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ORIGINAL RESEARCH REPORT

Turn Characteristics During Gait Differ With and Without a Cognitive Demand Among College Athletes

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Context: Sports often involve complex movement patterns, such as turning. Although cognitive load effects on gait patterns are well known, little is known on how it affects biomechanics of turning gait among athletes. Such information could help evaluate how concussion affects turning gait required for daily living and sports. ***Objective:*** To determine the effect of a dual task on biomechanics of turning while walking among college athletes. ***Design:*** Cross-sectional study. ***Setting:*** University laboratory. ***Participants:*** Fifty-three participants performed 5 trials of a 20-m walk under single- and dual-task conditions at self-selected speed with a 180° turn at 10-m mark. The cognitive load included subtraction, spelling words backward, or reciting the months backward. ***Interventions:*** Not applicable. ***Main Outcome Measures:*** Turn duration, turning velocity, number of steps, SD of turn duration and velocity, and coefficient of variation of turn duration and velocity. ***Results:*** Participants turned significantly slower (155.99 [3.71] cm/s vs 183.52 [4.17] cm/s; $P < .001$) and took longer time to complete the turn (2.63 [0.05] s vs 2.33 [0.04] s; $P < .001$) while dual tasking, albeit taking similar number of steps to complete the turn. Participants also showed more variability in turning time under the dual-task condition (SD of turn duration = 0.39 vs 0.31 s; $P = .004$). ***Conclusions:*** Overall, college athletes turned slower and showed more variability during turning gait while performing a concurrent cognitive dual-task turning compared with single-task turning. The slower velocity increased variability may be representative of specific strategy of turning gait while dual tasking, which may be a result of the split attention to perform the cognitive task. The current study provides descriptive values of absolute and variability turning gait parameters for sports medicine personnel to use while they perform their concussion assessments on their college athletes.

Keywords: concussion, Mini-Mental State Examination, gait variability, dual task

Concussion, defined as a traumatically induced alteration in mental status, often results in widespread disruption of neurologic functioning.[1] An increasing body of literature suggests that motor deficits exist postconcussion. Recent work has observed that gait, an activity of daily living, is altered in terms of shorter stride length and lesser step length variability, following sport-related concussions.[2–5] Concussion appears to induce a loss of motor control, whereby dynamic balance control is altered, resulting in a more excessive and faster center-of-mass movement pattern during gait.[6,7]

Athletes have balance and cognitive deficits postinjury and often undergo cognitive tests to assist with clinical management.[8] The addition of a secondary motor/cognitive task may improve the functional assessment of concussion recovery. In fact, such additions have been shown to present a more complex challenge to the athlete's brain and thereby be more sensitive in detecting motor deficits.[9] Previous research has used dual-task paradigms to show that gait impairments exist postconcussion but even after self-reported symptom resolution.[6,10–14] In addition, a dual-task methodology has been useful to identify that these gait impairments persist for a longer period of time after athletes experience a concussion.[15,16] These dual-task deficits in athletes who suffered a concussion may be due to altered cortical connectivity that affects availability and allocation of attentional resources to execute different tasks efficiently.[12,17–19] Dual-task paradigms usually involve individuals performing a secondary cognitive or motor task in addition to the primary motor task and are useful to understand the attentional limitations to perform the primary task. Gait is not automatic and requires attentional resources from higher brain centers that may be limited due to concussion. Performing an additional cognitive task while walking places an additional demand on the executive function and working memory evidenced by activation of frontal lobe areas such as the dorsolateral prefrontal cortex.[20,21] Athletes often encounter very physically and cognitively demanding situations during practice and game play. Furthermore, concussions have been shown to affect both motor and cognitive functions, and a dual-task testing paradigm can help elicit the extent of these affects both individually and together.[16,22] Understanding attentional limitations using dual-task conditions can be useful to detect subtle impairments even after symptom resolution and help them get ready for return-to-play postconcussion and/or other injuries. Although there are numerous studies on using a dual-task paradigm for evaluating gait in athletes, such an assessment of turning while walking has received little attention to date.

The ability to complete a turn is not only essential for daily activities but also during sports. Turning requires the central nervous system to coordinate movement patterns toward a new

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travel direction, while continuing with the on-going step cycle and maintaining postural stability.[23] One recent study observed altered turn kinematics in the walking patterns of 4 concussed athletes.[5] These athletes turned with a longer stride time and lower velocity during a dual-task cognitive condition when compared with healthy controls, despite the absence of any clinical deficits. Previously, it has also been suggested that as the complexity of movement tasks increases in terms of the required sensory and cognitive information processing, higher brain centers are increasingly utilized.[24] Moreover, navigating complex motor tasks, such as walking along an obstructed path, have been shown to be problematic for athletes with concussion even after they were considered symptom free and fully recovered, suggesting that usage of complex motor tasks could play a crucial role in assessing the recovery of athletes.[25] The sensory and cognitive demands and biomechanics of turning gait are different and perhaps more complex than regular gait as turning while walking requires an athlete to respond to an internal balance perturbation because of the need to change direction.[26] Hence, adding a dual-task paradigm to turning gait may pose as a more challenging task to a population such as college athletes during their postconcussion recovery evaluation. Thus, examining turning while walking, particularly under a dual-task paradigm, may allow clinicians to gain valuable information pertaining to movement abilities.

The purpose of our study was to determine the effect of dual task on biomechanics of turning during gait in college athletes. We also sought to identify the descriptive turning values that may be used to identify postinjury deficits. We hypothesized that participants would perform worse by turning slower and with greater variability when completing the turning gait task with a cognitive load compared with completing the turning gait task without cognitive load.

Methods

Participants

Fifty-three division I uninjured varsity athletes participated in the study as part of a baseline concussion protocol. Demographic information is presented in Table 1. Participants who had any lower-extremity injury or concussion within last 6 months from the day of testing that could affect their gait were excluded. All volunteers provided written consent approved by Elon University's Institutional Review Board to participate in the study.

Table 1 Participant Demographics

Age, y, mean (SD)	18 (1.1)	
Height, m, mean (SD)	1.79 (0.11)	
Mass, kg, mean (SD)	79.6 (19.8)	
Sex	Female (n = 16)	Male (n = 37)
Self-reported history of concussion	0 concussions (n = 39)	At least 1 concussion (n = 14)
Type of sport	Contact	Limited contact
	Football (n = 19)	Baseball (n = 15)
	Women's soccer (n = 1)	Women's volleyball (n = 5)
	Men's basketball (n = 3)	Softball (n = 4)
	Women's lacrosse (n = 4)	
	Women's basketball (n = 2)	

Instrumentation and Experimental Protocol

Participants wore 6 Opal sensors (APDM, Inc, Portland, OR), placed on each foot, each wrist, the lumbar spine, and the sternum with elastic bands. Each sensor weighed about 22 g and was 3.5 cm × 3.5 cm in dimensions. Data were collected at 128 Hz. The sensors have the capability to either wirelessly stream data during data collection via an access point or store to transmit the data at a later time to the data collection computer. APDM's Opal sensors, along with Mobility Lab, its associated software, have been used in several studies involving athletes[27–29] and other populations with Parkinson's disease.[30] Participants completed 1 practice trial and 5 test trials of turning while walking under a single-task condition first and then under a dual-task condition. Five trials were used to capture both representative performance and variability of turning gait.[3] During both conditions, the participants walked barefoot for 10 m at self-selected comfortable speed, turned 180° around a target (an 18-cm tape on the floor), and returned to the original position (Figure 1). Barefoot walking was utilized for testing purposes to eliminate possible confounding effects of different footwear on walking. During the dual-task condition, the participants were tested using an exam previously used during dual-task investigations.[2,4,27] The exam consisted of 3 cognitive tasks: (1) spelling 5 letter words in reverse order, (2) reciting the months of the year in reverse order beginning with a random month of the year, and (3) subtracting by 6s or 7s from a random 2-digit number. A standard order consisting of the 3 cognitive conditions was used for each participant. The order was as follows: trial 1: spell a word backward, trial 2: recite the months in reverse order, trial 3: subtract by 7s, trial 4: spell a word backward, and trial 5: subtract by 6s. The participants performed the cognitive task prior to receiving a verbal cue to begin walking and continued performing the cognitive task until they returned to the original position. No instructions were given to prioritize motor (walking/turning) or cognitive task during a dual-task condition. The participants were also instructed to continue performing the cognitive task even after the walk had been completed. The dependent variables of turning velocity, duration, and number of steps during the turn were directly obtained from the Mobility Lab software (APDM, Inc). Turning velocity was the peak angular velocity of the trunk sensor in the transverse or horizontal plane. The trunk and lumbar sensors and a mathematical model developed by APDM were used to detect the exact moment of beginning and end of turning.[31] Briefly, the model uses the angular velocity signal from the yaw rotations of the in-built gyroscope of the sternum. The angular velocity signal is then integrated. The beginning and end of the 180° turn are determined based on the change of the yaw rotation by 180°.

Data Processing and Statistical Analysis

The average, SD, and coefficient of variation of the 5 trials under each condition were then calculated for each variable for each participant. Normality was checked using the Shapiro–Wilk test.

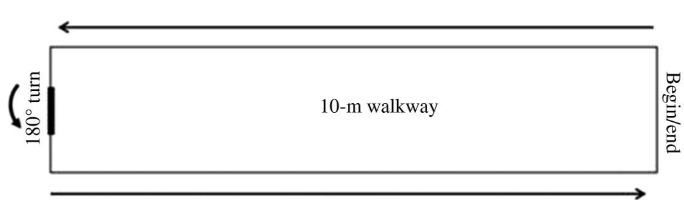

Figure 1 — Schematic of experimental setup.

As the data were normally distributed, a paired samples *t* test was performed to compare the dependent variables under single- and dual-task conditions. Bonferroni post hoc correction was applied, and an alpha value of .007 was used to determine statistical significance. An SPSS 22.0 (IBM, Inc, Armonk, NY) was used for all statistical analyses. Effect sizes were computed. An effect size <0.2 was deemed small, between 0.2 and 0.5 was deemed moderate, and > 0.5 was deemed strong.[32]

Results

During the dual-task condition, participants took significantly longer time (12.88%; $P < .001$) to complete the turns, turned significantly slower (15.01%; $P < .001$), and had significantly greater turning time variability (25.81%; $P = .004$) than the single-task condition with moderate to strong effect sizes (Table 2). No other measures were significantly different between the 2 conditions (Table 2).

Discussion

We hypothesized that athletes would perform worse while walking under a dual-task condition when compared with a single-task condition. Measures of duration and turning velocity were significantly different between conditions. Specifically, college athletes took a longer time to complete the turn and turned slower, while also demonstrating more variability during turning and concurrently completing a cognitive task.

The slower velocity may be representative of a specific strategy of turning gait while dual tasking, which may be a result of the need to distribute attention across multiple domains to complete the cognitive task. Results of the current study concur with those observed for walking in young and older adults, where walking speed was decreased while performing a concurrent cognitive task.[33–35] Although there are various theories, the results could be explained based on the capacity-sharing theory, which suggests that when 2 tasks simultaneously demand attention, performance on either or both of the tasks may deteriorate due to limited availability of resources.[36] The bottleneck theory suggests that certain mental operations may have to be performed sequentially thereby leading to poor or lack of performance of one task before another task is carried out.[37] Although it is possible that the results of the current study could also be partially explained by the bottleneck theory, anecdotally, none of the participants stopped performing the cognitive task and/or the motor task (turning); thereby, lending less support to the bottleneck theory. An analysis of the cognitive task performance can shed more light into explaining the attentional deficits during turning while performing a concurrent cognitive task.

In the current study, variability of turn duration was greater during a dual-task condition. This could imply that when presented with an additional cognitive task, athletes used different turning strategies to complete turns. Plausible usage of these different turning strategies could be due to the aforementioned dual-task interference theories. To our knowledge, the current study is the first to quantify turn variability under single- and dual-task conditions in college athletes, and so options for similar comparisons with other studies are limited. However, turning gait variability has been examined in other populations. For example, a recent study used similar instrumentation and showed that older adults who experienced more than 1 fall in the previous 12 months took significantly longer time to turn, turned slower, and took more number of steps to complete the turn.[30] Moreover, variability of number of steps required to complete the turn was also reported to be larger in prospective fallers.[30] Increased variability during turning gait while performing a dual task has also been reported for older adults, individuals poststroke,[38] and individuals with Parkinson's disease.[39] Significantly greater variability in turning strategy in these populations compared with healthy controls may reflect poor balance. Conversely, significantly lesser variability may be associated with rigid motor behaviors and a lack of necessary adaptive skills for balance control during turning.[40] However, there is a paucity of such information on optimal variability for college athletes postconcussion, and the current study is the first to provide reference normative values of what is expected as a normal variability while examining turning gait while dual tasking. Recent evidence also supports the use of such normative values for assessing an athlete postconcussion.[27,41]

The current study supports utilizing a dual-task paradigm for evaluating athletes' performance.[2,4–6,12,13,16,27,29,42] Results from these studies have consistently shown that postconcussion deficits such as slower gait speed can be seen in athletes while performing dual task during regular gait,[2,4,6] tandem gait,[16,29] and even static postural control.[43] Our study extends this notion, as evaluating a turn while walking in college athletes may provide information pertaining to recovery of functional abilities after a concussion. It is plausible that postconcussion athletes may display impairments such as slower turning gait while performing a concurrent cognitive task. Results from the current study will help in determining if such impairments are within the threshold of what is expected during a dual-task turning gait. In fact, Fino et al[5] found that 4 athletes who experienced concussion performed worse than uninjured controls

Table 2 Mean ± SE (95% Confidence Interval) of Turning Characteristics While Walking

Type of measure	Measure	Single task	Dual task	*P*	Effect size (interpretation)
Absolute	Mean turn duration,* s	2.33 ± 0.04 (2.26–2.41)	2.63 ± 0.05 (2.54–2.72)	<.001	1.07 (strong)
	Mean turn velocity,* cm/s	183.52 ± 4.17 (175.35–191.69)	155.99 ± 3.71 (148.73–163.25)	<.001	1.15 (strong)
	Mean number of steps	3.7 ± 0.2 (3.4–4.0)	3.9 ± 0.1 (3.6–4.2)	.09	0.26 (moderate)
Variability	SD turn duration,* s	0.31 ± 0.02 (0.27–0.35)	0.39 ± 0.02 (0.34–0.43)	.004	0.41 (moderate)
	SD turn velocity, cm/s	19.88 ± 1.49 (16.95–22.80)	20.26 ± 1.84 (16.65–23.86)	.91	0.03 (small)
	CV turn duration, %	13.29 ± 0.79 (11.75–14.84)	14.76 ± 0.88 (13.02–16.49)	.23	0.21 (moderate)
	CV turn velocity, %	10.75 ± 0.78 (9.23–12.27)	12.76 ± 0.98 (10.84–14.68)	.08	0.25 (moderate)

Abbreviation: CV, coefficient of variation.
*Significant difference ($P < .01$).

during turning when asked to perform a concurrent dual task: they turned slower and took more time to complete the stride.

Combined with results from the current study, turning while walking may be a useful evaluative technique as part of the motor assessments for postconcussion evaluations. Dependent variables used in the current study such as turn duration and number of steps can easily be measured in a clinical setting along with gait testing by clinicians. This is particularly important because turning is a complex motor task that involves multisegmental rotation and temporal coordination of head, trunk, and pelvis while maintaining postural stability of the whole body. Previous research reported that healthy young adults use a top-down segmental approach to turning while walking where the head rotates toward the new direction prior to trunk that rotates prior to pelvis.[23] However, older adults and persons with Parkinson's disease exhibit different strategies suggestive of difficulties with making such a turn. Such strategies include slowing down before turning, reducing the step length and increasing the step width, and displaying altered intersegmental coordination while turning.[44–50] Whether such altered kinematics exist during turning gait postconcussion among athletes needs to be determined in future research studies using dual-task paradigms. Moreover, limited research on nonturning gait variability and stability while dual tasking in college athletes suggests that concussed athletes walk with decreased local dynamic stability, increased stride time variability, greater variability in hip–knee and knee–ankle interjoint coordination during dual tasking.[12,50] Future studies need to examine if and how turning gait variability is affected in athletes postconcussion.

Limitations of the current study include potential influence by the choice of dual task, gender, and sport. Previous research has shown that an arithmetic-type cognitive task affects walking differently compared with a fluency-type cognitive task.[51,52] Performance on cognitive task during single tasking and dual tasking was not recorded to observe any task prioritization effects. For example, persons with Parkinson's disease have been shown to prioritize the concurrent cognitive task instead of focusing on postural control when not explicitly instructed to focus on maintaining posture.[53] However, when explicit instructions are given, gait improvements were seen in individuals with Parkinson's disease.[54,55] Future research can examine such task prioritization effects while dual tasking in athletes. Future studies should examine the potential use of an average velocity metric instead of a peak velocity metric to account for the different strategies of turning that the athletes might employ. Results of the current study could also have been influenced by the nonrandomized order in which the single- and dual-task conditions were presented. Although the sample size is representative of similar studies, more research with larger sample sizes is needed to address these limitations. Furthermore, future experiments can include a concurrent motor task (such as carrying a box/an object/glass of water in a tray) during turning gait to assess if the crosstalk theory can be validated.[37] According to the crosstalk theory, 2 tasks belonging to the similar domain provide minimal interference with the executing of either of the tasks.

Conclusion

When performing a dual task while walking, college athletes turned with a significantly slower velocity and showed more variability in the amount of time to complete the turn while dual tasking, albeit taking a similar number of steps to complete the turn. Thus, examining turning under a dual-task condition may allow clinicians to evaluate a complex ability that could provide beneficial information during concussion examinations.

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