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Altered Gait Termination Strategies Following a Concussion

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Abstract

The purpose was to determine if planned gait termination can identify acute and lingering motor control strategy alterations in post-concussion individuals. Controls completed 2 standard gait and 5 planned gait termination trials once while concussed individuals were tested on Day-1 and Day-10 post-concussion. Dependent variables included gait velocity and normalized, relative to standard gait, peak propulsive and braking forces. Control and only Day-1 post-concussion gait velocity differed. Normalized peak propulsive and braking forces were altered on both Day-1 and Day-10. Altered propulsive and braking forces persisted despite all concussion participants achieving their baseline values on standard concussion clinical tests. Thus gait termination can detect both acute and lingering motor control strategy alterations following concussion.

INTRODUCTION

Balance impairments are a cardinal post-concussion symptom and balance assessment is a recommended component of a multifactorial assessment.¹ The post-concussion neurometabolic cascade is proposed to last for 10 days; however, traditional concussion balance assessments reportedly return to baseline values 3–5 days post-injury despite the continued presence of both self-reported symptoms and neurocognitive deficits.^{2,3} Recent investigations have suggested that lingering balance deficits during dynamic postural tasks may persist beyond this apparent recovery and result in altered movement strategies during locomotion.^{4,5}

Gait termination (GT) is a central nervous system process that anticipates, controls, and arrests the forward momentum of the COM.⁶ Central neurophysiological control of GT is suggested to occur within the inferior frontal gyrus and pre-supplementary motor area.⁷ GT possesses a known and invariant set of parameters which constrains the multiple degrees of freedom of the lower extremity.^{8,9} Thus experiments using planned GT can challenge centrally mediated motor control mechanisms¹⁰ and may be an ideal task to identify altered

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Conflict of Interest Statement

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movement strategies associated with post-concussion balance impairments.^{10,11} Thus, the purpose of this investigation was to determine if planned GT can identify acute (Day-1) and lingering (Day-10) alterations in motor control strategies post-concussion. We hypothesized that both acute and lingering alterations would be present despite recovery on traditional measures.

METHODS

Participants

Participants included 26 uninjured controls (age: 20.3 ± 1.7 years, height: 167.0 ± 9.5 cm, weight: 66.9 ± 13.4 kg), and 21 concussed individuals (age: 19.0 ± 1.0 years, height: 173.6 ± 12.5 cm, weight: 76.6 ± 21.2 kg; 9.5% LOC rate; 0.8 ± 1.0 prior concussions). Controls were active (intercollegiate or recreational athlete) college aged individuals free from lower extremity pathologies and concussions for 3 months prior to testing, and other balance disorders. Controls were tested on one occasion as part of a larger study on the biomechanical analysis of GT. Concussed individuals, intercollegiate student-athletes, were formally diagnosed with a concussion by team physicians and tested within 24 hours of the injury and again 10 days later. All concussed participants performed standard clinical post-concussion assessments.¹² All participants provided written informed consent as approved by the University's IRB.

Procedures

Gait and GT were performed barefoot along an 11-meter walkway. Participants completed two standard gait trials walking at a self-selected pace along the 4.9m Gaitrite walkway (CIR Systems, Sparta, NJ.), across 4 adjacent forceplates (AMTI, Watertown, MA.), and an additional 2.5m (Figure 1). After practicing for several trials, so that natural foot fall would occur on the force plates, the planned GT protocol was completed^{10,11} by walking across the same 4.9m walkway at a self-selected pace before stopping on either force plate #1 or #2 after the penultimate step occurred on force plate #3 or #4 depending on their natural footfall. A total of 5 GT trials were recorded.

Data and Statistical Analysis

Gaitrite calculated gait velocity from the stride prior to contacting the force plates during all trials.^{10,11} Propulsive and braking forces were calculated from ground reaction forces collected at 1000 Hz. During all trials, peak propulsive force was recorded during foot contact with force plate #3 or #4 while peak braking force was recorded during the contralateral foot contact with force plate #1 or #2.^{10,11,13} Peak propulsive and braking forces for both gait and GT trials were normalized to the participant's gait velocity. Normalized GT forces were then expressed as a percentage of the normalized forces observed during standard gait trials (Figure 2).

Independent t-tests compared group demographics. Separate one-way ANOVAs, with post-hoc testing, compared gait velocity, propulsive %, and braking % among the Control, Day-1, and Day-10 time points. Significance was set at $p = 0.05$ and effect sizes were calculated.

RESULTS

All participants completed all trials without incidents. There were no differences between groups for height ($p=0.054$) or weight ($p=0.120$); however, the control participants were significantly older ($p=0.002$). Concussed participants had returned to their baseline values on all traditional concussion assessment measures, including BESS (2.6 ± 1.9 days), standard assessment of concussion (2.2 ± 1.7 days), self-reported symptoms (4.4 ± 2.0 days), and

computerized neuropsychological tests (5.8 ± 3.3 days) in timeframes consistent with previous concussion studies.³ Significant main effects, with the concussed participants performing worse, for Gait Velocity ($F:6.20$, $p=0.04$), Propulsive % ($F:21.27$, $p<0.001$), and Braking % ($F:18.10$, $p<0.001$) were observed (Table 1).

DISCUSSION

The main finding of this study was a noted alteration in GT performance, independent of gait velocity, which persisted for at least 10 days post-injury despite recovery on all aspects of the traditional clinical assessment battery. Specifically, post-concussion GT performance was characterized by relative increases in both the propulsive force of the penultimate limb and the braking force of the termination limb. Conversely, no differences were noted in gait velocity between groups at day 10 post-injury (Table 1) suggesting an altered movement strategy occurred. These findings support a growing body of literature suggesting that impairments in balance persist longer than indicated by clinical tests.^{4,5,14} Both neural plasticity and reallocation of functional reserves are hypothesized to be sufficient to mask impairments on less complex tasks (i.e. clinical tests) thus giving the appearance of recovery despite lingering impairments.¹⁵

Sophisticated challenges to postural control (e.g., responses to visual field motion, dual-task gait, obstacle avoidance) have demonstrated lingering impairments well beyond clinical recovery¹ which is consistent with the demands of GT. Indeed, the noted initial reduction and subsequent recovery in gait velocity is consistent with previous post-concussion studies;⁵ however, GT strategies remained altered at Day-10. The post-concussion participants in this study, relative to their standard gait trials, significantly increased the propulsive force generated by the limb behind the COM (the limb striking forceplate #3 or #4) and increased the braking force of the terminating limb (striking forceplate #1 or #2). Non-stereotypical GT patterns have been observed in those with Parkinson's disease⁸ cerebellar disease,⁹ and vestibular hypofunction.⁹ Alterations have included ankle musculature co-contractions during the penultimate step and modified forward-to-lateral transfers of upper body energy.^{8,9} The mechanism for these observed alterations is unclear but may be a posturally conservative strategy to reduce forward momentum or result from impaired supraspinal pathways in the prefrontal area, secondary to the noted post-concussion "spreading depression".^{2,7-9} The results of this study suggest that GT may be an appropriate investigatory mechanism to assess alterations in movement strategies,¹⁰ following a sports-related concussion.

Limitations included the use of an external control group rather than pre-concussion data from a significantly older (1.3 years) experimental group and limited biomechanical analysis. With proof of concept established, a more robust analysis will better elucidate the underlying mechanisms of post-concussion GT alterations. Further, we are inferring alterations in centrally mediated motor control mechanisms from behavioral outcome measures which should be addressed in future research.

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Highlights

- Gait termination performance was evaluated following a concussion.
- Gait termination strategies are impaired immediately following concussion.
- Impaired gait termination strategies persist for at least 10 days.
- Traditional concussion assessments may not identify persistent impairments.

Figure 1.

Laboratory Set-up. Participants began the gait termination trials at the starting position and continuously walked the 2.5 meters to the GAITRite and the 4.9 meter walkway and terminated gait with the penultimate step occurring on force plate #3 or #4 and the termination step occurring on force plate #1 or #2 depending on natural footfall. For standard gait trials, the participant began at the starting position and walked continuously across the GAITRite and force plates until reaching the end of the walkway, 2.5 meters passed the force plates.

Figure 2.

(A) Representative propulsive and braking force curves. Peak propulsive (black lines) and braking forces (grey lines) from both standard gait and gait termination trials were identified (horizontal lines) and normalized to the trials gait velocity. Normalized gait termination forces were then expressed as a percentage of the normalized forces observed during standard gait trials. (B) The formulas used to calculate the Propulsive and Braking %.

Table 1

Means, standard deviations, 95% Confidence Intervals, and Effect sizes.

	Control	Day 1 Post-Concussion	Control to Day 1 Post Hoc p-values (Effect Size)	Day 10 Post-Concussion	Control to Day 10 Post Hoc p-values (Effect Size)
Gait Velocity (m/s)	1.32±0.14 (1.26 to 1.38) n=26	1.16±0.14 ^{*/†} (1.08 to 1.23) n=15	0.01 (1.14)	1.33±0.19 (1.21 to 1.46) n=12	0.97 (0.06)
Propulsive %	-0.25±0.53 (-0.41 to -0.10) n=26	0.44±0.17 ^{*/†} (0.24 to 0.64) n=15	<0.01 (0.85)	0.46±0.13 ^{*/†} (0.23 to 0.69) n=12	<0.01 (0.85)
Braking %	-0.30±0.20 (-0.39 to -0.21) n=26	-0.05±0.27 ^{*/†} (-0.17 to 0.07) n=15	<0.01 (0.54)	0.16±0.23 ^{*/†} (0.03 to 0.29) n=12	<0.01 (0.95)

^{*} Significant difference from the control group.

[†] Significant difference from the Day 10 time point.