# Gait Stability following Concussion

TONYA M. PARKER, LOUIS R. OSTERNIG, PAUL VAN DONKELAAR, and LI-SHAN CHOU

*Motion Analysis Laboratory, Department of Human Physiology, University of Oregon, Eugene, OR*

**ABSTRACT**

PARKER, T. M., L. R. OSTERNIG, P. VAN DONKELAAR, and L. CHOU. Gait Stability following Concussion. *Med. Sci. Sports Exerc.*, Vol. 38, No. 6, pp. 1032–1040, 2006. **Introduction:** The need to identify functional impairment following a brain injury is critical to prevent reinjury during the period of recovery. However, little is known about the effect of concussion on dynamic motor function. **Purpose:** The purpose of this study was to examine the effect of concussion on a dynamic motor task under conditions of divided and undivided attention over the course of 28 d. **Methods:** Fifteen subjects with concussions (CONC) and 15 uninjured controls (NORM) were observed while walking with undivided attention and while concurrently completing simple mental tasks. The CONC were assessed within 48 h of injury and again at 5, 14, and 28 d postinjury. The NORM were evaluated at the same time intervals. Whole-body motion data were collected to examine displacement and velocity of the center of mass (COM) and the maximum separation between the COM and center of pressure (COP). Three-way repeated-measures mixed-design ANOVA and Tukey *post hoc* tests were completed to determine differences between group, task, and testing day ($P < 0.05$). **Results:** Several aspects of gait stability were compromised in the CONC group for up to 4 wk after injury. CONC were found to walk significantly slower during dual tasks on all testing days when compared with the uninjured controls. The injured subjects were also found to have greater sway and sway velocity than controls when attention was divided for up to 28 d postinjury. **Conclusion:** The findings of this study suggest that concussion may have long-term observable and measurable effects on the control of gait stability. **Key Words:** MILD TRAUMATIC BRAIN INJURY, GAIT STABILITY, ATTENTION, RECOVERY

According to the Centers for Disease Control and Prevention, concussions have reached epidemic proportions, with an estimated 300,000 cases per year (6), (www.cdc.gov/ncipc/dacrrdp/tbi.htm). As more becomes known about the increased risk of subsequent brain injuries and the potentially fatal consequence of second-impact syndrome (5), accuracy in the identification of functional impairment following a concussion becomes increasingly important. A number of studies have focused on neuropsychological testing (4,19,20,23,25), reaction time (4,9,21), and static balance control (11,12,23,27) following concussion in attempts to estimate the characteristics of recovery following concussion.

Neuropsychological testing has been advocated as the "cornerstone" of proper postconcussion management (20). Prior studies on neuropsychological testing have examined the timeline of recovery following concussion and revealed largely consistent results. Macciocchi et al. (20) found that performance on neuropsychological tests resolved within 5 d of injury for collegiate football players, whereas Bleiberg et al. (4) found that boxers recover from 3 to 7 d following a single concussion. A National Collegiate Athletic Association football concussion study determined that recovery of cognitive processing speed and verbal fluency was evident by day 7 (23). These studies of mild concussions suggest that normalization on neuropsychological tests occurs between 5 and 7 d following concussion in a large number of individuals. However, speed of information processing was found to remain significantly diminished at day 10 postinjury among a heterogeneous population of athletes (27), suggesting that other neuropsychological functions may require a longer recovery time. McAllister et al. (22) used neuropsychological tests and functional magnetic resonance imaging to examine mild traumatic brain injury an average of 26.9 d postinjury. They found that neuropsychological tests of response speed and letter fluency displayed small group differences between the injured subjects and their controls. However, the brain activation induced by a working memory task was significantly altered in the concussed subjects compared with their uninjured controls. Working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning (22). Unlike controls, the concussed subjects did not increase brain activation in response to increased working memory load, suggesting that they recruited most of their available resources at a lower load. This finding implies that working memory may take several weeks to recover following concussion.

Tests of simple motor function, such as reaction time, have been shown to have a longer recovery time following concussion than commonly used neuropsychological tests of cognitive function. In an examination of reaction time following concussion, Makdissi et al. (21) found that athletes

Address for correspondence: Li-Shan Chou, Ph.D., Department of Human Physiology, 1240 University of Oregon, Eugene, OR 97403; E-mail: chou@ uoregon.edu.
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had not recovered to a preseason baseline measurement by 14 d postinjury, whereas Bleiberg et al. (4) reported that recovery of reaction time in boxers had not returned to baseline by 10 d following injury. In an attempt to determine the effects of repeated subconcussive blows in soccer, it was discovered that individuals with a long history of participation displayed a pattern of slowing on tests of motor speed and reaction time (9). However, the results were not correlated with a history of concussions. These studies suggest that reaction time may be impaired for 14 d or longer following concussion or repeated subconcussive impacts.

To assess some of the more complex reactive components of motor function, static postural control tests have been conducted following concussion. These studies have determined that static postural control returns to baseline within 3 to 5 d following concussion, even when the subjects have not returned to normal on other measures such as symptom score and cognitive function (11,12,21). However, Peterson et al. (27), using a similar testing protocol, found that composite static postural control had not returned to baseline 10 d after injury. They attributed this difference to the longer testing timeline. Because the concussed individuals were not tested beyond day 10, no extrapolation was made regarding the actual extent of recovery time. The disagreement among these studies suggests that the duration of postconcussion static postural control deficit is variable, and a longer recovery time may be associated with more complex tasks.

Few data are available on the performance of dynamic motor tasks following concussion. However, such information is important in recommending when a person should return to unrestricted preinjury activities. Johnson et al. (16) found that the use of an instrumented agility task was not sensitive enough to detect functional changes following concussion. Prior studies on gait stability have focused on the risk of falling for the elderly. Chou et al. (7) reported that mediolateral motion of the center of mass (COM) distinguishes healthy elderly individuals from those with balance disorders. Other studies have also measured differences in COM motion during gait between brain-injured subjects and uninjured controls (2,8). The findings from these studies supported the contention that COM motion during gait is a sensitive measure of gait stability. However, the subjects from these studies had suffered head injuries that were severe and had continuing complaints of "dizziness and unsteadiness" at the time of testing. In a study of acute mild concussions (grade II) (1), it was found that within 48 h of injury, mediolateral COM sway significantly increased when subjects engaged in simple mental activities (dual-tasking) while walking compared with undisturbed gait (26). This effect was not shown among a group of matched control subjects. However, no information is currently available on how long this pattern of altered stability continues.

The dual-task, or divided attention, protocol has not been fully explored in the existing concussion literature. Lajoie et al. (18) observed that attentional demands appeared to increase as the physical requirements of the task increased. Reaction time to an auditory stimulus during sitting was faster than while standing, which was faster than while walking. They also reported that the single-stance phase of walking resulted in slower reaction times than the more stable double-support phase. Other studies found that divided attention reduced successful obstacle avoidance while walking (28) and that mean digit recall was reduced while walking compared with quiet standing (10). However, these studies were performed with healthy adults without a history of brain injury or disease, and little is known to date about the effect of divided attention on concussed individuals.

Whereas results from tasks such as static postural control and neuropsychological testing show postconcussion recovery times of up to 14 d, more complex dynamic motor tasks such as walking under varying conditions may possibly require a longer recovery period. Therefore, the purpose of this study was to examine the recovery pattern of a dynamic motor task under varying conditions of attention over the course of 28 d.

## METHODS

Thirty college-aged volunteers served as subjects for this study. The subject groups consisted of 15 college-aged men and women who had sustained a concussion (CONC) and 15 uninjured controls (NORM). Each CONC subject was matched to a NORM subject by gender, age, height, weight, and physical activity profile. All participants were involved in intercollegiate, club, or intramural sports, or recreational activities. All CONC had sustained a grade 2 concussion as defined by the American Academy of Neurology Practice Parameter (1) Table 1). All CONC subjects in the study had sustained a head injury resulting in one or more postconcussion symptoms including, but not limited to, headache, dizziness, lack of awareness, confusion, amnesia, and poor concentration. These symptoms lasted for more than 15 min, and no subject lost consciousness due to the injury. All symptoms were self-reported and recorded at each testing session. CONC participants were initially identified by certified athletic trainers and attending medical doctors in the university intercollegiate athletic program and the student health center and were referred for testing as soon as possible following the injury. None of the NORM subjects had a history of neurological diseases, visual impairment not correctable with lenses, musculoskeletal impairments, or persistent symptoms of vertigo, lightheadedness, unsteadiness, falling, or a history of concussion

TABLE 1. American Academy of Neurology practice parameter (1997).

| Grade | Description |
|---|---|
| 1 | Transient confusion<br>No loss of consciousness<br>Concussion symptoms or mental status changes resolve within 15 min |
| 2 | Transient confusion<br>No loss of consciousness<br>Concussion symptoms or mental status changes lasting > 15 min |
| 3 | Loss of consciousness either brief or prolonged |

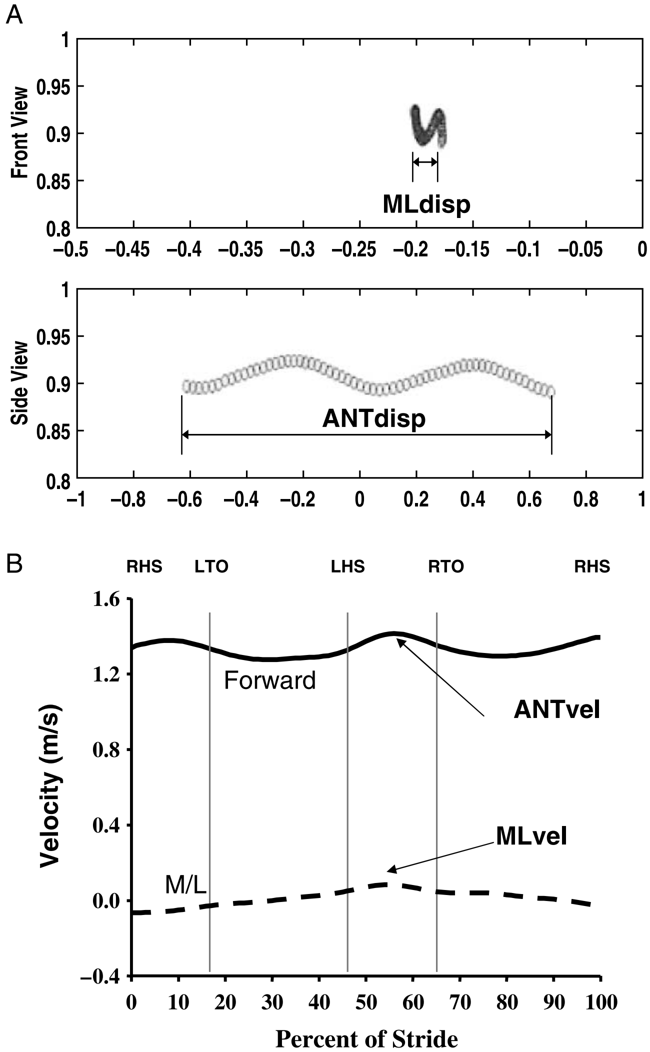


**FIGURE 1—A. Front and side views of the whole-body COM during unobstructed level walking. B. Typical time histories of the anterior and mediolateral velocities of the whole-body COM during unobstructed level walking. A positive value indicates a forward or leftward velocity. RHS, right heel-strike; RTO, right toe-off; LHS, left heel-strike; LTO, left toe-off.**

within the past year. The experimental protocol was approved by the institutional review board of the university. The experimental procedures were explained to all subjects prior to testing, and verbal and written consents were obtained.

All CONC subjects were tested within 48 h of injury (day 2) and again at 5, 14, and 28 d postinjury. The NORM participants were tested at the same time intervals. Administration of tests within 48 h and 5 d is consistent with previous research (4,11,12,20,23). Recent studies suggest that 5–7 d may be sufficient for recovery for many individuals (23). However, in an examination of a simple motor function following concussion (reaction time), Makdissi et al. (21) found that athletes had not recovered to a preseason baseline measurement by 14 d postinjury. In addition, Chou et al. (8) found that control of the COM during gait was impaired for all levels of severity for several weeks following injury. This suggests that motor function may require ≥ 4 wk to recover postinjury. Therefore, subjects were tested at four time periods: within 48 h and 5, 14, and 28 d following injury.

The gait protocol was the same for each testing day. It consisted of level walking with no obstructions and was performed by each subject under two conditions: 1) with undivided attention (single task), and 2) while simultaneously completing simple mental tasks (dual task). These tasks consisted of spelling five-letter words in reverse, subtraction by sevens, and reciting the months of the year in reverse order (3). These tasks are frequently used in mental status examinations to assess attention and concentration. Each type of dual task was completed by every subject, with the order of individual tasks rotated across trials. All dual-task walking trials were conducted in the same manner, with verbal instructions given immediately prior to the command to begin walking. The subjects were not given instructions on which task (walking or mental) they were to focus their attention. Each testing session began with five trials of single-task walking followed by four to five trials of the dual-task condition. The participants were instructed to walk down a 10-m walkway at a comfortable, self-selected walking speed. To avoid any shoe-type differences, all subjects were tested while barefoot.

To assess gait variables, a set of 25 reflective markers were placed on bony landmarks of the participant. Fifteen markers were used to define the foot, leg, and thigh segments of both lower extremities. These markers were placed on the following anatomic landmarks: between the second and third metatarsals (dorsal), the posterior calcaneus, the lateral malleoli, the lateral femoral epicondyles, the lateral distal tibia and thigh, both anterior superior iliac spines, and the sacrum. Nine markers defined the head, arm, and trunk segments. These markers were placed on the wrists, lateral epicondyles of the humerus, acromioclavicular joints of the shoulder, just anterior to each ear, and the top of the head. One additional marker was placed on the right scapula for tracking purposes. A six-camera ExpertVision™ HIRES system (Motion Analysis Corporation, Santa Rosa, CA) was used to capture and reconstruct the three-dimensional trajectory of the surface markers. Three-dimensional marker trajectory data were collected at 60 Hz and low-pass filtered using a fourth-order Butterworth filter with the cutoff frequency set at 8 Hz. Virtual marker positions were estimated using EVa software (Version 6.0, Motion Analysis Corp.) to represent internal segment endpoints from the external markers and the relative positions of the segmental COM. External markers and estimated joint centers were used to calculate the three-dimensional motion for individual body segments and locations of segmental COM. Anthropometric reference data were adapted from Winter (29) for both age groups and genders. Whole-body COM position data (Fig. 1) were calculated as the weighted sum of each body segment, with 13 segments representing the whole body (head–neck, trunk, pelvis, upper and lower arms, upper and lower legs, feet). Velocities and accelerations of the COM were estimated using the generalized cross-validated spline algorithm (30). The motion analysis system was calibrated

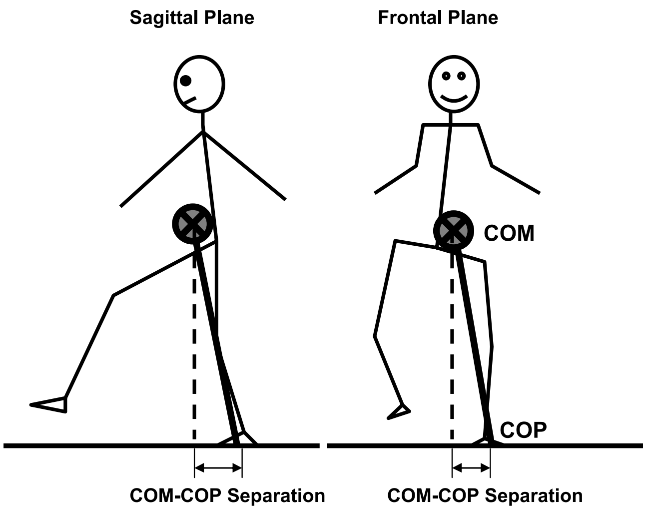


**FIGURE 2—Schematic representation of the inverted pendulum model defined by the whole-body center of mass (COM) and center of pressure (COP) in sagittal and frontal planes. *Arrows* represent COM−COP separation in anterior and mediolateral directions.**

before each session (volume = 4 m long, 1.5 m wide, 2 m high). To compute the center of pressure (COP), ground reaction forces were collected by two force plates (Advanced Mechanical Technology, Inc., Watertown, MA) positioned in series along the gait path and sampled at a frequency of 960 Hz. Motion data were analyzed from heel strike of the limb as it struck the first force plate to the next heel strike of that same limb. OrthoTrak 4.0 (Motion Analysis Corporation) was used in the calculation of temporal-distance parameters. Data were averaged across trials for each task condition (single and dual).

Variables were examined in one gait cycle, operationally defined as the heel strike of the first limb on the force plate to the next heel strike of that same limb. Temporal-distance parameters included gait velocity, stride length, stride time, and step width. The COM displacement was monitored in the anterior (ANTdisp) and mediolateral (MLdisp) directions (Figs. 1 and 2). Other variables included peak maximum instantaneous linear velocities of the COM in the anterior (ANTvel) and mediolateral (MLvel) directions (Fig. 1B), and maximum separation between the COM and COP of the supporting foot in the anterior (COM/COP − ANTmax) and mediolateral (COM/COP − MLmax) directions (Fig. 2). The effects of group (CONC vs NORM) and task (single vs dual) over the testing days (2, 5, 14, and 28) on these variables were examined. Repeated-measures (2 × 4 × 2) mixed-design ANOVA with Bonferroni corrections for multiple comparisons and Tukey *post hoc* tests, where appropriate, were computed to determine whether differences ($P < 0.05$) existed for each dependent variable between groups and task and within day.

## RESULTS

No significant differences in anthropometric data were observed between the two subject groups (dependent-samples *t*-test: age, $P = 0.83$; height, $P = 0.89$; weight, $P = 0.86$; Table 2). The percentage of correct responses for the two subject groups were not significantly different on any day for the cognitive tasks (CONC = 88.3%; NORM = 90.3%; $P = 0.17$). Self-reported symptoms varied across time and resolved between the second and third testing sessions.

### Temporal-Distance Gait Variables

**Gait velocity.** Day × group ($P < 0.012$) and day × task ($P < 0.001$) interactions were found for gait velocity. In both single- and dual-task conditions, the CONC walked significantly slower than the NORM within the first 48 h following injury (day 2); however, they increased their walking speeds by day 5 and approached NORM group values from days 5 to 28 (Fig. 3). Gait velocity was affected by type of task; however, the duration of this effect differed between groups. The CONC walked significantly faster in the single-task compared with the dual-task condition at every testing period (days 2–28), whereas this was true for the NORM only at the first two testing periods (days 2 and 5).

**Stride length.** Stride length was also found to have day × group ($P < 0.016$) and day × task interactions ($P < 0.005$). Similar to gait velocity, stride length was affected by type of task for both groups but at different testing periods. Stride length was significantly longer for the single task compared with the dual task for the CONC group on days 2 and 5 and for the NORM on days 2 and 28. For both tasks, the stride length for the NORM group was found to be significantly longer than the CONC for days 2 and 14 (Table 3).

**Stride time and step width.** No significant interactions were observed for stride time; however, significant main effects were found for day ($P < 0.001$) and task ($P < 0.000$). The single-task stride time was significantly shorter than the dual-task time for both groups. No significant main effects or interactions were found for step width (Table 3).

### COM Variables

**ANTdisp.** A task × day interaction was found for anterior displacement of the COM ($P < 0.005$) with the NORM group displaying significantly less displacement in the dual-task compared with the single-task condition for day 2 only while this same effect was extended to day 5 for the CONC (Table 4).

**ANTvel.** A task × day interaction was also revealed for peak anterior instantaneous velocity of the COM ($P < 0.001$), with the single-task condition resulting significantly faster anterior velocity than the dual-task condition

TABLE 2. Subject demographics, group mean ± SD.

| Characteristic | CONC | NORM | *t*-test |
|---|---|---|---|
| Age (yr) | 20.60 ± 1.55 | 20.60 ± 1.80 | $P = 0.83$ |
| Height (m) | 1.80 ± 0.13 | 1.79 ± 0.12 | $P = 0.89$ |
| Weight (kg) | 91.00 ± 28.67 | 89.03 ± 30.03 | $P = 0.86$ |
| Gender (men/women) | 9/6 | 9/6 | |
| Mean time from injury to testing (h) | 38.93 ± 11.35 | NA | |

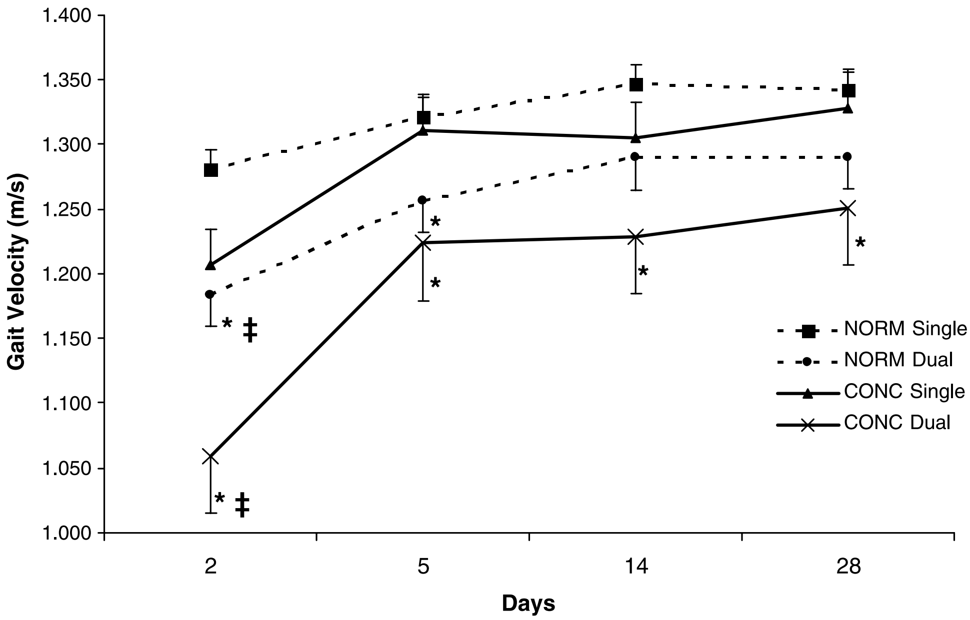


**FIGURE 3—Group means and SE for NORM and CONC groups for gait velocity in single- and dual-task conditions for each test day. * Dual < single; ‡ CONC < NORM.**

in both groups. This was detected solely on day 2 for the NORM but on all testing days for the CONC (Table 4).

**Mediolateral displacement (MLdisp).** A three-way day × task × group interaction was observed for COM mediolateral sway ($P < 0.013$). The CONC group was found to sway significantly more in the dual-task than the single-task condition on days 2 and 28, whereas the NORM were not affected by task at any testing period (Fig. 4). During the dual-task condition, CONC swayed significantly more than the NORM on days 2, 5, and 28. The single-task condition produced no between-group differences for mediolateral sway (Fig. 4).

**MLvel.** Task was found to have a significant effect on MLvel ($P < 0.000$) with the dual-task condition generating faster velocities than the single-task condition for both groups (Table 5).

**COM/COP separation.** A day × group interaction ($P < 0.005$) was observed for the maximum separation distance between the COM and COP in the anterior direction (COM/COP − ANTmax). The NORM exhibited a significantly larger separation distance than the CONC for the single-task condition on days 2 and for the dual-task condition on days 2, 14, and 28 (Fig. 5). There were no significant group or task condition effects at any testing day for the maximum separation distance between the COM and COP in the frontal plane (COM/COP − MLmax; Table 5).

## DISCUSSION

Although the CONC group did not consistently exhibit typical recovery patterns, several aspects of gait stability were observed to be compromised in this group at 4 wk after injury. Individuals in this group tended to adopt a conservative gait strategy in that they walked slower and had less separation between the COM and COP than NORM. In addition, concussed individuals swayed more in the frontal plane than their matched controls. This was especially evident when attention was divided from the primary motor task.

**Temporal-distance gait variables.** Although no longitudinal study to date has examined temporal-distance parameters after mild concussion, data are available on these variables immediately postinjury and after months of recovery from more severe brain injuries. Parker et al. (26)

TABLE 3. Means ± SD of the stride length, stride time, and step width for NORM and CONC groups in single- and dual-task conditions for each test day.

| | | D 2 | | D 5 | | D 14 | | D 28 | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | Group | Single | Dual | Single | Dual | Single | Dual | Single | Dual |
| Stride length (m) | NORM | 1.384 ± 0.079 | 1.3229 ± 0.082[a] | 1.412 ± 0.088 | 1.379 ± 0.087 | 1.438 ± 0.076 | 1.407 ± 0.086 | 1.446 ± 0.080 | 1.400 ± 0.103[a] |
| | CONC | 1.326 ± 0.086[b] | 1.224 ± 0.115[a,b] | 1.403 ± 0.110 | 1.342 ± 0.114[a] | 1.391† ± 0.086 | 1.350† ± 0.098 | 1.406 ± 0.095 | 1.372 ± 0.103 |
| Stride time (s) | NORM | 1.088 ± 0.083 | 1.129 ± 0.086[c] | 1.075 ± 0.076 | 1.105 ± 0.089[c] | 1.074 ± 0.084 | 1.099 ± 0.088[c] | 1.082 ± 0.076 | 1.089 ± 0.072 |
| | CONC | 1.112 ± 0.126 | 1.171 ± 0.120[c] | 1.073 ± 0.068 | 1.101 ± 0.087[c] | 1.068 ± 0.068 | 1.104 ± 0.086[c] | 1.062 ± 0.074 | 1.103 ± 0.085[c] |
| Step width (m) | NORM | 0.114 ± 0.035 | 0.121 ± 0.033 | 0.114 ± 0.032 | 0.115 ± 0.036 | 0.117 ± 0.036 | 0.120 ± 0031 | 0.117 ± 0.031 | 0.117 ± 0.031 |
| | CONC | 0.125 ± 0.062 | 0.125 ± 0.058 | 0.127 ± 0.040 | 0.122 ± 0.048 | 0.118 ± 0.042 | 0.117 ± 0.047 | 0.117 ± 0.047 | 0.120 ± 0.045 |

[a] Single > dual.
[b] CONC < NORM.
[c] Single < dual.

TABLE 4. Means ± SD of the anterior displacement and peak anterior velocity of the COM for NORM and CONC groups in single-task and dual-task conditions for each test day.

| | | D 2 | | D 5 | | D 14 | | D 28 | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | Group | Single | Dual | Single | Dual | Single | Dual | Single | Dual |
| ANTdisp (M) | NORM | 1.389 ± 0.080 | 1.343 ± 0.078[a] | 1.416 ± 0.086 | 1.392 ± 0.091 | 1.445 ± 0.087 | 1.421 ± 0.087 | 1.438 ± 0.085 | 1.420 ± 0.091 |
| | CONC | 1.326 ± 0.087 | 1.259 ± 0.117[a] | 1.406 ± 0.102 | 1.329 ± 0.116[a] | 1.394 ± 0.069 | 1.358 ± 0.100 | 1.396 ± 0.093 | 1.371 ± 0.119 |
| ANTvel ($m \cdot s^{-1}$) | NORM | 1.404 ± 0.149 | 1.324 ± 0.134[a] | 1.447 ± 0.121 | 1.402 ± 0.145[a] | 1.482 ± 0.147 | 1.444 ± 0.158 | 1.472 ± 0.138 | 1.441 ± 0.144 |
| | CONC | 1.324 ± 0.129 | 1.202 ± 0.135[a] | 1.437 ± 0.121 | 1.347 ± 0.120[a] | 1.424 ± 0.102 | 1.355 ± 0.112[a] | 1.444 ± 0.117 | 1.371 ± 0.144[a] |

[a] Single > dual.

examined the acute effects of concussion on a dynamic motor task. Gait stability was found to be compromised within the first 2 d of injury, as indicated by decreased gait velocity and stride length when attention was divided. In the present study, the effect of divided attention on the CONC was shown to continue for up to 14 d for stride length and to 28 d postinjury for gait velocity. In contrast, the NORM appeared to accommodate to the dual task by day 5. Other research has examined the lasting effects of severe brain injury on dynamic stability. In individuals complaining of "unsteadiness" many months after severe concussion, gait velocity and stride length were found to be significantly diminished (2). Whereas the concussions in the present study were classified as mild and the time since injury was shorter than for subjects reported by Basford et al. (2), gait velocity and stride length were nonetheless similarly decreased, suggesting that common effects on these variables may be present in mild and severe brain injury.

**COM variables.** Sagittal plane displacement and peak instantaneous anterior velocity of the COM tended to mirror the differences in stride length and gait velocity, respectively. Significant task differences in stride length and forward displacement of the COM resolved by day 14 in the CONC group, whereas anterior velocity, similar to gait velocity, was significantly less when attention was divided at all testing periods through day 28 postinjury (Tables 3 and 4). However, the relationship of the COM to the base of support in the anterior direction continued to be significantly smaller for the concussed subjects at day 28. These differences suggest that concussed individuals tend to adopt a conservative strategy for maintaining gait stability while walking, especially with divided attention. One possible explanation for this is the concept of a "feasible stability region," presented by Pai and Patton (25) and defined as the range of velocity of the COM and its distance from the base of support within which dynamic stability may be maintained. A reduction in the instantaneous forward velocity or distance that the COM is allowed to move in reference to the base of support may represent a decrease in this conceptual feasible stability region. In the present study, the findings that the concussed subjects had a lower anterior velocity and COM displacement during the dual task suggest a conservative adjustment in their control of the COM motion, thereby reflecting a compromised ability in balance control. Whereas the NORM were challenged by the dual-task scenario initially, they accommodated by day 5, as no significant between task differences were found after this time period. It is possible that such an accommodation was due to practice effects from the number of trials performed by the subjects. However, the CONC group was not able to accommodate the demands of the dual task and continued to show significant between-task and between-group differences on several variables even at day 28.

It has been shown that participants with mild traumatic brain injury demonstrated impaired postural stability for

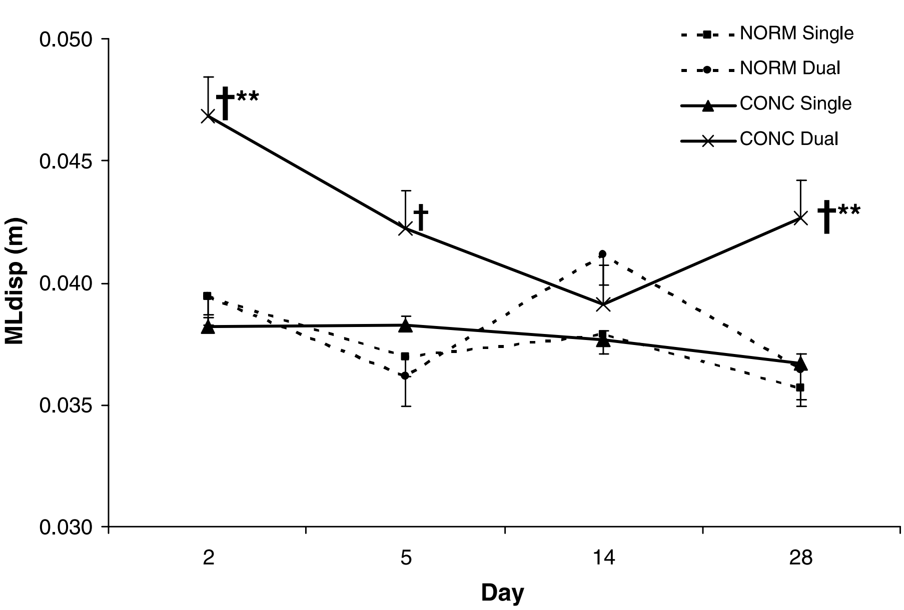


**FIGURE 4—Group means and SE for NORM and CONC groups for center of mass mediolateral motion in single-task and dual-task conditions for each test day. ** Dual> single; † CONC > NORM.**

TABLE 5. Mean ± SD of the peak mediolateral velocity of the COM and maximum separation distance between COM and COP for NORM and CONC groups in single-task and dual-task conditions for each test day.

| Variable | Group | Day 2 | | Day 5 | | Day 14 | | Day 28 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Single | Dual | Single | Dual | Single | Dual | Single | Dual |
| MLvel ($m \cdot s^{-1}$) | NORM | 0.133 ± 0.025 | 0.147 ± 0.024[a] | 0.137 ± 0.031 | 0.159 ± 0.068[a] | 0.138 ± 0.031 | 0.147 ± 0.029 | 0.135 ± 0.032 | 0.138 ± 0.033 |
| | CONC | 0.135 ± 0.046 | 0.148 ± 0.039[a] | 0.135 ± 0.041 | 0.150 ± 0.047[a] | 0.137 ± 0.035 | 0.140 ± 0.043 | 0.134 ± 0.038 | 0.151 ± 0.042[a] |
| COM/COP | NORM | 0.081 ± 0.022 | 0.081 ± 0.025 | 0.082 ± 0.023 | 0.081 ± 0.021 | 0.090 ± 0.030 | 0.089 ± 0.022 | 0.093 ± 0.035 | 0.097 ± 0.039 |
| MLmax (m) | CONC | 0.082 ± 0.031 | 0.080 ± 0.027 | 0.086 ± 0.034 | 0.086 ± 0.027 | 0.086 ± 0.028 | 0.087 ± 0.035 | 0.080 ± 0.031 | 0.078 ± 0.027 |

[a] Single < dual.

3–5 d following injury (11,12,23). Guskiewicz et al. (12) reported no relationship between symptoms, performance on tests of cognitive function, and static postural stability. The data suggested that recovery of motor function, as demonstrated by static postural control following mild traumatic brain injury, might be independent of cognitive recovery, and that a longer recovery time may be associated with more complex tasks. In the current study, the concussion group's mediolateral sway was significantly affected in the divided-attention, dual-task condition, when compared with NORM, whereas the single-task condition resulted in no between-group differences. However, the added demands of the task increased sway and sway velocity without an associated increase in step width, indicating that the additional task may have challenged their stability. It is interesting to note that dual-task mediolateral COM sway of the CONC was significantly affected on the first two testing days (2 and 5) in comparison with controls and then tended to normalize by day 14. However, the CONC sway values increased again at day 28 to 20% greater than that of the NORM. One possible explanation for this finding may be related to effects of the injured subjects' return to activity. All concussion subjects in the current protocol had returned to their preinjury activities by day 14. However, they had not normalized on measures of COM motion by this time, suggesting that they may not have been sufficiently recovered. It is possible that mediolateral sway might be particularly sensitive to changes in gait stability due to the return to activity. Basford and colleagues (2) found mediolateral sway to be a sensitive measure of dynamic stability following concussion without the presence of definitive clinical neuromuscular measures.

It is known that exertion can increase signs and symptoms of concussion during the period of recovery (20). It has recently been reported that the relative risk for reinjury for those with a history of concussion is almost six times greater than those with no history of concussion (31). In addition, Guskiewicz and colleagues (13) found that 91.7% of repeat concussions occurred within 10 d of the initial injury. The findings from these studies suggest potential brain vulnerability in the weeks following concussion. Whereas no subjects from the current study sustained a subsequent brain injury during their testing period, the measures on day 28 may have been influenced by enhanced brain susceptibility to the effect of brain injury resulting from the return to physical activity (20).

The dual-task protocol has been often used in the study of attention and capacity interference (17,20). According to Weerdesteyn et al. (28), the total available capacity for attention and processing information is limited, and when this capacity is exceeded by the undertaking of concurrent tasks, performance on one of these tasks will decline. It has

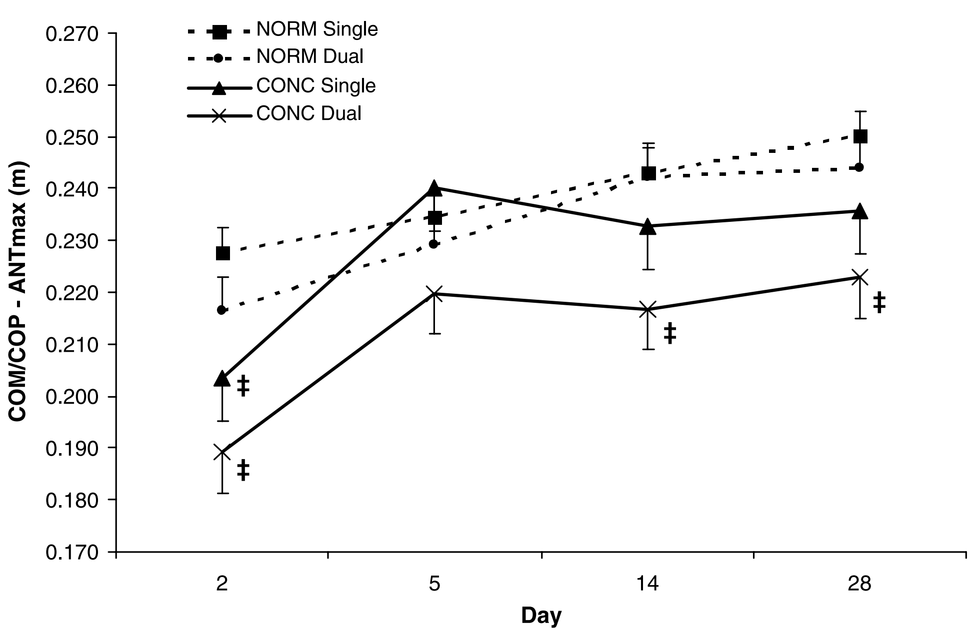


**FIGURE 5—Group means and SE for NORM and CONC groups for the maximum separation distance of the center of mass and center of pressure in the anterior direction for single- and dual-task conditions for each test day. ‡ CONC < NORM.**

also been hypothesized that a mild brain injury may diminish this already limited attention capacity (10). The results of the present study support this hypothesis. The mediolateral sway of the NORM in the present study was not significantly affected by the inclusion of the concurrent secondary task. In contrast, the CONC were able to maintain their mediolateral stability when attention was not divided but were unable to preserve their stability and swayed more and faster compared with uninjured controls in the dual-task condition. The dual task provided a gait stability challenge to which the CONC were unable to adequately respond. A limitation is that the NORM group was not tested for any concussion-like symptoms that may be present in otherwise healthy individuals. However, the NORM data for COM displacement and gait temporal-distance measures are consistent with previously reported studies on healthy young adults (15,26).

The significant between-group and between-task differences found in this study can only be speculated on at this time. A large majority of the between-group differences occurred during the dual-task condition. In addition, the concussed group was affected to a greater extent by the dual task than the NORM. This suggests that the increased demands of attention and concentration can affect gait stability, especially following a brain injury, and that such effects may be evident for up to 28 d postconcussion. If these differences are detectable in a controlled laboratory environment, it is plausible that concussed patients may have greater difficulty maintaining stability when engaged in athletic competition, or a complex work environment, where the integration of multiple inputs is required.

Several testing protocols have been developed in an attempt to determine the most appropriate time to return concussed individuals to their preinjury activities. The current position statement of the National Athletic Trainers Association recommends an incremental return to physical activity after all symptoms have resolved and clinical testing is returned to normal for that player (14). The statement stresses that no one test is appropriate for determining recovery and suggests neuropsychological and static postural stability testing is needed to provide objective information regarding recovery. In a recent report (24), it was suggested that neuropsychological testing should not be the sole basis of postconcussion management decisions and that balance testing may offer additional information and may be used as part of an overall concussion management strategy. It was noted further that postconcussion activities requiring concentration and attention may exacerbate symptoms and delay recovery, and it was suggested that return-to-play strategy after concussion include a stepwise process whereby the patient is regularly monitored before increasing activity levels (24). To the extent that gait stability testing, under varying conditions of concentration and attention, can be incorporated into baseline and postconcussion monitoring, better information may be made available regarding a patient's readiness to return to preinjury activity.

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