A Clinically Feasible Dual-Task Assessment Using Tandem Gait For Concussion Evaluation

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Dual-task testing (DT) using laboratory equipment has shown to detect post-concussion deficits even after traditional measures such as neuropsychological and balance tests returned to normal. However, the efficacy of a clinically feasible DT as a concussion evaluation tool remains questionable. Purpose of the study was to compare the clinically feasible DT outcomes between concussed and control participants. Tandem gait (TG) was used as a motor task and the Auditory Pure Switch Task (APST) was used as a cognitive task to compose a clinically feasible DT.

This study was prospective cohort study. Nine concussed athletes diagnosed by a physician and nine control participants with matched characteristics (sex, age, height, weight, and shoe size) from local high schools and a university participated this study. The concussed group completed data collections 7-10 days post-concussion (subacute) and after return to play (RTP). Control group completed the same protocol with a matched timeline. Local high school athletic training rooms and/or university laboratories were used for data collection. TG completion time (sec) was collected as an outcome and the mean of the two trials was utilized for analysis. Mixed-model ANOVA (time x group) was used with an alpha level of $p < 0.05$.

Concussed group walked significantly slower than control during DT at subacute and after RTP ($p = 0.01$). This group difference was not indicated during ST ($p = 0.11$). DT TG was associated with learning effect ($p = 0.013$), and there was no time by group interaction (ST: $p = 0.44$, DT: $p = 0.51$). Our findings suggest that the TG combined with APST detected the group difference that TG alone could not. Concussed athletes took approximately 5 seconds longer to complete DT TG than control even after RTP. A Clinically feasible DT should be considered as an adjunct concussion evaluation to assess the post-concussion deficits and readiness for return to daily and sports activities.

Introduction

Assessment of Sports-Related Concussion (SRC) can be challenging as it disturbs multiple brain systems resulting in a variety of signs and symptoms. [1] The 2016 Concussion Consensus Statement recommended using multidisciplinary and comprehensive assessment tools including a symptom checklist, cognitive testing, balance testing, and neurological exam to evaluate SRC. [2] This approach allows clinicians to evaluate SRC with more than 90% sensitivity; [3] however, repetitive follow-up assessments throughout the recovery have shown to produce practice effects.

[4,5] This poses challenges to clinicians determining whether the improvements were from the recovery itself or adaptations to the testing procedure. Thus, there is a need for the testing battery to assess the readiness to return to daily and sports activities after SRC while minimizing practice effects. In addition, those traditional concussion assessment tools are designed to assess the individual's ability to perform one task at a time known as a Single-Task (ST) which may not fully challenge the complicated neurocognitive functions that are required in daily and sports activities.

Dual-task (DT) is designed to challenge the executive function of the brain, specifically divided attention, and has been used to assess fall risk for the elderly and patients with neurological disease. The executive function is an integrative skill that involves a set of cognitive functions and enables us to process information from multiple cortical sensory systems to produce and adjust behavior. One of the specific examples of executive function is the divided attention which refers to the ability to perform more than one task simultaneously. [6] This skill plays an important role in daily and sports activities such as talking on the phone while grocery shopping or kicking a ball while thinking about the next play. [1] However, there is a limit to the number of tasks one can perform simultaneously due to attentional capacity limits. The capacity-sharing theory describes that the performance of one or both tasks deteriorates when an appropriate amount of attention cannot be allocated to each task as a result of dividing one's attention among multiple tasks beyond one's capacity. [7] Furthermore, evidence suggests that the ability to allocate attention appropriately to perform multiple tasks simultaneously decreases following concussion. [8,9] These deficits persist up to 2 months for adolescents and younger adults specifically. [10,11]

Currently, DT is the closest tool to replicate sports activity where cognitive and balance functions are challenged simultaneously. [3] Assessment of DT may give clinicians further insights regarding readiness for return to sports following SRC. The efficacy of DT to identify post-concussion deficits has been investigated in the gait laboratory setting. The results showed that concussed individuals demonstrated significantly worse gait performance during DT compared to healthy controls. [12,13] Fait et al. reported that decreased gait performance during DT was observed even after concussed athletes were asymptomatic and established normal neuropsychological test scores. [14] This raises questions about the use of symptoms and neuropsychological test as a solo indicator of concussion recovery. Another study by Catena et al. stated that there was no significant ST gait performance difference between concussed and control participants 6 days post-concussion; however, concussed participants demonstrated decreased gait performance compared to control participants when a cognitive task was performed during gait. [14,15] These evidence suggest that there are lingering post-concussion deficits with traditional concussion assessments as they are not designed to induce executive function. Therefore, DT may provide additional and useful information in clinical assessments.

The limitation to these aforementioned studies was that the gait assessments were conducted in laboratory settings equipped with tools that are not readily available in most clinical settings. Only a few studies investigating whether DT can be used in traditional clinical settings exists. [16-18] Howell et al. used the completion time of Tandem Gait (TG) to investigate the effectiveness of DT in identifying post-concussion deficits on adolescents. [19] The study reported concussed athletes took significantly longer to complete DT TG compared to healthy controls. One of the possible limitations of the study is that this study utilized 3 different cognitive tasks, and there was no uniformity as to which cognitive task was completed by each participant. The effect on divided attention is altered depending on the difficulty of cognitive tasks. The outcome of physical tasks could significantly decrease when combined with a more complex cognitive task as participants prioritize more complex attention-demanding cognitive tasks over physical tasks, which could lead to an increased risk of falling especially for those who are concussed. [20] Therefore, the cognitive task should be standardized to isolate the concussion effect and to ensure concussed participants' safety when assessing the outcome of a physical task performed under the DT condition. Previous DT studies investigated different types of cognitive tasks and recommended to use Auditory pure switch task (APST) to compose DT. [17,20] APST is a relatively simple task which requires a participant to answers if a given number is odd or even, and has been reported to have high reliability with no practice effect when used under DT conditions. [21]

Based on the current evidence, it is likely that some portion of concussed athletes return to play guided by the traditional concussion assessment outcomes while still showing post-concussion deficits under DT condition. Howell et al. compared DT's ability to detect post-concussion deficits to a matched control group prospectively at 72 hours, 1-week, 2-weeks, 1-month, and 2-months post-concussion. [10] The control group in the study was matched with concussed group by age, sex, height, mass, and sport. They found that concussed athletes displayed post-concussion deficits under DT condition even at 2-months post-concussion; however, the timeline relative to RTP is unclear in this study. Therefore, the purpose of this study is: 1) to compare the outcomes of a clinically feasible DT between concussed athletes and their matched healthy counterparts, and 2) to compare ST and DT outcomes between groups prospectively at 7-10 days post-concussion (subacute) and after RTP. It is hypothesized that performance during DT among concussed athletes is significantly lower than their matched healthy counterparts, and DT deficits in the concussed group are present after the completion of the RTP protocol.

Materials and Methods

This study utilized a 2 x 2 (between and within subjects) mixed design. Two groups (concussed and control groups) completed two separate testing sessions during which both ST and DT were performed. The first data collection was 7-10 days post-concussion (subacute) and the second was after the completion of the return to play (RTP) protocol. Data collection occurred in quiet indoor facilities with minimal distractions at either local high schools' athletic training rooms or university laboratories. A single researcher administered 2 trials of ST, followed by DT for each participant.

Nine concussed athletes and nine healthy athlete participants (concussed participants: male n = 5 and female n = 4, healthy participants: male n = 5 and female n = 4) who met the inclusion criteria agreed to participate in this study. Concussed participants, diagnosed with a concussion by a sports medicine physician, and control participants were recruited from local high schools and a university between August 2019 through February 2020. The inclusion criteria for the concussed group were: ages between 12 and 49 years old, being diagnosed with a concussion, and being able to walk a 6-meter distance. Healthy control participants were matched individually to concussed participants based on age, sex, height, and shoe size, with secondary criteria of weight and sport. The exclusion criteria were: a history of lower extremity injuries, active neurological disorder, history of cognitive deficiency, existing psychiatric condition, and other conditions which may affect the result of this study. Individuals who were over 18 years old and wished to participate in the study were given informed consent forms, and individuals who were younger than 18 years old were given assent forms after their parents or legal guardians were given informed consent forms. The written informed consent and assent forms, approved by the university's human studies program internal review board, were signed by participants and/or parents or legal guardians prior to the data collection.

At the beginning of the data collection, all participants completed a Graded Symptom Checklist (GSC) where participants rated 22 concussion symptoms on a scale from 0 to 6, with 0 indicating that the participant is not experiencing the listed symptom, and 6 indicating the highest severity for that symptom. To ensure the safe participation of concussed participants, changes in symptoms were monitored. After a brief explanation of the procedure, participants were asked to perform TG (physical task) and APST (cognitive task) separately as STs, followed by a DT (TG + APST). Participants performed each task twice. During TG, participants performed a heel-to-toe gait on a 3-meter line of athletic tape, made 180 degrees turn at the end of the line, and returned to the starting point of the line. The time (seconds) taken to complete the task was used as an outcome using a stopwatch of mobile devices. Participants were instructed to complete TG as quickly as possible. The separation of heel and toe and/or stepping off the tape was considered a failed trial, and participants performed another trial until 2 successful trials were completed. An average of 2 successful trials was used for analyses. During APST, participants were instructed to answer whether a given number was odd or even. A number, from four odd numbers (1, 3, 5, and 7) and four even numbers (2, 4, 6, and 8), was called out in a nonconsecutive and random order by a researcher immediately after the participant's response. The outcome for APST was not analyzed in this study. During DT, no instruction was provided to prioritize either motor or cognitive tasks to elicit participants' natural responses. At the end of data collection, participants filled out the GSC again to compare symptoms prior to the data collection.

All data were analyzed using Statistical Package for Social Science (SPSS) Version 25.0 (IBM®, Chicago, IL) with an alpha level of $p < 0.05$. Independent sample t-tests were conducted to analyze the differences in demographic characteristics and the time intervals in the two data collections between groups. Paired sample t-tests were utilized to analyze the changes in GSC before and after the data collection at subacute and after RTP timelines. Mixed-method ANOVA (time-by-group) was conducted separately for DT and ST outcomes to assess the group difference and change over time. Post hoc paired samples t-test were conducted following the mixed-method ANOVA if significance was indicated.

Results

There were 18 total participants who completed the study: 9 athletes with a concussion (age: 17.22 ± 3.27 years, height: 175.12 ± 15.77 cm, mass: 72.22 ± 22.43 kg, shoe size: 27.33 ± 2.90 cm) and 9 control participants (age: 17.22 ± 3.27 years, height: 174.32 ± 14.26 cm, mass: 68.17 ± 14.10 kg, shoe size: 26.83 ± 1.79 cm). Demographic characteristics for all participants by the group are presented in Table 1. The concussion group completed the first data collection at a mean of 8.00 ± 1.00 days (range: 7-10) and the second data collection at 27.44 ± 10.94 days (range: 13 - 47) post-concussion (Table 2). The interval between initial and second data collection dates for the concussed group was 19.44 ± 10.90 days (range: 5 - 40). The interval for the control group was 16.44 ± 12.70 days (range: 6 - 39), and there was no statistical difference in intervals between the two groups ($p = 0.60$).

Table 1

Demographic data for concussion and control group.

	Concussion (Mean ± SD)	Control (Mean ± SD)	*p*-value
Male (n)	5	5	
Female (n)	4	4	
Age (y)	17.22 ± 3.27	17.22 ± 3.27	1.000
Height (cm)	174.32 ± 14.26	175.12 ± 15.77	0.912
Body Mass (kg)	68.17 ± 14.10	72.22 ± 22.43	0.652
Sport (n)	Volleyball: 4	Volleyball: 3	0.666
	Football: 2	Football: 3	
	Basketball: 1	Basketball: 1	
	Swimming: 1	Swimming: 1	
	Soccer: 1	Waterpolo: 1	

Figure 1.

Table 2

Timing of data collection relative to concussion incidence.

Time since (days)	Concussion (Mean ± SD)	Control (Mean ± SD)	*p*-value
Onset to 1st data collection	8.00 ± 1.00	N/A	
Onset to 2nd data collection	27.44 ± 10.94	N/A	
1st to 2nd data collection	19.44 ± 10.90	16.44 ± 12.70	0.6

Figure 2.

Total GSC score and mean number of symptoms before and after the data collection at subacute and after RTP are presented in Table 3. At subacute time point, total scores of the concussed group decreased slightly, although not significant, after the data collection (8.67 ± 13.49) compared to before (9.22±14.59), indicating the data collection did not exacerbate their symptoms ($p = 0.33$). The number of symptoms reported by the concussed group was 4.33 ± 5.57 before the data collection and 4.44 ± 5.50 after ($p = 0.73$). Total scores reported by the control group before and after the data collection were 4.78 ± 8.69 and 1.22 ± 3.31($p = 0.10$), respectively. The number of symptoms reported by the control group before and after the data collection were 2.67 ± 3.84 and 0.67 ± 1.66, respectively, and this decrease was statistically significant ($p = 0.03$). During the data collection after RTP, no changes in total scores between before and after the data collection for both groups were indicated (concussed group before the data collection:1.44 ± 2.13, after the data collection: 1.22 ± 2.05, $p = 0.35$, control group before the data collection: 1.00 ± 1.32, after the data collection: 0.78 ± 1.56, $p = 0.62$). The number of symptoms reported by the concussed group decreased slightly after data collection (1.00 ± 1.50) than before (1.22 ± 1.64), but it did not reach statistical significance ($p = 0.35$). The control group reported 0.56 ± 0.73 symptoms before the data collection and 0.56 ± 1.33 symptoms after. ($p = 1.00$).

Table 3

GSC Total Score and Number of Symptoms before and after data collection at subacute and after RTP time points.

		Subacute		After RTP	
		Before data collection	After data collection	Before data collection	After data collection
Group	GSC	(Mean ± SD)	(Mean ± SD)	(Mean ± SD)	(Mean ± SD)
Concussion	Total Score	9.22 ± 14.59	8.67 ± 13.49	1.44 ± 2.31	1.22 ± 2.05
	Number of Symptoms	4.33 ± 5.57	4.44 ± 5.50	1.22 ± 1.64	1.00 ± 1.50
Control	Total Score	4.78 ± 8.69	1.22 ± 3.31	1.00 ± 1.32	0.78 ± 1.56
	Number of Symptoms	2.67 ± 3.84*	0.67 ± 1.66*	0.56 ± 0.73	0.56 ± 1.33

Abbreviations: GSC, Graded Symptom Checklist; RTP, Return to Play.

*Concussed participants had a significant decreased in number of symptoms after data collection at subacute time point ($p = 0.01$).

Figure 3.

The completion time of TG during ST and DT at subacute and after RTP are presented in table 4. The time-by-group analysis for ST TG revealed that there was no significant group effect ($p = 0.11$), time effect ($p = 0.15$), and time-by-group interaction effect ($p = 0.51$). (Figure 1) The time-by-group analysis for DT TG indicated a significant group effect ($p = 0.01$) and time effect ($p = 0.01$), but no significant time-by-group interaction effect ($p = 0.44$). (Figure 2)

Table 4

ST and DT TG completion time measurement between concussion and control groups at subacute and after RTP time points.

		Subacute	After RTP
Group	Condition	(Mean ± SD)	(Mean ± SD)
	Single-Task (sec)	24.34 ± 6.36	23.38 ± 3.36
Concussion	Dual-Task (sec)	27.14 ± 6.14#	24.83 ± 4.82*#
Control	Single-Task (sec)	22.41 ± 4.34	19.41 ± 3.73
	Dual-Task (sec)	22.73 ± 3.72	18.93 ± 2.31*

Abbreviations: ST, Single-Task; DT, Dual-Task; TG, Tandem Gait, sec, seconds; RTP, Return to Play.

*Concussed participants walked significantly slower than the control participants after RTP time point ($p = 0.002$).

#Concussed participants walked significantly faster after RTP time point compared to the subacute time point. ($p = 0.03$).

Figure 4.

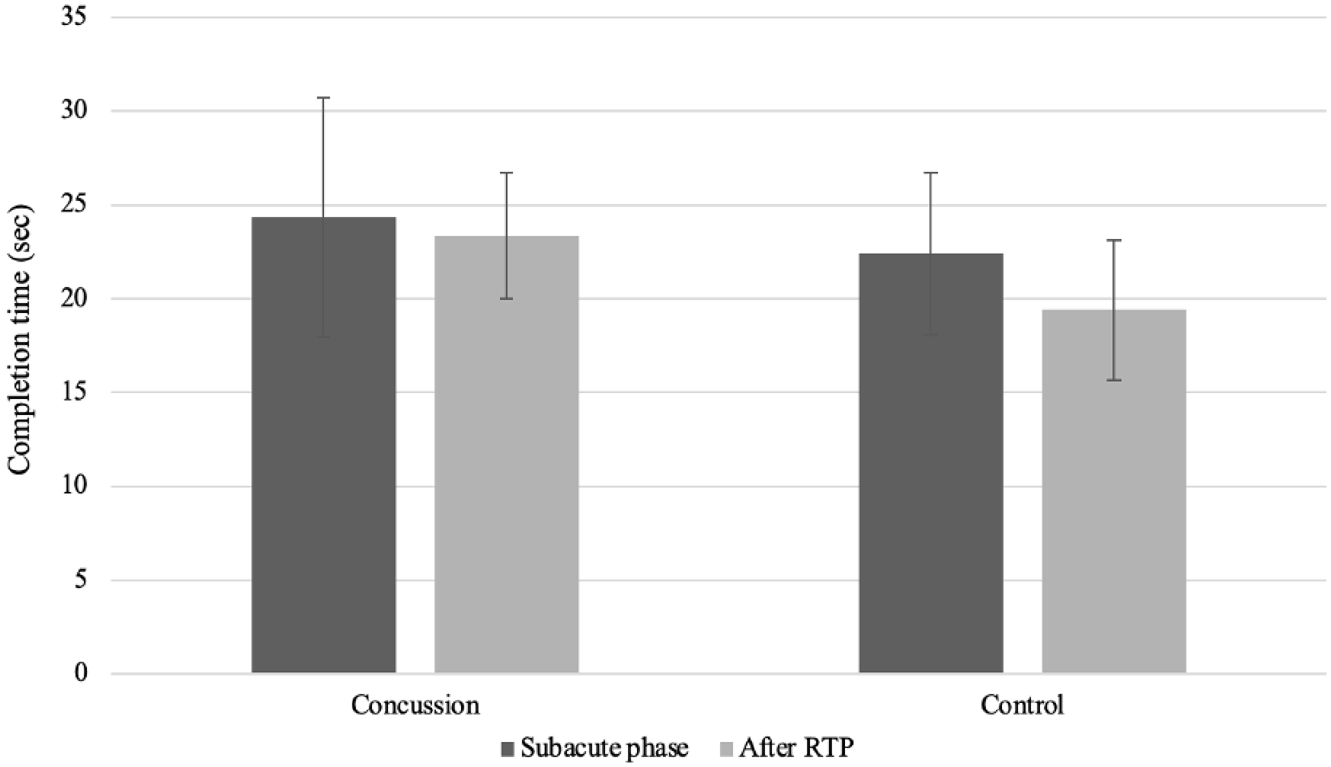

Fig. 1. Comparison of TG completion time during ST between concussed and control participants at subacute and after RTP time points. Abbreviations: TG, Tandem Gait, ST, Single-Task, RTP, Return to Play.

Figure 5.

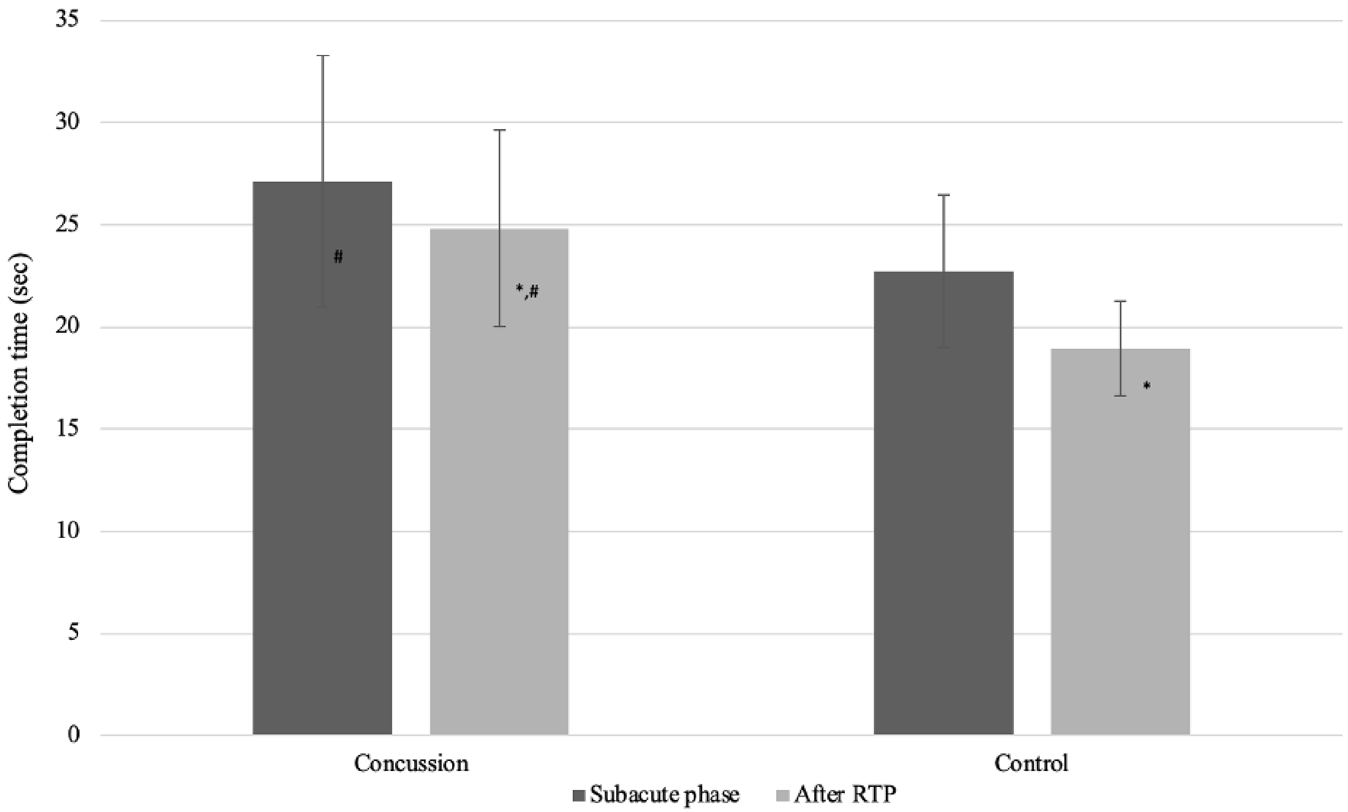

Fig. 2. Comparison of TG completion time during DT between concussed and control participants at subacute and after RTP timepoints. Abbreviations: TG, Tandem Gait, DT, Dual-Task, RTP, Return to Play. *Concussed participants walked significantly slower than the control participants after RTP time point (p = 0.002). #Concussed participants walked significantly faster after RTP time point compared to the subacute time point (p = 0.03).

Figure 6.

The main group effect for DT TG indicated that the concussed participants walked 5.03 seconds slower than the control group (95% confidence interval of 0.97 to 9.09 seconds, p = 0.02). Post hoc paired samples t-test showed that DT outcome was statistically significant between concussed and control participants after RTP time point (p = 0.002), but not at a subacute time point (p = 0.062). At the subacute phase, the concussed group took 4.4 seconds longer to complete DT TG than the control group, which did not reach the statistical significance (95% confidence interval of -0.28 to 9.10 seconds, p = 0.062). After RTP, the concussed group took 5.9 seconds longer to complete DT TG, compared to the control group (95% confidence interval of 2.78 to 9.00 seconds, p = 0.002).

The main time effect for DT TG indicated that the completion time after RTP time point was 2.8 seconds faster compared to the subacute time point (95% confidence interval of 0.33 to 5.26 seconds, p = 0.03), suggesting the possible practice effect. Post hoc paired samples t-test showed that the concussed group walked 3.80 seconds faster after RTP time point than subacute time point (95% confidence interval of 0.60 to 7.00 seconds, p = 0.03), while the control group walked 2.32 seconds faster after RTP time points compared to the subacute time point, which was not statistically significant (95% confidence interval of -1.60 to 6.22 seconds, p = 0.21). There were no practice effects associated with ST TG for both concussed (95% confidence interval of - 4.27 to 3.03 seconds, p = 0.70) and control groups (95% confidence interval of - 1.11 to 7.21 seconds, p = 0.13).

Discussion

This is the first study to report the lasting post-concussion deficits detected by a clinically feasible

DT after the completion of the Return to Play (RTP) protocol. Our concussed participants continued to have longer DT completion time (24.8 ± 4.8 seconds) compared to control participants (18.9 ± 2.3 seconds) after RTP (p = 0.01). In contrast, ST gait deficits resolved more quickly and showed no significant difference between groups after RTP (concussed: 23.38 ± 3.36 seconds, control: 19.41 ± 3.73 seconds, p = 0.11). Our results support the previous study reporting that concussed children and adolescents had longer TG completion time than healthy control at 2 months post-concussion when assessed using DT. [18] While TG and APST are relatively simple tasks, combining these tasks challenged the executive function and revealed lasting post-concussion deficits. Although the sample size was relatively small (n = 18), the mean difference of 5.9 seconds between groups during DT indicated a large effect size (d = 1.56). The results of this study suggest that the clinically feasible DT is able to identify post-concussion impairments that are not detected by a battery of traditional ST concussion assessments, and provides a unique measure associated with executive function to assess the readiness for return to daily and sports activities.

Appropriate task selection is necessary when composing DT for a concussion assessment. Task difficulty and familiarity play a critical role in multitasking as individuals have attentional capacity limits. McCulloch et al. compared walking with various cognitive tasks on patients with acquired brain injury and healthy young adults. [21] The cognitive tasks used were the following in an order of ease: repeating the alphabet, recalling the alphabet that was given earlier, reciting the alternate letters of the alphabet (i.e. A, C, E, G). Stop walking while repeating the alphabet and walking while repeating the alphabet were too easy to differentiate the two groups. On the other hand, walking while reciting alternate letters of the alphabet exceeded attentional capacity limits even for healthy individuals and showed no significant difference between groups. Walking and recalling the alphabet task was easy enough for most participants to complete while challenging enough to differentiate patients with acquired brain injury from healthy young adults. In the current study, healthy participants were able to perform APST with TG efficiently while it was challenging enough for concussed participants resulting in taking a significantly longer time to complete the task. These findings suggest that APST is an appropriate cognitive task to be paired with TG to elicit observable differences between concussed and healthy control groups.

Only the concussed group in our study improved their DT TG performance at the second data collection. Since the control group did not show significant improvements during the second data collection, this improvement in the concussed group was most likely an indicator of concussion recovery. According to our results, there were no practice effects for the control group when DT TG was performed with an interval of 16.44 ± 12.70 days (range: 6 - 39 days). The interval between initial and second data collection dates for the concussed group was 19.44 ± 10.90 days (range: 5 - 40 days), and there was no statistical difference in intervals between the two groups (p = 0.60). However, the practice effects with more than 2 trials and/or with shorter intervals are currently unknown. As a gradual RTP protocol requires athletic trainers to perform multiple follow-up assessments, it is important to take into consideration that potential improvements in performance could be due to both recoveries from injury and practice effects. Previous studies noted that TG test itself had high test-retest reliability, [22] that was higher than other postural control assessments such as BESS. [23] Manaseer et al. reported acceptable reliability with DT TG; however, it also suggested that repeated task administrations were associated with learning effects. [24] For the clinical application of DT, it is suggested for clinicians to initially monitor the recovery of ST then administer DT after the ST deficits are resolved to avoid repetitiveness and to effectively check the readiness for return to sports.

Preexisting conditions such as psychological distress, [25] ADHD, [26] and headaches [27] are known to negatively influence neurocognitive performance; therefore, the baseline testing is recommended to address individual differences in the DT performance level. [28] However, implementing the baseline testing of all concussion assessments for all athletes would place a tremendous amount of burden for both athletes and athletic trainers especially in secondary school settings. Schmidt et al. suggested that normative data could be used for postural control, neurocognitive test, and symptom assessment instead of baseline. [29] As to the authors' knowledge, however, there is no normative data available for DT and the baseline testing is recommended until the normative data is established.

Although there is room for further research to find appropriately leveled physical and cognitive tasks for different age groups, DT TG is a safe and clinically applicable tool to detect additional and unique post-concussion deficits. Dumphy et al. compared the reaction time and DT ability between concussed and healthy participants in a simulated driving environment. Data collection took place at 2 weeks to 3 months post-concussion, and all participants were cleared to participate using SCAT3; however, 14% of concussed participants complained of symptoms such as nausea and dizziness during the protocol and had to drop out of the study. [30] In the current study, all participants were able to complete the entire procedure safely without provoking the symptoms indicated by no changes in both the number and the total scores of symptoms in concussed participants after the data collection. In addition, TG and APST are both easily replicable in clinical settings without having to purchase additional equipment. The results support that the combination of TG and APST is a safe and effective tool to assess DT ability.

Limitations to our study include the lack of baseline testing, unstandardized testing timeline after RTP, and differences in the amount of distractions, albeit minimal, during the testing sessions. Although all concussed participants completed the RTP protocol by the time of the second data collection, our study did not control for the time interval between the actual date of RTP protocol completion and the second data collection due to scheduling difficulties. While the matched control group served to provide the “normal” outcome, the use of baseline would accommodate the individual differences and be recommended for clinical practice. In addition, the use of multiple testing sites might have resulted in an inconsistent amount of distraction imposed by noise and room size. Furthermore, our study only examined high school and college individuals (college n = 6, high school n = 12), and our result may not be applicable to other populations. Future study with a larger sample size is warranted to make this clinically feasible DT test widely applicable and to identify the possible confounding factors such as age, sex, and concussion history.

Conclusions

We examined the efficacy of a clinically feasible DT using physical and cognitive tasks that do not require expensive biomechanical laboratory equipment, with the aim of developing a concussion assessment tool suitable for evaluating more complex functions similar to daily activities and sports participation. Our findings indicate that the outcome of DT using TG and APST provides observable differences in performance level between individuals with a concussion and healthy counterparts at both subacute and after return to play. Furthermore, this group difference is not detected by ST TG indicating that the DT outcome provides unique and additional information likely associated with executive function. Clinically feasible DT using TG and APST should be considered as an adjunct concussion assessment tool to supplement the current concussion assessment.

AUTHOR DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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