

Balance Performance With a Cognitive Task: A Continuation of the Dual-Task Testing Paradigm

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Context: To ensure that concussed athletes return to play safely, we need better methods of measuring concussion severity and monitoring concussion resolution.

Objective: To develop a dual-task model that assesses postural stability and cognitive processing in concussed athletes.

Design: Repeated measures study.

Setting: University laboratory.

Patients or Other Participants: Twenty healthy, college-aged students (10 men, 10 women; age = 20 ± 1.86 years, height = 173 ± 4.10 cm, mass = 71.83 ± 35.77 kg).

Intervention(s): Participants were tested individually in 2 sessions separated by 2 days. In one session, a balance task and a cognitive task were performed separately. In the other session, the balance and cognitive tasks were performed concurrently. The balance task consisted of 6 conditions of the Sensory Organization Test performed on the NeuroCom Smart Balance Master. The cognitive task consisted of an auditory switch task (3 trials per condition, 60 seconds per trial).

Main Outcome Measure(s): For the balance test, scores for each Sensory Organization Test condition; the visual, vestibular, somatosensory, and visual-conflict subscores; and the composite balance score were calculated. For the cognitive task, response time and accuracy were measured.

Results: Balance improved during 2 dual-task conditions: fixed support and fixed visual reference ($t_{18} = -2.34, P < .05$) and fixed support and sway visual reference ($t_{18} = -2.72, P = .014$). Participants' response times were longer ($F_{1,18} = 67.77, P < .001, \eta^2 = 0.79$) and choice errors were more numerous under dual-task conditions than under single-task conditions ($F_{1,18} = 5.58, P = .03, \eta^2 = 0.24$). However, differences were observed only during category-switch trials.

Conclusions: Balance was either maintained or improved under dual-task conditions. Thus, postural control took priority over cognitive processing when the tasks were performed concurrently. Furthermore, dual-task conditions can isolate specific mental processes that may be useful for evaluating concussed individuals.

Key Words: posture, stability, executive function, response time, concussions, mild traumatic brain injuries

Key Points

- Under a dual-task condition (balance task plus cognitive task), postural control appeared to take priority over cognitive processing.
- Measuring cognitive processes involved in performing complex, computer-based tests during the simultaneous performance of a balance task may provide a sensitive means of detecting subtle cognitive changes in patients with concussions.

McCrea et al¹ reported in 2002 that 90% of the more than 2 000 000 traumatic brain injuries that occurred annually in the United States were classified as concussions. In 2006, Langlois et al² estimated that approximately 1.6 to 3.8 million sport-related concussions occur annually.²

This alarming rate of sport-related concussions warrants improved methods of measuring concussion severity and resolution in order to determine appropriate time frames for safe return to play. Clinicians use a variety of tools, including self-reporting of symptoms, neuropsychological testing, and postural-stability assessment to track concussion resolution and ultimately identify a time frame for returning the athlete to play. Although a number of tests have been linked to traumatic brain injury, none has been shown to be the sole indicator of concussion occurrence and/or resolution.³

Several experiments have been conducted in which participants perform a balance task while simultaneously engaging in a mentally challenging cognitive task. Hunter and Hoffman⁴ had participants perform visual and auditory cognitive tasks while in tandem stance on a force plate to measure postural sway. Compared with the single-task condition, decreased sway velocity was observed during the dual-task condition, which resulted in increased medial-lateral and anterior-posterior center-of-pressure (COP) sway. The authors⁴ hypothesized that dual-task conditions decreased muscle activation, allowing for less COP movement, and suggested that the single-task balance conditions increased attention allotted to balance, eliciting increased muscle tension and resulting in increased COP medial-lateral and anterior-posterior sway. Other research suggests that incorporating a visual task while balancing

decreases COP range and speed. Broglio et al⁵ evaluated the interrelation between balance perturbation and a visual cognitive-switch task designed to assess executive function (ie, planned, goal-directed behavior). Balance perturbations were elicited by the Smart Balance Master Sensory Organization Test (SOT) (NeuroCom International, Inc, Clackamas, OR). Participants performed 4 SOT conditions that incorporated only visual input. The balance protocol was performed separately or concurrently with a visual cognitive-switch task. Compared with single-task conditions, participants' SOT balance scores improved. Response times increased in a linear fashion across the 4 balance conditions, which were progressively more demanding. These results indicate that under dual-task conditions, balance control takes priority, with cognitive functions becoming more impaired as balance perturbation increases.⁵

Although some studies provide evidence that posture is maintained at the expense of cognitive functioning, other authors report the opposite. Barra et al⁶ used spatial and verbal tasks in conjunction with a balance task performed by young, healthy adults and reported an increase in falls during spatial-task performance. The authors concluded that cognitive performance was maintained at the expense of balance, but the use of a safety rail may have resulted in increased risk-taking behavior by participants. Researchers⁷ have shown decrements in balance during concurrent performance of a cognitive task conducted primarily in middle-aged to older-aged samples.

The purpose of our study was to investigate the dual-task method as a possible sport-related concussion-assessment tool. This study replicated and extended previous work⁵ by including both visual and nonvisual SOT conditions in the protocol, increasing the length of each trial to 60 seconds, and incorporating an auditory executive-function task. Our hypothesis was that sway would decrease, whereas cognitive performance, measured as response time and accuracy, would worsen.

METHODS

Participants

Twenty healthy, college-aged students recruited from exercise science classes participated in this study (10 men, 10 women; age = 20 ± 1.86 years, height = 173 ± 4.10 cm, mass = 71.83 ± 35.77 kg). Men and women were included in equal numbers to reduce any potential sex bias. Twenty participants were recruited to achieve a large effect size ($d = 0.75$), as suggested by prior research and power calculations.^{8,9} Volunteers were excluded if they had a history of concussion, English was not their primary language, or they were receiving treatment for a lower extremity injury.

Tests

Balance Test. Testing consisted of a modified SOT that comprised 6 conditions developed for balance assessment: fixed surface and fixed vision (fixed-fixed), fixed surface and absent vision (fixed-absent), fixed surface and sway-referenced vision (fixed-sway), sway-referenced surface and fixed vision (sway-fixed), sway-referenced surface and absent vision (sway-absent), and sway-referenced surface

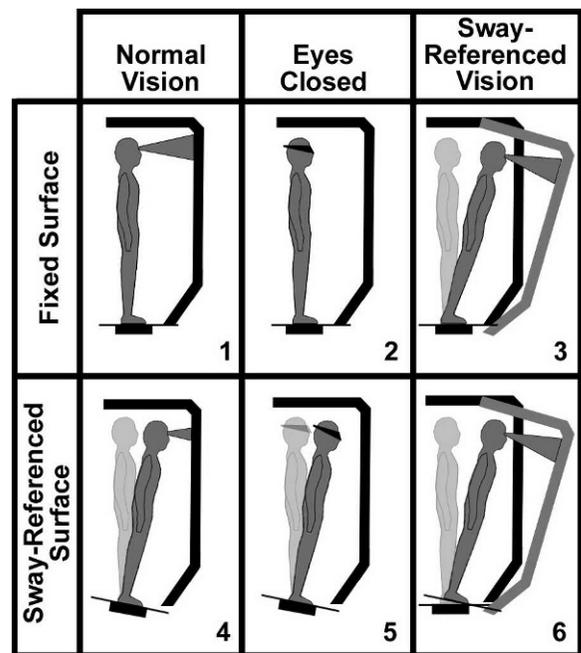


Figure 1. Six conditions of the Sensory Organization Test. Used by permission of NeuroCom International, Inc.

and sway-referenced vision (sway-sway) (Figure 1). The length of each trial was extended to 60 seconds (standard is 20 seconds). Sway gain was set at 1.0, matching sway referencing to the participant's sway as described in the *System Operator's Manual*.⁸ Each participant underwent each of the 6 conditions 3 times, for a total of 18 separate trials.¹⁰ Each trial lasted 60 seconds, and each volunteer was given a 15-second rest between trials. During those 15 seconds of rest, data calculation for the previously performed balance trial was completed. The 18 trials were randomized to minimize practice effects.

Cognitive Test. The cognitive task was an auditory switch test that involved the presentation of 40 computer-generated letters or numbers via a commercial software program (SuperLab version 2.01; Cedrus Corporation, San Pedro, CA) to a headphone. The letters consisted of 5 vowels (A, E, I, O, and U) and 5 randomly selected consonants (B, D, L, C, and J). The numbers consisted of 4 even numbers (2, 4, 6, and 8) and 4 odd numbers (1, 3, 5, and 7). Participants responded to each stimulus by pressing a key on a serial mouse (even number: left key, odd number: right key, vowel letter: left key, consonant letter: right key). Each key press was followed 100 milliseconds later by the presentation of the next stimulus. Letters or numbers were presented as 1 stimulus or 2 or 3 stimuli. The letter-number category discrimination switched after each series. The initial 4 trials of each test were considered practice and were not evaluated. The remaining 36 trials consisted of 24 nonswitch trials (ie, repetitive, within-category discriminations) and 12 switch trials (ie, a change in category discrimination), with an equal number of switches to even-odd and vowel-consonant conditions. Response times and response accuracy were recorded for each trial. The test terminated with a computer-generated command to stop. A set of 36 unique tests was developed in which the order of blocks of nonswitch and switch trials was randomized.

Each participant was trained to perform the auditory switch task in 5 phases. Initially, the task was described to the participant, who stood next to a computer station. He or she was directed to attend to a chart at eye level that described the correct stimulus-condition and mouse-key response pairings. Next, the volunteer donned a set of headphones, was instructed to hold the mouse in the right hand with both arms at the side, and was then asked to monitor a series of 15 letters and numbers stimuli presented every 500 milliseconds (adjusting the loudness of the stimuli to the preferred level via a volume-adjustment dial on the headphone cord). The participant was directed to listen to a series of 30 numbers and to discriminate between even and odd numbers with the appropriate mouse-key press. A series of 30 letters was presented and the participant was asked to discriminate between vowels and consonants with the appropriate key press. Finally, he or she was told that both letters and numbers were going to be presented and to respond as quickly and accurately as possible. Stimuli consisted of 120 letters or numbers, which were repeated in series lengths of 1, 2, or 3 and then switched from one category to the other. There were 80 nonswitch and 40 switch trials, with an equal number of switches to even-odd and vowel-consonant conditions.

Procedures

Participants read and signed a consent form approved by the institutional review board, which also approved the study, and completed a brief questionnaire of self-reported demographics. Testing consisted of 2 sessions separated by 48 to 72 hours, performed at the same time of day. During session 1, each participant was familiarized with the balance and cognitive protocol by completing truncated versions of the full tests. For the balance task, participants completed 10 seconds of 1 trial of all 6 conditions. For the cognitive task, participants completed shortened versions of both the nonswitch and switch tasks.

The balance test was conducted by trained researchers using the Smart Balance Master (NeuroCom) in concert with the Data Acquisition Toolkit (version 2.0; NeuroCom). The latter portion of the first session consisted of 1 of 2 scenarios: in the first, the cognitive and balance tasks were performed separately (single task); in the second, the cognitive and balance tasks were performed concurrently (dual task). The unused protocol, either single task or dual task, was used for the second testing session. Sessions 1 and 2 were counterbalanced across participants. The single-task and dual-task conditions were delivered by 1 and 2 investigators, respectively. For the single-task balance condition, volunteers were provided the same instructions as given in the practice session, that is, to respond to the cognitive stimuli as quickly and accurately as possible. After initiation of data collection, no verbal cues were given. Data were collected for the eighteen 60-second trials. After completion of the balance task, the participant was asked to step out of the device and prepare for the cognitive task. The dual-task session began with instructions. After confirming that the participant understood the procedure, testing began with a volume-adjustment trial and a 120-trial practice test, which was administered to the participant while he or she was standing next to the computer station. The participant was then instructed to

step on the platform and to perform the cognitive test while maintaining balance under 6 test conditions. Each balance and cognitive test began simultaneously. Each participant finished the cognitive test before completing the balance trial.

Data Analysis

Balance Assessment. The initial 5 and final 20 seconds were discarded from data analysis to limit extraneous and between-subjects variability associated with the beginning and completion of the dual-task protocol. Scores for each SOT condition; visual, vestibular, somatosensory, and visual-conflict subscores; and a composite balance score were calculated from data obtained during the remaining 35-second period in which dual-task conditions were in effect. Scores were derived as described in the *System Operator's Manual*.⁸ We used paired *t* tests to assess differences between scores obtained from the single-task and dual-task protocols for condition; visual, vestibular, somatosensory, and visual-conflict; and composite ratio scores. The data obtained from 1 male participant were excluded from analyses due to extreme SOT scores, which were below the normative data provided by NeuroCom for both the single-task and dual-task protocols. The exclusion of this participant did not affect the overall power of the study.¹¹

Cognitive Assessment. Cognitive test performance was assessed by evaluating each participant's response time (RT) and response accuracy to stimuli presented on trials immediately before a category switch (nonswitch trials) and to stimuli presented immediately after a category switch (switch trials). Participants' RTs and proportion of response errors were averaged over 3 successive tests performed under the single-task condition and 3 tests performed under each of the 6 dual-task conditions. The RT scores and response errors were analyzed separately via a within-subjects 2 (trial type: nonswitch, switch) \times 2 (test condition: single task, dual task) \times 6 (balance conditions) analysis of variance. All data were analyzed using SPSS (version 15.0; SPSS Inc, Chicago, IL). Sample size was estimated using a large effect size ($d = 0.80$) from previously related research.⁴

RESULTS

Balance Assessment

Differences in balance scores were noted between 2 of the 6 conditions. Scores were higher under during the dual-task fixed-fixed ($t_{18} = -2.35$, $P = .030$) and fixed-sway ($t_{18} = -2.72$, $P = .014$) conditions. Condition, subscore, and composite means and SDs for the 35-second assessment of balance during single-task and dual-task conditions are provided in the Table.

Cognitive Assessment

Response times were longer for switch trials than nonswitch trials under both single-task and dual-task conditions ($F_{1,18} = 67.77$, $P \leq .001$, $\eta^2 = 0.79$). An interaction was noted for response time between trial type (nonswitch versus switch) and test condition (single task versus dual task) ($F_{1,18} = 5.084$, $P = .037$, $\eta^2 = 0.22$). As

Table. Balance-Task Condition Scores, Subscores, and Composite Scores (Mean ± SD)^a

Balance Condition	Balance Test Only	Dual Task (Balance Test + Cognitive Test)
1 (fixed surface, fixed vision)	89.5 ± 6.0	91.6 ± 3.4 ^b
2 (fixed surface, absent vision)	86.0 ± 5.3	88.0 ± 3.2
3 (fixed surface, sway-referenced vision)	84.1 ± 9.5	89.7 ± 4.2 ^c
4 (sway-referenced surface, fixed vision)	85.2 ± 7.8	85.2 ± 5.4
5 (sway-referenced surface, absent vision)	72.7 ± 9.5	73.9 ± 7.4
6 (sway-referenced surface, sway-referenced vision)	71.5 ± 10.5	71.7 ± 7.0
Visual	95.0 ± 9.4	92.5 ± 4.5
Vestibular	81.0 ± 11.1	80.3 ± 7.8
Somatosensory	96.5 ± 8.4	95.7 ± 2.4
Visual conflict	99.4 ± 9.7	100.2 ± 5.1
Composite score	91.4 ± 5.7	93.2 ± 3.5

^a The range of possible scores is 0 to 100.

^b $P < .05$.

^c $P \leq .05$.

seen in Figure 2, RT during dual-task conditions was longer than during single-task conditions but only for switch trials. Analyses of response errors yielded main effects for trial type ($F_{1,18} = 5.58, P = .03, \eta^2 = 0.24$), which were qualified by a trial type \times test-condition interaction ($F_{1,18} = 8.35, P = .01, \eta^2 = 0.32$). As shown in Figure 3, participants made more errors during dual-task conditions but only on switch trials.

DISCUSSION

The purpose of our study was to investigate the effects of introducing visual and nonvisual conditions of the SOT in conjunction with an auditory cognitive task on balance and cognitive performance. Our results confirmed and extended the findings obtained by Broglio et al,⁵ which indicated that balance would be maintained at the expense of cognitive function with regard to both RT and errors.

Similar to prior researchers,^{4,5,7,12} we found that young adults' postural stability increased during the fixed-fixed and fixed-sway conditions and remained unchanged during the remainder of the balance conditions. With respect to the cognitive task, we observed a concomitant increase in RT and number of errors with increasing difficulty of the balance task.

A physiologic explanation of our findings is that cerebral processing during dual-task conditions apparently modifies how the central nervous system controls postural stability. Under normal conditions, balance is controlled via integration of sensory information provided by the visual, vestibular, and somatosensory systems.^{5,13} Input based on limb positioning is transmitted to the basal ganglia. This signal is integrated with planned actions developed in the premotor cortex and supplementary motor cortex in the cerebellum. The descending pathway continues via alpha motor neurons, which innervate skeletal muscle, allowing

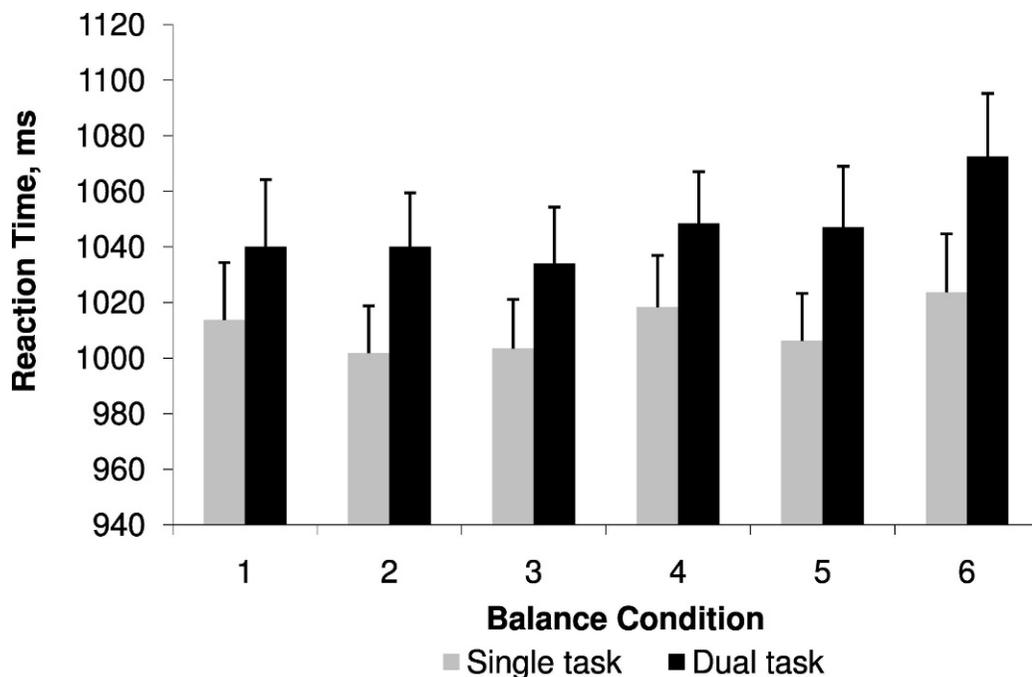


Figure 2. Reaction time for single-task and dual-task methods for 6 balance conditions: (1) fixed surface, fixed vision; (2) fixed surface, absent vision; (3) fixed surface, sway-referenced vision; (4) sway-referenced surface, fixed vision; (5) sway-referenced surface, absent vision; (6) sway-referenced surface, sway-referenced vision.

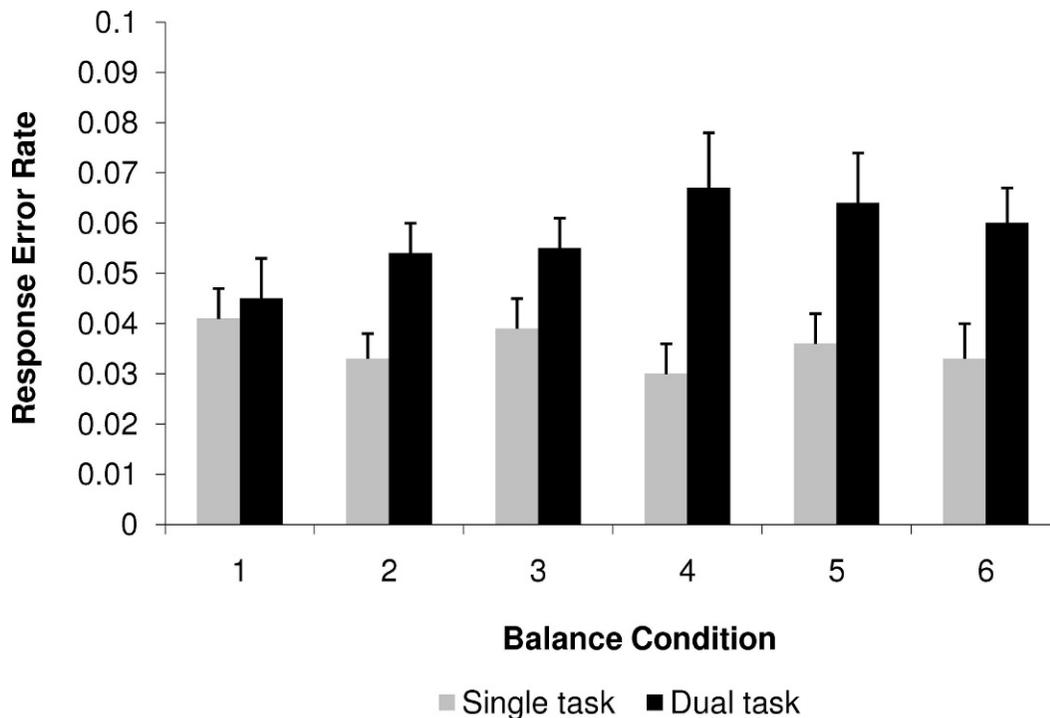


Figure 3. Errors in single-task and dual-task methods for 6 balance conditions: (1) fixed surface, fixed vision; (2) fixed surface, absent vision; (3) fixed surface, sway-referenced vision; (4) sway-referenced surface, fixed vision; (5) sway-referenced surface, absent vision; (6) sway-referenced surface, sway-referenced vision.

for regulation of balance.^{5,14,15} Typically, the visual and somatosensory inputs provide the majority of information to maintain postural stability.^{5,16}

Theoretically, our findings support the “posture-first” principle, which suggests that postural control is attentionally demanding, requiring increased allocation of attentional resources in accordance with the complexity of the postural task.^{17,18} Vuillerme and Nafati¹⁹ proposed 2 additional hypotheses to account for the maintenance of or increase in postural stability during the dual-task condition. The first suggests that increased attention during a reaction-timed cognitive task increases muscular stiffness and, subsequently, postural control.¹⁹ This hypothesis was supported by Hunter and Hoffman,⁴ who found decreased medial-lateral COP movement during a balance task in participants simultaneously performing a visual cognitive task.

The second hypothesis suggests that dual-task conditions facilitate control at the sensory-motor level.²⁰ Although attentionally demanding, postural stability occurs primarily via automatic processes in everyday life, making a single-task condition involving balance alone somewhat unnatural. The authors¹⁹ of a related study instructed a sample of young participants to focus on reducing their sway, compared with a control group who received no instruction during a quiet-standing task. The experimental group, which allocated additional attention to reduce postural sway, had increased COP and center-of-gravity amplitudes and frequencies. Incorporating a secondary cognitive task into the dual-task method may better represent everyday and sport situations and force individuals to allocate attention to the secondary cognitive task, leaving postural stability to the aforementioned automatic processes. Simply stated, deliberately controlling

posture is less efficient than controlling posture more automatically.²⁰

In contrast to our results, decrements in balance during a cognitive task have been reported by Peterson,²¹ who observed compromised balance in gymnasts performing a cognitive task. Although an important finding, the author’s use of a gross measure of balance (ie, walking on a balance beam) and cognitive task (serial sevens) did not allow subtle neurocognitive changes to be captured.^{5,21} These results are similar to those found in an older sample but opposite those found with a dual-task procedure in younger participants,⁷ who may possess greater ability to allocate attention. This ability may allow for muscle recruitment to maintain or improve postural stability with increased RT and error response rates during the dual-task protocol.

Our results are similar to those observed by Broglio et al.⁵ Participants’ performance on an auditory executive-function task that assessed speed and accuracy revealed longer RTs under dual-task than single-task conditions. Notably, longer RTs and an increase in response errors were observed during dual-task conditions for trials that followed a category switch (consonants to vowels or odd numbers to even numbers) versus for trials in which the stimulus category did not change. Thus, the perturbation of balance produced specific effects on cognitive functioning. In addition, the increased complexity of the cognitive task demanded executive processing to inhibit responses to one stimulus set and to respond to a different, now relevant, stimulus set. The process-specific effects of balance disruption on cognitive performance may help to explain, at least in part, the conflicting results obtained by previous researchers who used cognitive tasks that did not depict subtle cognitive changes.

One limitation of this investigation was our study of a healthy sample to determine whether cognitive deficits existed in a nonconcussed state and to evaluate the dual-tasking model as a possible concussion-assessment test. Further research regarding this dual-task condition protocol will include a concussed sample for comparison. Other limitations were participant motivation and frustration during completion of the cognitive task. Although participant compliance and effort were considered good, extraneous variables such as these can only be controlled to a certain extent.

Our results are particularly important for researchers interested in assessing the effects of concussion on athletes' cognitive function. Currently, no single evaluative test can determine the effect of a concussion on cognitive function and help clinicians make return-to-play decisions. The relationships among self-reported symptoms, computerized neuropsychological testing, and postural stability are well documented in the concussion literature. When delivered separately, these tools have demonstrated sensitivities of 68%, 79%, and 62%, respectively; when delivered together, greater than 90% sensitivity was achieved.²² Although these results are encouraging, not all clinicians have access to these tests due to financial constraints and limited availability of the professional support needed to properly evaluate such tests.

The results of the present study suggest that measures of cognitive processes involved in performing complex computer-based tests while concurrently performing a balance task may provide a sensitive means of detecting subtle cognitive changes in a young, healthy sample. Although our findings show promise as an alternate tool for concussion assessment, continued research on a concussed sample is imperative before we implement this protocol in the management of concussion. Like any tool used for clinical decision making, each evaluative tool suggested to help in the management of sport-related concussion must meet the stringent criteria of the laboratory setting before being used in clinical practice.^{9,23,24} Our methods may be more academic and laboratory based, but the results provide meaningful contributions to aid in the development of a more clinically based tool. A novel tool that incorporates both a motor and a cognitive task to detect deficiencies associated with sport-related concussion may prove to be both time- and cost-effective for the clinician.

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