescents and adults with brain injury.[16] Psychometric properties have also been established for the 10MWT specifically among populations with mild traumatic brain injuries (mTBI), which include concussion.[17-19] More importantly, Cleland et al[20] reported that among adults with a history of cerebrovascular accident (CVA), the 10MWT demonstrated fair-to-moderate agreement (ICC = 0.46-0.89) during comfortable walking speeds and high agreement (ICC = 0.91-0.96) during maximal walking speeds with the GAITRite® portable walkway, a valid and reliable[21-23] "gold standard"[24] computerized walkway system with software capable of deriving spatiotemporal parameters of gait. These findings suggest that clinically accessible assessments of gait such as the 10MWT may be valid for examining the effects of neuromuscular insults on spatiotemporal parameters of gait. However, studies do not exist that implement such conditions with inclusion of the dual-task model in a sample of adolescent athletes with or without sport-related concussion (SRC).

Additionally, the 10MWT does not assess other spatiotemporal parameters of gait, such as stride length, cadence, or step length.[18] Nevertheless, clinicians such as athletic trainers and physical therapists routinely assess aspects of gait including pertinent changes in velocity, gait biomechanics, step length, stride length, and potential discrepancies in weight bearing between the lower extremities. Therefore, an analysis form with relevant formulas for calculating critical gait parameters may be a clinically relevant adjunct for the 10MWT. Given that walking speed and step length, compared to other parameters, have been found to strongly correlate with prolonged symptom recovery in athletes with concussion,[25] it is important to discern if clinical assessments of gait, whether via a validated tool or clinical calculations (i.e., TGA), differ in practical util-

Table 1. Results of inter-rater reliability testing.

Outcome Measure	Interclass Correlation Coefficient
10MWT average gait speed	$ICC_{3,k}$ = 0.946*
TGA (distance traveled)	$ICC_{3,k}$ = 0.941*
TGA (average time for completion)	$ICC_{3,k}$ = 0.936-0.980*
TGA (average step count)	$ICC_{3,k}$ = 0.996-1.00*

Abbreviations: 10MWT, 10-Meter Walk Test; TGA, Timed Gait Analysis. *$ICC_{3,k}$ values equal to or greater than 0.90 are considered excellent.

ity from computerized equipment for assessment of such parameters. Additionally, without research that first establishes baseline data among healthy adolescent athletes using such a gait assessment battery, clinically feasible assessments following SRC may continue to be limited in the proper and efficient evaluation of dual-task gait paradigms.

Therefore, the purpose of this study was to compare normalized velocity and step length data using low- and high-tech equipment during single- and dual-task gait. The investigators hypothesized that there would be no significant differences between data collected using the 10MWT, TGA, and GAITRite®.

METHODS

PARTICIPANTS

Prior to data collection on subjects for the current study, inter-rater reliability was established for the primary investigators using each outcome measure (Table 1). A convenience sample of 10 healthy undergraduate students from the University of Central Arkansas were recruited for reliability testing based on results from an *a priori* power analysis that determined 10 participants were required to achieve 90% power with an alpha of 0.05. Intraclass correlation coefficient interpretations were based upon clarification provided by ten Hove et al.[26]

For data collection, the authors of this cross-sectional, repeated-measures study utilized a convenience sample of healthy male (n=23) and female (n=20) athletes between the ages of 14-18 years old, who were recruited from a regional high school in Central Arkansas. The Institutional Review Board at the University of Arkansas for Medical Sciences approved the study. All participants and guardians provided written informed assent and consent respectively to participate. Participants were included based upon their enrollment in junior varsity and varsity athletic programs (football for boys and soccer for girls). Athletes were included in the study if they were healthy (determined by a sports physical examination performed by a physician), participating in sport programs through their school, were between the ages of 14-18 years old, and had a completed informed consent from the parent/guardian. Participants were excluded if they had a diagnosed concussion in the last three months, two diagnosed concussions in the last year, or a recent lower extremity injury that affected postural stability.

PROTOCOL

All data collection was performed on a section of the athletes' outdoor high school running track. Participants were randomly assigned to take their place in line for data collection at a GAITRite®, 10MWT, TGA, or leg length measurement station, each of which was operated by a research team member. The four stations were established in a single line, so participants moved to the next station after completing data collection at the first one. Each participant's leg length was measured as the distance from greater trochanter to floor for each leg to calculate normalized velocity, thereby accounting for variability in participants' morphology. This normalized velocity was calculated by dividing each athlete's velocity values derived from the 10MWT, TGA, and GAITRite® by their mean leg length (average of right and left leg length) and converting all values to meters per second (m/s). Normalized velocity and step length were assessed using the GAITRite® and TGA, while the 10MWT only assessed velocity. Both parameters were assessed by instructing each of the athletes to walk at a self-selected speed during undivided attention trials first and divided attention trials second. During each divided attention trial, a visuospatial memory task was given to the participants to complete on a hand-held tablet (Microsoft Surface Pro, 2016) while walking. The tablet, rather than participants' own cell phones, was used to achieve novelty and required attention to the device. The task (Pattern Memory by ProProfs.com, available at www.memory-improvement-tips.com), similar to the visuospatial memory tasks commonly included in the neurocognitive testing used in concussion management, consisted of a one-second period of time to view a pattern of shapes arranged spatially on the tablet screen. After one second, the shapes disappeared. The person completing the task was instructed to place the shapes in the original position relying upon visuospatial working memory. For the current study, participants who typically wore corrective eyewear (e.g., glasses or contact lens) wore them during the assessment. All participants were allowed three practice attempts with the hand-held tablet to learn the task in static stance.

The 10-Meter Walk Test: The 10MWT assesses self-selected walking speed in meters per second (m/s) over a distance of six meters.[15] Participants were asked to walk at their own typical walking speed for a total of four trials[15]: two without the tablet activity and two with the tablet activity. A member of the research team documented the time it took to walk a marked distance. The two trials for each walking task (with or without the tablet activity) were averaged for velocity and used in data analysis. For this assessment, participants walked a total of 10 meters; however, only the intermediate six meters were used for data collection, as the first and last two meters accommodate acceleration and deceleration.[15]

The Timed Gait Analysis: The TGA is comprised of relevant formulas commonly used in clinical environments as part of physical therapists' broader skillsets to assess gait

biomechanics over a distance of six meters. For the purposes of this study, participants were asked to walk at their own typical walking speed for a total of four trials, two without the tablet activity and two with the tablet activity. A member of the research team documented the time it took to walk a marked distance and how many steps were taken to achieve that distance during single- and dual-task trials. Then, the two trials for each walking task (with or without the tablet activity) were averaged to calculate velocity (m/s) and step length (m), and these means were used for data analysis. Like the 10MWT, the first and last two meters were used to accommodate acceleration and deceleration.

The GAITRite® Walkway System: The GAITRite® was used to derive gait velocity (cm/s) and step length (m) data.[20-24] Participants were asked to walk a total distance of 10 meters at their own typical walking speed for a total of six trials,[23,24] three without the tablet activity and three with the tablet activity. Subjects initiated the task two meters prior to stepping onto the pathway to account for acceleration and allow the task to continue throughout the entirety of the sensor pathway. A member of the research team utilized the GAITRite® software, which averaged the three gait trials under each walk condition providing means for velocity (m/s) and step length (m).

STATISTICAL METHODS

All data were analyzed using nlme: Linear and Nonlinear Mixed Effects Models R package version 3.1- 164.[27] Descriptive analysis, including means and standard deviations, was used to summarize all participant data. Assumptions of normality, homogeneity of variances, and sphericity were tested. A three-way mixed analyses of variance (ANOVA) was conducted to explore the impact of walk status (walking with or without the dual task condition), assessment tool (10MWT, TGA, or GAITRite®), and sex (male or female) on normalized velocity values. A similar three-way mixed ANOVA was conducted to assess the influence of the same variables without the 10MWT on step length values. Walk status and assessment tool were within-subjects variables while sex was a between-subjects variable. The level of statistical significance was set at $p < 0.05$. Post hoc analysis was performed using Tukey's HSD adjustment for multiple comparisons.

RESULTS

Demographic information including age, sex, and race/ethnicity for all participants is presented in Table 2.

The means and standard deviations for single and dual-task efforts are summarized in Tables 3 and 4 for normalized velocity and step length, respectively. Data for one female subject was excluded due to missing values. Thus, 23 males and 19 females contributed data for analysis.

There was no significant interaction effect between walk status, assessment tool, and sex for normalized velocity ($p > 0.369$) using the GAITRite®, 10MWT, and TGA or step length ($p > 0.530$) using the GAITRite® and TGA. However,

Table 2. Participant demographics by sex, race, and ethnicity.

	Males (n=23)	Females (n=20)
Mean Age (Years (± SD))	16.3 (± 0.82)	16.2 (± 1.12)
Race		
Caucasian	8	15
African American	15	1
Two or More	0	4
Ethnicity		
Hispanic	0	0
Non-Hispanic	23	20

Abbreviations: SD, standard deviation

there was a significant main effect for walk status when measuring normalized velocity (estimate = 0.185, SE = 0.0148, $p < 0.0001$) and step length (estimate = 0.067, SE = 0.00492, p <0 .0001) with both males and females walking with decreased velocity and shortened step length during dual-task activity. There was only a significant main effect for sex when measuring normalized velocity (estimate = 0.206, SE = 0.0538, $p < 0.0004$) with females walking with significantly increased velocity but not statistically significantly different step lengths compared to males.

When measuring normalized velocity, there was a significant main effect for assessment tool between the 10MWT and the other two tools (10MWT/GAITRite®, estimate = 0.0772, SE = 0.0243, p <0 .0074 and 10MWT/TGA, estimate = 0.0612, SE = 0.0232, p < 0.03); However, there was not a significant difference between the TGA and GAITRite® (estimate = 0.016, SE = 0.0178, p > 0.65) for normalized velocity. When measuring step length, there was a significant effect for assessment tool when comparing the TGA and GAITRite® (estimate = 0.0489, SE = 0.00579, p <0.0001).

DISCUSSION

The current study sought to examine the potential addition of clinical assessments of gait, such as the 10MWT and TGA, in multimodal assessments of concussion. Lowe et al[4] previously explored spatiotemporal parameters of gait among healthy adolescent athletes using computerized technology, the GAITRite® Walkway System. Additionally, authors have previously utilized similar technologies to assess parameters of gait among adolescent[25,28] and collegiate[29-31] athletes with and without concussion. However, such high-end, computerized instruments may not be readily available during clinical assessment of concussion.

Similar to findings presented by Lowe et al,[4] the current study found a significant main effect for walk status suggesting that males and females both walked significantly faster during single-task trials compared to dual-task trials using all three assessment tools. Significant differences between walk conditions were not surprising, given prior findings highlighting a significant dual-task cost (i.e., the change from a focused-attention single-task relative to a

Table 3. The means and standard deviations of normalized velocity (m/s) when male (n=23) and female (n=19) subjects walked without (single-task) and with (dual-task) a concurrent visuospatial cognitive task using each assessment tool.

	Single-Task		Dual-Task	
Assessment	Males	Females	Males	Females
10MWT	1.32 (0.204)	1.55 (0.256)	1.12 (0.243)	1.30 (0.233)
TGA	1.37 (0.152)	1.56 (0.248)	1.18 (0.168)	1.36 (0.192)
GAITRite®	1.37 (0.161)	1.59 (0.213)	1.22 (0.193)	1.40 (0.213)

Abbreviations: 10MWT, 10-Meter Walk Test; TGA, Timed Gait Analysis.

Table 4. The means and standard deviations of step length (m) when male (n=23) and female (n=19) subjects walked without (single-task) and with (dual-task) a concurrent visuospatial cognitive task using only the TGA and GAITRite®.

	Single-Task		Dual-Task	
Assessment	Males	Females	Males	Females
TGA	0.67 (0.054)	0.66 (0.063)	0.61 (0.066)	0.61 (0.060)
GAITRite®	0.72 (0.072)	0.71 (0.066)	0.65 (0.072)	0.65 (0.065)

Abbreviations: TGA, Timed Gait Analysis

divided attention dual-task condition) in spatiotemporal parameters of gait in healthy adolescent and collegiate athletes.[4,7,25] Also consistent with previous data, females in this sample of adolescent athletes walked faster than their male peers.[4] Furthermore, results demonstrate that overall, normalized velocity (m/s) was significantly different when measured using the 10MWT as opposed to both the TGA and GAITRite®, suggesting that the 10MWT may not be used interchangeably with the other two tools in a multimodal clinical assessment battery for this population. These results are similar to those of Kim et al.[24] which showed lack of agreement between the 10MWT and GAITRite® when measuring gait speed for adults with chronic ankle instability.

When assessing step length, the current study revealed, like previous work,[7] that during a single or dual task walking activity, there was no significant main effect for sex. Regarding dual task cost, however, the data from the current study suggest that these adolescent male and female athletes shortened their step length during a dual-task walking activity when assessed by both the TGA and the GAITRite®. Of note, there were significant differences between the TGA and GAITRite® when assessing step length, suggesting that these tools may not be used interchangeably. The authors hypothesize that these differences may be rooted in the ability of the GAITRite® to measure exact differences in step length, while the TGA provides a mathematical estimate of step length based upon an assumed symmetrical gait.

The findings from this study should be interpreted considering its limitations. The generalizability of the results to racial/ethnic groups is limited, as no Hispanic students were assessed, and an unequal sample of Caucasian and African American participants were represented in the male and female groups. Additionally, only male football and female soccer players were selected from a single high school, which potentially limits generalizability across region and sport. A formal power analysis was not performed prior to data collection. Rather, investigators aimed to recruit a convenience sample of at least 30 athletes to promote an approximately normal distribution. Athletes completed assessments for each of the tools in random order based on arrival time, length of lines for testing, and/or instruction by researchers; however, no formal randomization technique was incorporated. Therefore, threats to internal validity may exist. Furthermore, each subject was assessed in the company of fellow peers, which may have influenced results due to behavioral factors despite detailed and consistent instruction by researchers regarding execution of all tasks. Future studies may benefit from larger and more diverse sample sizes.

CONCLUSION

Over the past two decades, consensus statements have been made from organizations studying concussion data calling for more comprehensive dual-task assessments of balance and gait for adolescent athletes with SRC.[1,2,11] Most of the spatiotemporal gait data from dual-task assessments have been captured using costly computerized equipment, which may not be clinically feasible in non-experimental settings. This study's findings suggest that measurements of normalized velocity were not significantly different between the TGA and GAITRite®, providing a more clinically feasible option for collecting these data. Future work with larger sample sizes and increased diversity across sport, race, and ethnicity may provide more information about the viability of clinical assessments like the 10MWT, TGA, and the TGT.

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