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Postural Stability Under Dual-Task Conditions: Development of a Post-Concussion Assessment for Lower-Extremity Injury Risk

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Context: Concussions are consequence of sports participation. Recent reports indicate there is an increased risk of lower-extremity musculoskeletal injury when returning to sport after concussion suggesting that achieving "normal" balance may not fully indicate the athlete is ready for competition. The increased risk of injury may indicate the need to refine a screening tool for clearance. ***Objective:*** Assess the between-session reliability and the effects of adding a cognitive task to static and dynamic postural stability testing in a healthy population. ***Setting:*** Clinical laboratory. ***Participants:*** Twelve healthy subjects (6 women; age 22.3 [2.9] y, height 174.4 [7.5] cm, weight 70.1 [12.7] kg) participated in this study. ***Design:*** Subjects underwent static and dynamic postural stability testing with and without the addition of a cognitive task (Stroop test). Test battery was repeated 10 days later. Dynamic postural stability testing consisted of a forward jump over a hurdle with a 1-legged landing. A stability index was calculated. Static postural stability was also assessed with and without the cognitive task during single-leg balance. Variability of each ground reaction force component was averaged. ***Main Outcome Measures:*** Interclass correlation coefficients ($ICC_{2,1}$) were computed to determine the reliability. Standard error of measure, mean standard error, mean detectable change, and 95% confidence interval were all calculated. ***Results:*** Mean differences between sessions were low, with the majority of variables having moderate to excellent reliability (static .583–.877, dynamic .581–.939). The addition of the dual task did not have any significant effect on reliability of the task; however, generally, the ICC values improved (eyes open .583–.770, dual task .741–.808). ***Conclusions:*** The addition of a cognitive load to postural stability assessments had moderate to excellent reliability in a healthy population. These results provide initial evidence on the feasibility of dual-task postural stability testing when examining risk of lower-extremity musculoskeletal injury following return to sport in a concussed population.

Keywords: brain concussion, reliability, return-to-play, sport management

Concussions are a significant problem in athletic populations and can cause several severe symptoms.[1] Studies have shown that athletes who suffer concussions often have persistent postural stability deficits.[1] Long-term effects include an increased risk of lower-extremity injury,[2] although the reason for the increased risk is not clear.

The effects of concussion can last months after diagnosis, and many traditional tests do not detect persistent deficits.[3] The use of a dual-task assessment, which adds a cognitive load to a motor assessment, has the potential to be a more sensitive test of concussion.[4] The addition of a cognitive load may affect postural stability due to the finite amount of resources available to process loads simultaneously.[2]

Postural stability is an important measure of neuromuscular control that can also identify risk for musculoskeletal injury.[5] Both static and dynamic postural stability are common measurement tools. One commonly used postural stability assessment is the Dynamic Postural Stability Index (DPSI), which is a proven reliable measurement of dynamic postural stability in conjunction with a single-leg landing.[6] Because athletic activity requires simultaneous processing of cognitive and dynamic postural stability information, it is important to measure postural stability under similar conditions. Common dual-task assessments include postural stability assessments paired with a cognitive load such as the Stroop test.[3,4] The Stroop test, a visual, color-based load, has good test–retest reliability.[4]

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One of the first steps in the development of a tool to screen for musculoskeletal injury following concussion is to determine the reliability of the assessment in a healthy population. Both static and dynamic dual-task postural stability tests were examined for test–retest reliability. The Stoop test was used in conjunction with postural stability due to reliability and ease of testing.[4,5] If successful, the results of this study would be an important step toward utilizing these assessments in a concussed population to identify risk of lower-extremity injury following concussion.

Methods

Twelve participants (6 women) were recruited to participate in this study. Prior to any data collection, each subject signed an informed consent that was approved by the Duke University Institutional Review Board panel. Subject demographics are presented in Table 1. All subjects completed both test sessions of this study within a 10-day retest window (1.91 [1.16]).

The participants were physically active, free of injury at the time of testing, and had no history of lower-extremity injury. In addition, subjects did not have any known symptoms of concussion and no history of concussion within the past year. Eligibility was confirmed via a verbal questionnaire.

Ground reaction forces during the dynamic postural stability assessment were collected with a single force plate (AMTI, Watertown, MA) at 1200 Hz. An 80-in monitor (NEC, Irving, TX) was used to display the Stroop test or a dot for subjects to focus on during the tasks. Subjects first completed 3 static postural stability conditions: eyes open, eyes closed, and dual task. The order of conditions was systematically varied for each subject using Latin square randomization such that each condition was performed 5 times. Subjects were instructed to stand barefoot on one foot with their opposite foot lifted halfway up their tibia. Touchdowns with the lifted foot were allowed, but any shifting of the planted foot warranted recollection. Subjects also were instructed to keep their hands on their hips. During dual-task conditions, a Stroop test ran continuously on the monitor, with the word changing every 2 seconds. The subject was instructed to say the color of the font of each word displayed. After a practice trial of each condition, fifteen 10-second trials were collected for each limb. Subjects had 30 seconds of standing rest between each trial and a 1-minute sit down rest after every 5 trials.

Subjects then completed dynamic postural stability testing with 2 conditions: normal DPSI and dual task. Again, the order of conditions was systematically varied using Latin square randomization such that each condition was performed 5 times. For all conditions, a 12-in hurdle was placed at a distance of 20% of the subject's height from the end of the force plate, and the subject at 40%. Subjects were instructed to jump off with both feet over the hurdle and land on the involved limb only. Upon landing, they were instructed to maintain the static balance position for 10 seconds with no touchdowns allowed. For dual-task conditions, the subject first answered 3 Stroop tests, was instructed to jump, land, and complete 5 more tests. Subjects had 3 to 6 practice trials for the regular DPSI and 1 to 3 practice trials for dual task. There was 30 seconds of standing rest between trials and a 1-minute sit down rest after every 5 trials. Trials were recollected if the subject shifted upon landing or touched down. This experimental protocol was previously found to be reliable.[7]

Force data were run through a Butterworth filter via Nexus software (Vicon Motion Systems, Culver City, CA). All results were processed using custom MATLAB (Natick, MA) code. The first 3 seconds of force data (in newton) were used to calculate the medial/lateral (MLSI), anterior/posterior (APSI), vertical (VSI), and dynamic (DPSI) postural stability indexes for dynamic trials,[6] and all 10 seconds of static data were used to calculate SDs in all anatomical directions.

Routine descriptive statistics were used to summarize the data. The mean of the first 3 successful trials of postural stability tests was used. Statistical analysis was performed using the Statistical Package for the Social Sciences (version 24.0; SPSS, Chicago, IL). Intraclass correlation coefficients (ICCs), 95% confidence intervals (CIs), and SEM were calculated for each variable between days.

Results

Means, SDs, ICCs, 95% CI, and SEM for static postural stability testing are presented in Table 2. All Stroop tests were answered correctly. All postural measurements obtained during static testing were reliable according to the Guideline for Reporting Intraclass Correlation Coefficients.[8] ICC values less than .5, between .5 and .75, between .75 and .90, and greater than .9 are responsible for poor, moderate, good, and excellent reliabilities, respectively.[8] Using these standards, 8 of the 9 measures had good reliability. The eyes-open medial/lateral task was the only measure with moderate reliability. The 95% CIs for all tasks did not include 0, signifying that there was no significant differences. The SEM also indicates that the task was reliable, with all session 2 data falling within 1 SEM of the session 1 data.

Means, SDs, ICCs, 95% CI, and SEM for dynamic testing are presented in Table 3. Again, all Stroop tasks were answered correctly. Seven of the 8 measures were reliable. Only the dual-task APSI measure had an ICC value below .5 (.32, poor reliability).

Table 1 Subject Demographics

	Specific aim (reliability)					
	Males (n = 6)		Females (n = 6)		Total (N = 12)	
	Mean	SD	Mean	SD	Mean	SD
Age, y	22.5	3.1	22.0	2.8	22.3	2.9
Height, cm	178.7	7.4	170.1	4.4	174.4	7.5
Mass, kg	78.4	9.3	61.8	9.8	70.1	12.7

Table 2 Intersession Reliability for Static Postural Stability Tasks ($ICC_{2,1}$)

	Session 1		Session 2					
	Mean	SD	Mean	SD	ICC	95% CI		SEM
EO ML	3.16311	1.38518	3.47727	1.91735	.583	.042	.859	1.1433
EO AP	2.38354	0.87703	2.57431	1.09675	.842	.558	.951	0.4079
EO Vert	4.94863	2.04872	5.48185	2.87402	.770	.397	.927	1.2474
EC ML	9.24754	6.39022	9.24674	4.97510	.769	.364	.928	2.9694
EC AP	5.36885	2.41194	4.98718	1.93508	.873	.633	.961	0.8037
EC Vert	11.84418	5.55210	10.85351	5.42519	.877	.643	.963	1.9716
EODT ML	3.48746	1.48913	3.50462	1.40133	.741	.304	.919	0.7931
EODT AP	2.62934	1.15748	2.52879	0.89581	.808	.462	.941	0.4859
EODT Vert	5.60937	2.54767	5.27791	2.19556	.736	.311	.916	1.3011

Abbreviations: AP, anterior/posterior force; CI, confidence interval; EC, eyes closed; EO, eyes open; EODT, eyes-open dual task; ICC, intraclass correlation coefficient; ML, medial/lateral force; Vert, vertical force.

Table 3 Intersession Reliability for Dynamic Jump Tasks ($ICC_{2,1}$)

	Session 1		Session 2					
	Mean	SD	Mean	SD	ICC	95% CI		SEM
APSI	0.14211	0.00810	0.13954	0.01162	.581	.057	.857	0.0068
MLSI	0.03296	0.00792	0.03412	0.00727	.670	.184	.892	0.0047
VSI	0.31836	0.04600	0.31923	0.04628	.785	.399	.933	0.0231
DPSI	0.35635	0.03836	0.35060	0.04423	.939	.808	.982	0.0103
Dual-task APSI	0.13901	0.00977	0.14050	0.01561	.323	–.327	.749	0.011
Dual-task MLSI	0.03574	0.00963	0.03407	0.00714	.800	.461	.937	0.004
Dual-task VSI	0.32298	0.04147	0.31360	0.03741	.774	.409	.928	0.019
Dual-task DPSI	0.35570	0.03989	0.34691	0.03515	.781	.423	.931	0.018

Abbreviations: APSI, anterior/posterior stability index; CI, confidence interval; DPSI, dynamic postural stability index; ICC, intraclass correlation coefficient; MLSI, medial–lateral stability index; VSI, vertical stability index.

The dual-task APSI measure was unreliable with a 95% CI below 0 (–.327, .749). Two measures had moderate reliability (APSI and MLSI), while 4 measures had good reliability, and the standard DPSI had excellent reliability. The 95% CI for all other measures included nonzero, positive values, and SEM values were low.

Discussion

The association between concussion and lower-extremity injury suggests the need for an assessment specific to post-concussion RTS decisions. Therefore, a test to reliably measure both static and dynamic postural stability paired with cognitive function was developed. We found that during dual-task conditions, static postural stability testing had moderate to excellent reliability for all variables, while the dynamic postural stability also ranged from moderate to excellent, with the exception of the dual-task APSI.

These results are similar to previous studies that measured a dual task. A study of reaction times during dual-task testing, through the use of an incongruent Stroop test paired with a sensory organization test, had good test–retest reliability ($ICC_{2,k} = .745$).[4] An additional study of postural stability in adults also found that the addition of a cognitive load was reliable for center of pressure and sway measures.[9] The study also concluded that adding a cognitive task was more sensitive to distinguish concussed individuals from healthy individuals.[9] Our study was able to confirm that tests of static and dynamic postural stability during dual-tasks conditions were, for the majority of measures, reliable.

The only measure that was not reliable was the APSI measure during dual-task conditions. There are several factors that could have affected the intrasubject variability during the jump tasks, such as jumping and landing mechanics. A previous study showed variables were significantly different when subjects were instructed to jump with and without swinging their arms.[10] Subjects during our testing were given no instruction about mechanisms, so differences like these could have led to the lower reliability score for certain measures.

The results of this study indicate that postural stability under a dual-task condition as assessed in this research project has good reliability as hypothesized. Preliminary data show no significant differences between single- and dual-task conditions; however, this could be due to only testing a healthy population for reliability purposes. Although future research is necessary in a concussed population, the results indicate it can be used for baseline testing of healthy subjects and/or longitudinal studies of healthy populations similar to the population included in this study.

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