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Altered dynamic postural control during gait termination following concussion

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ABSTRACT

Impaired postural control is a cardinal symptom following concussion. Planned gait termination (GT) is a non-novel, dynamic task that challenges postural control in individuals with neurological deficits, and it could be an impactful measure for identifying dynamic postural control impairments following concussion. Therefore, the purpose of this study was to assess acute post-concussion dynamic postural control utilizing a planned GT task. The concussion participants (n = 19, age: 19.0 ± 0.8 years, height: 177.0 ± 10.1 cm, weight: 83.3 ± 20.0 kg) completed five planned GT trials during preseason baseline testing (Baseline) and on Day 1 post-concussion (Day-1). Healthy control participants (n = 19, age: 20.4 ± 1.2 years, height: 173.8 ± 8.9 cm, weight: 80.2 ± 17.6 kg) completed the same trials a week apart. The dependent variables of interest included COP displacement and velocity in the mediolateral (ML) and anteroposterior (AP) axes during the three phases (braking, transitional, stabilization) of planned GT. There were significant interactions observed in both the braking ML and transitional AP displacement ($p = 0.042$, $p = 0.030$) and velocity ($p = 0.027$, $p = 0.030$). These results suggest a conservative post-concussion motor control strategy during planned GT. Further, these results support the use of dynamic postural control tasks as measures of post-concussion impairments.

1. Introduction

Impairments in postural control are a primary concussion symptom; thus, postural control testing is a recommended component of the multifaceted concussion assessment battery [1,2]. Current concussion assessments include both clinical (Balance Error Scoring System (BESS)) and experimental (Sensory Organization Test (SOT)) protocols. The most commonly utilized clinical assessment tool, BESS, is limited by low interrater and intrarater reliability scores, test administration environment, and low sensitivity (0.34) acutely post-concussion [3–6]. Despite its limitations, the BESS does have high content validity for identifying balance impairments following a concussion, and the modified version of the BESS, which is recommended by the 3rd edition of the Sport Concussion Assessment Tool, has demonstrated good reliability [7–9]. However, both the BESS and SOT are limited by substantial practice effects, potentially because these are novel tasks (e.g., standing barefoot on a foam surface with the eyes closed), and repeat administration has routinely identified improved performance [10,11]. Further, the BESS and SOT are static assessments that rely on feedback mechanisms to maintain upright posture on an unstable surface and do not evaluate transitional, dynamic movements, which are likely more challenging to the postural control systems [12]. These limitations may explain the surprising finding that post-concussion static postural control often recovers prior to both symptom resolution and cognitive deficits [6]. Therefore, the utilization of common dynamic motor activities of daily living (ADL), which are unlikely to be subjected to a practice effect, may be more appropriate for identifying post-concussion impairments [13].

An acute post-concussion conservative gait strategy, consisting of reduced step velocity, step length, center of pressure (COP) and center of mass (COM) separation, as well as increased double support time and frontal plane COM sway, has been consistently

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identified [14,15]. These deficits appear to persist for up to two months post-injury, suggesting impairments in dynamic postural control persist well beyond BESS recovery [16]. Gait is an innate, or non-novel, dynamic task, and the parameters are not generally susceptible to the practice effects in otherwise healthy young adults [17]. Gait performance is highly consistent in healthy college-aged recreational and student-athletes [18]. Specifically, changes in gait parameters (e.g., velocity, stride length) are most pronounced up to age 10, after which there are minimal changes in gait pattern [17]. Unlike quiet standing, unobstructed gait is less reliant on sensory feedback as both supraspinal planning (motor cortex and pyramidal tract) and central pattern generators are largely responsible for feedforward control [19,20]. Further, transitional movements, such as initiating or terminating gait, are likely more challenging to dynamic postural control systems than gait, which likely increases the neurological resources required to safely complete the task [21].

Planned gait termination (GT) is a transitional motor task that encompasses the shift from cyclical gait to quiet standing and requires the central nervous system to anticipate, control, and slow the forward momentum of the body while maintaining the COM within the base of support (BOS) [22]. This transitional task is divided up into three phases: braking (S1), transitional (S2), and stabilization (S3). In fRMI studies, planned GT appears to be controlled supraspinally, with activation patterns identified within the right prefrontal area, specifically the right inferior frontal gyrus [19]. The planned GT task requires the participant be aware of the location or time to terminate gait and is comprised of a penultimate (second to last step before termination) and termination step [22]. Mechanically, planned GT requires two coupled braking mechanisms: (1) a reduction in the foot propulsive force during the penultimate step and (2) an increase in the braking force during the terminating step [22]. Thus, it is not surprising that GT has already identified both acute and lingering alterations in post-concussion propulsive and braking forces only; however, the COP trajectories have not been elucidated [23]. Further, individuals with compromised neurological systems (e.g., Parkinson's disease, Cerebellar disease, moderate to severe traumatic brain injury) have noted planned GT deficits, including diminished COP displacements.

Planned GT is a stable, non-novel ADL task that challenges the postural control systems and that relies on active feedforward control [20]. Impaired postural control is a known consequence of concussion; however, most assessment protocols utilize novel static tasks that have not been associated with specific postural control mechanisms. Therefore, the purpose of this study was to evaluate planned GT performance between baseline and post-concussion individuals with comparison to healthy individuals. We hypothesize an interaction will be present wherein herein healthy control participants will demonstrate consistent task performance whereas the post-concussion participants will demonstrate an impairment during GT.

2. Methods

2.1. Participants

There were 38 participants in this study; 19 National Collegiate Athletic Association Division I student-athletes, from a single institution, diagnosed with a sports-related concussion and a control group consisting of 19 uninjured, physically active individuals from the same institution (Table 1). All concussions were identified by a certified athletic trainer and subsequently diagnosed by the team physician. The inclusion criteria for the concussion participants was a diagnosed concussion with valid baseline data, and the control participants were intercollegiate or recreational athletes with no history of concussion within the past 6 months. The exclusion criteria included any self-reported neurological disorders, current lower extremity orthopedic injury, and metabolic, vestibular, vision disorders or other conditions that would impair gait performance. A current lower extremity orthopedic injury was classified as any ongoing or past orthopedic injury that would alter an individual's normal gait pattern. Each participant provided oral and written informed consent in accordance with the University's IRB.

2.2. Instrumentation and procedure

Kinetic data was collected at 1,000 Hz from four 400 mm × 600 mm force plates (AMTI, Model OR-6, Watertown, MA. USA) mounted flush with the walkway surface and COP was calculated with standard biomechanics formulas [24]. The concussion participants completed their first test during pre-participation physical examinations (Baseline), prior to any participation as an intercollegiate student-athlete, and were retested on the first day following their concussion (Day-1). The median time between baseline testing and Day-1 post-concussion was 118 days (range: 49–807 days). The control participants completed the trials on an initial day (Baseline) were retested one week later (Day-1) outside of their intercollegiate season. While gait termination, to our knowledge, has not been evaluated for stability across time, it has been established that there are minimal changes to an individual's gait pattern after age 10 [17]; therefore, it is likely that any differences identified herein were associated with the concussion and not the testing interval. Furthermore, the feasibility of recruiting healthy student-athletes for additional testing sessions within season is logistically difficult.

Each participant performed 5 planned GT trials during each testing session. Participants were instructed that, in response to a verbal cue, they would traverse an 8-m walkway and perform planned GT on the force plates. The penultimate step impacted either force plate #3 or #4, depending on footfall, and the terminating step occurred on force plates #1 and #2 (Fig. 1). Practice trials were performed to ensure a natural footfall on the force plates and if errors, occurred during the test trials (e.g., irregular footfall pattern, falling to stop) it was repeated.

Table 1
Participant Demographics. There were no significant differences ($p > 0.05$) between groups for demographics.

	Age (years) M ± SD	Height (cm) M ± SD	Weight (kg) M ± SD	Concussion History
Concussion (n = 19)	19.0 ± 0.8	177.0 ± 10.1	83.3 ± 20.0	0.9 ± 1.0
Control (n = 19)	20.4 ± 1.2	173.8 ± 8.9	80.2 ± 17.6	0.8 ± 1.2

1/19 concussion participants presented with loss of consciousness (LOC).
4/19 concussion participants presented with post-traumatic amnesia (PTA).