Original Research

Leg Dominance Effects During Single- and Dual-Task Modified Balance Error Scoring System Assessment in Collegiate and High School Athletes

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Background: The modified Balance Error Scoring System (mBESS) incorporates nondominant leg stance for a ceiling effect, but that may not be the worse balancing leg. Updated recommendations call for single- and dual-task tandem gait, but limited research has explored these effects on the mBESS.

Purposes: To compare mBESS performance between dominant and nondominant legs during single and dual tasks and to determine 1-week test-retest reliability.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 119 intercollegiate, collegiate club, and high school athletes were administered a baseline mBESS battery consisting of performance on both legs and during single and dual task at 2 time points, 1 week apart. Measures consisted of mBESS errors and sway index during counterbalanced single- and dual-task conditions on dominant and nondominant legs. Wilcoxon signed-rank tests were conducted to determine differences in errors and sway index between dominant and nondominant legs and single- and dual-task performance. Spearman correlations were used to measure reliability at 1 week ± 2 days.

Results: No differences were observed between nondominant and dominant single-leg errors (P = .79) and sway index (P = .98), nor tandem stance errors (P = .95) and sway index (P = .86). Greater errors were committed during dual-task single-leg stance (P = .05) but not on sway index (P = .69). No differences existed between single and dual tasks on tandem errors (P = .63) and sway index (P = .53). Test-retest coefficients were weak to moderate (r_s = −0.009 to 0.368) for normal mBESS errors and fair for sway index (r_s = 0.389 to 0.442) at a 1-week interval.

Conclusion: Our study demonstrated that leg dominance does not appear to affect mBESS errors or sway index, indicating that either leg may be used, in the absence of lower extremity injury history or instability. Incorporation of a dual task provides little clinical utility and may not be specific enough to elicit postural control changes on the mBESS, further indicating the use of optional foam conditions or single- and dual-task tandem gait. Caution is needed when using mBESS after a 1-week time point.

Keywords: head injury/concussion; athletic training; proprioception/balance

Balance remains an essential piece of multimodal concussion evaluation and management, as the recent consensus statement recommends its incorporation along with symptoms, gait, and cognitive screening to detect suspected injury.[26] The Sports Concussion Assessment Tool–sixth edition (SCAT6)[9] is the newly established recommended tool that was recently updated from the fifth edition (SCAT5),[10] to be used to evaluate sport-related concussions, within 72 hours after injury. Balance assessment on the SCAT5 consisted of the modified Balance Error Scoring System (mBESS),[11] a tool to measure errors (eg, falling out of position, lifting forefoot) during double-leg, single-leg, and tandem stances. The updates reflected in the SCAT6 now include further evaluation, such as an optional foam assessment and both timed and dual-task tandem gait. Per the instructions on the mBESS,[11] the suspected injured athlete will complete a series of leg stances on his or her nondominant foot in anticipation that the dominant leg may be too stable, thus creating less

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likelihood of errors in both an injured and an uninjured state. However, the literature on the effects of leg dominance on the mBESS is scarce.

Bressel et al[5] noted that balance performance consisting of BESS errors and Star Excursion Balance Test (SEBT) reach distance were not influenced by leg dominance in female collegiate athletes. While other researchers have yielded the same findings of single-leg balance on the SEBT,[20,25] the nature of the test is more dynamic, rather than upright, static postural control. Using more clinically driven equipment to produce objective measures of bodily sway, single-leg dominance has been studied using the Biodex Balance System to manipulate the stability of the force platform[2,27]; however, these findings were produced for 20- to 40-year-old individuals. Other measures to examine leg dominance during single-leg stances have centered on center of pressure (CoP) displacement,[23] velocity,[3,31] and mean sway speed,[18] all indicating a lack of leg dominance outcomes, despite the lack of these measures in athletic training clinical settings. The majority of these investigations have included smaller sample sizes from a single sport or featured nonathletes. It also remains unclear how nondominant leg performance is affected during a tandem stance, as opposed to single-leg stances, especially when utilizing newer technology, such as the Biodex BioSway, that uses a nonpivoting force platform, to produce sway index metrics, which are more commonly implemented into athletic training and sports injury practice.[21,22] If the mBESS yields normal findings on the SCAT6, clinicians are instructed to proceed to administering a timed tandem gait assessment,[9] which is sensitive to the detection of balance impairments after concussion.[12,24,33] The SCAT6 also includes an optional dual-task condition of tandem gait, which has been theorized to alleviate any consciously controlled attention toward balancing, likely disrupting coordination and stability.[35] Dual-task tandem gait has been noted to increase the amount of time to completion by ~1 second and decrease steps per minute, but little effect in center of mass displacement compared with single task.[13] Using single-leg stances with dual-task conditions yielded similar decreases in performance with less range of motion and slower dynamic single-leg squatting, however mixed findings during a static, single leg stance, with faster sway speed during a visual memory task but slower speed during a visual reaction time task.[30] As both dual tasks were completed with eyes-open conditions and the mBESS features eyes-closed conditions, it is unclear how cognitive dual tasks may affect static balance as well as balance in nondistractive environments.[15]

To date, the only attempts to investigate dual task on BESS noted no differences between single task on overall errors[29] and noted acceptable reliability after same-day reassessment.[17] Tandem gait in both single and dual tasks have demonstrated high reliability,[12] further implicating its role in clinical evaluation and management of concussion. The effects of a dual-task condition on the mBESS have yet to be explored in high school and collegiate athletes. Coupling leg dominance effects of both error and sway index in both single- and dual-task assessment is warranted. Given the sensitivity of mBESS decreasing as low as 0.16 at 1 to 3 days postinjury and specificity remaining >0.90 at 1 week,[19] along with dual-task tandem gait increasing sensitivity compared with single task within 1 week,[33] test-retest reliability of performance in these conditions is needed. Therefore, the purpose of this study was to compare mBESS error and sway index scoring between leg dominance and during single- and dual-task assessment. A secondary purpose was to examine 1-week test-retest reliability. It was hypothesized that mBESS errors and sway index would not differ between nondominant and dominant leg stance assessment and that errors and sway index would increase during dual-task assessment. A second hypothesis was that errors and sway index would be fair to moderately correlated after 1 week.

METHODS

Participants

A total of 119 (age, 19.13 ± 2.3 years) intercollegiate (n = 40; 50% male; age, 19.98 ± 1.3 years), collegiate (n = 39; 51.3% male; age, 20.56 ± 2.5 years), and high school (n = 40; 50% male; age, 16.88 ± 0.7 years) athletes participated in the current study (Table 1). All participants provided written consent approved by our institutional review board committee (IRB# 22-03-5493) before participation. All high school–level participants had consent provided by a parent or legal guardian. Participants had to be free of a history of lower extremity musculoskeletal injury within 3 months that had time-loss, lower extremity surgeries in which metal or a graft were inserted in the limb, history of concussion, history of chronic ankle instability, and any underlying balance or vestibular disorders. Athletes participated at the university's athletic training research laboratory or at their respective athletic training facility, due to the portability of the equipment used in this study. Athletes provided demographics of age, sport, and leg dominance by answering, "*If you were going to kick a soccer*

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Ethical approval for this study was obtained from The University of Alabama (e-protocol 22-03-5493-R2).

TABLE 1
Patient Demographics[a]

	Male	Female
Age, y		
Intercollegiate	19.85 ± 1.4	20.10 ± 1.2
Collegiate club	20.90 ± 3.3	20.21 ± 1.5
High school	17.10 ± 0.7	16.65 ± 0.4
	Men's/Boy's	Women's/Girl's
Sport type		
Intercollegiate (n = 40)		
Baseball	5 (12.5)	–
Cheerleading	2 (5.0)	4 (10.0)
Football	8 (20.0)	–
Soccer	–	5 (12.5)
Swimming and diving	3 (7.5)	2 (5.0)
Tennis	2 (5.0)	3 (7.5)
Volleyball	–	6 (15.0)
Collegiate club (n = 39)		
Boxing	3 (7.7)	1 (2.6)
Cheerleading	–	2 (5.1)
Crew	5 (12.8)	–
Cricket	5 (12.8)	–
Gymnastics	–	1 (2.6)
Ice hockey	4 (10.3)	–
Lacrosse	–	1 (2.6)
Soccer	2 (5.1)	6 (15.4)
Swimming	–	1 (2.6)
Tennis	–	1 (2.6)
Ultimate	–	1 (2.6)
Water skiing	–	5 (12.8)
Wrestling	1 (2.6)	–
High school (n = 40)		
Baseball	5 (12.5)	–
Basketball	5 (12.5)	4 (10.0)
Cheerleading	–	6 (15.0)
Football	5 (12.5)	–
Soccer	–	5 (12.5)
Volleyball	1 (2.5)	4 (10.0)
Wrestling	4 (10.0)	1 (2.5)

[a]Data presented as mean ± SD or n (%). Dashes indicate that no athletes were included.

ball, which leg would you use?" A breakdown of age and sport participation by each athletic level are in Table 1.

Measures

Athletes completed an mBESS battery on the Biodex Medical System BioSway, an instrumented, portable force platform, which provided a sway index score. Sway index on the BioSway was calculated as the root mean square error distance of the CoP, 2-dimensional coordinates with a CoP sampling rate of 20 Hz.[8] The mBESS consisted of 1 trial of double-leg, single-leg, and tandem stances on both nondominant and dominant legs during single and dual tasks, with standard instructions (see p. 7 of SCAT5 for script[10]) and error scoring. Errors consisted of (1) hands lifted off iliac crest, (2) opening eyes, (3) step, stumble, or fall, (4) moving hip into >30° abduction, (5) lifting forefoot or heel, and (6) remaining out of test position >5 seconds.[4] Participants were randomly 4-way counterbalanced between leg dominance and task (single or dual) before testing. Participants completed a double-leg stance for the appropriate task, followed by a single-leg and tandem stance for the appropriate leg and task. Testing was then repeated for the other task and leg. Single task focused on just balancing, while dual task consisted of balancing while verbally completing a serial backward counting task from a random 2- to 3-digit number by 4s, 6s, or 7s.[14] Participants then returned to the original testing location 7 ± 2 days later to repeat the battery to establish test-retest reliability.

All mBESS errors were scored by a single licensed and certified athletic trainer (R.N.M.) who is a PhD-earned concussion expert, to eliminate the threat of intrarater reliability and subjectivity that comes with using multiple raters, along with 1 research assistant (M.H.) recording the sway index produced on the BioSway. For time purposes, no foam surfaces were used in this study.

Statistical Analysis

Descriptive and inferential statistics were used to express demographics and mean scoring for the sample and by level. Due to nonnormality of the data, nonparametric tests were used throughout. A series of Wilcoxon signed-rank tests were used to compare leg dominance on single- and dual-task mBESS performance. A series of Spearman rank-order correlations were used to examine test-retest reliability. Interpretation of correlation coefficients was ≤0.2 = weak, 0.3-0.5 = fair, 0.6-0.7 = moderate, and ≥0.8 = very strong.[1,7] Leg dominance comparisons were only produced for single-task only and both double leg and nondominant stances, as that is routine mBESS administration. Comparisons between single and dual tasks were also completed for double-leg and nondominant stances. Test-retest coefficients were produced for both leg dominances and tasks. Due to most scoring having 0 medians, means were provided in the tables for ease of interpretation and applicability to clinical measures of the mBESS and balance via the BioSway.

RESULTS

Of the 119 participants, 88.2% (n = 105) reported being right-leg dominant, with 90% (n = 36/40) at both the intercollegiate and the high school levels and 84.6% (n = 33/39) at the collegiate club level. For mBESS error performance, 2 individuals made errors in double-leg stance: 1 during single task and 1 during dual task. Single-leg errors ranged from 0 to 7, with 75.6% (n = 90) committing ≥1 error, while tandem errors ranged from 0 to 6, with 42.0% (n = 50) committing ≥1 error. Similar errors were made for dominant limb single task (range, 0-6; 69.0% committing ≥1 error) and tandem (range, 0-4; 38.7% committing ≥1 error).

There were no differences between leg dominance in the overall sample for single-leg errors ($Z = -0.260$; $P = .79$) and sway index ($Z = -0.024$; $P = .98$) nor tandem stance

TABLE 2
Normal mBESS Errors and Sway Index[a]

	Single-Leg Stance				Tandem Stance			
Level by Dominance	Errors	P	Sway Index	P	Errors	P	Sway Index	P
Overall sample								
Nondominant	1.69 ± 1.5	.79	2.91 ± 1.1	.98	0.70 ± 1.0	.95	2.15 ± 0.8	.86
Dominant	1.74 ± 1.6		2.97 ± 1.1		0.66 ± 1.0		2.19 ± 0.9	
Intercollegiate								
Nondominant	1.45 ± 1.4	.75	2.58 ± 0.8	.70	0.77 ± 1.2	.70	2.19 ± 1.1	.92
Dominant	1.38 ± 1.6		2.57 ± 1.0		0.65 ± 0.9		2.16 ± 1.0	
Collegiate club								
Nondominant	1.59 ± 1.5	.54	2.76 ± 1.0	.16	0.64 ± 0.9	.54	2.07 ± 0.6	.94
Dominant	1.77 ± 1.6		3.01 ± 1.0		0.77 ± 1.0		2.11 ± 0.9	
High school								
Nondominant	2.03 ± 1.5	.99	3.40 ± 1.2	.27	0.68 ± 1.0	.60	2.18 ± 0.7	.90
Dominant	2.08 ± 1.4		3.33 ± 1.3		0.58 ± 0.8		2.30 ± 0.7	

[a]Data are presented as mean ± SD between leg dominance. Normal mBESS is single task only with no dual task component. Double-leg stance not included. mBESS, modified Balance Error Scoring System.

errors ($Z = -0.064$; $P = .95$) and sway index ($Z = -0.171$; $P = .86$ (Table 2). These findings were consistent across intercollegiate (P range = .70-.98), collegiate club (P range = .70-.92), and high school (P range = .27-.99) levels. Greater errors were committed during dual-task single-leg stance (nondominant leg) than single task ($Z = -2.009$; $P = .05$), despite no differences on sway index ($Z = -0.0396$; $P = .69$) for the overall sample (Table 3). High school athletes contributed most to single-leg differences between single and dual tasks ($Z = -1.888$; $P = .06$). While no differences were observed between single and dual tasks on double-leg sway index ($Z = -1.300$; $P = .19$) for the overall sample, differences were apparent in the intercollegiate athletes, with improved balance in dual-task assessment ($Z = -2.073$; $P = .03$). No differences existed on tandem stance errors ($Z = -0.479$; $P = .63$) or sway index ($Z = -0.625$; $P = .53$) for the sample.

Retesting occurred 6.76 ± 0.6 days from initial testing, with the majority (66.1%; n = 78/118) exactly 7 days apart, and ranging from 5 (1.7%; n = 2) to 8 (5.9%; n = 7) days. There was 1 person that did not return to retest, and therefore the final sample size for test-retest reliability was 118. For the normal administration of the mBESS in single-task, nondominant stances, 1-week test-retest reliability of errors was weak for double-leg ($r_s = -0.009$; $P = .93$) stances, but fair to moderate for single-leg ($r_s = 0.508$; $P < .001$) stances and fair for tandem ($r_s = 0.368$; $P < .001$) stances (Table 4). Similar effects were noted during the dominant single-leg ($r_s = 0.576$; $P < .001$) and tandem stances ($r_s = 0.217$; $P = .02$) with fair to moderate and weak to fair correlation, respectively. Interestingly, reliability improved during dual-task assessments compared with single task (Table 4). Similar findings were noted on sway index during single task in nondominant stances, with fair correlation on single leg ($r_s = 0.473$; $P < .001$) and tandem ($r_s = 0.389$; $P < .001$) stances. Significant and similar correlations were also observed on mBESS errors during dual task ($r_s = 0.368\text{-}0.623$; $P_s < .001$) and dominant legs ($r_s = 0.217\text{-}0.651$; $P_s < .001\text{-}.007$).

DISCUSSION

The findings of this study indicated that leg dominance, whether balancing using the dominant or nondominant leg, did not differ between mBESS errors ($P = .79$) or sway index ($P = .98$) on single-leg stance, along with no differences on mBESS errors ($P = .95$) or sway index ($P = .86$) during tandem stance. When comparing performance between single and dual tasks, there were greater mBESS errors during the dual-task single-leg stance condition only ($P = .04$). No differences were observed between single- and dual-task tandem stance errors or sway index ($P \geq .53$). Last, 1-week test-retest coefficients were weak to moderate for mBESS errors and fair for sway index.

The first aim of this study was to examine the effects of leg dominance on mBESS performance. Our findings, which noted a lack of differences between nondominant and dominant leg errors, are supported by Bressel et al[5] who reported similar findings in female collegiate athletes. The fact that no differences were observed on errors may also further complement the lack of differences on sway index, since one would anticipate that sway would synonymously increase or decrease as CoP changes during errors or lack thereof.[28] Our lack of sway index differences between leg dominance is supported by previous findings utilizing the Biodex Balance System during single-leg stance,[2,27] despite both studies utilizing sedentary and recreational active postcollege–aged adults. Single-leg dominance has also revealed no differences using CoP sway via force plates in professional male rugby[31] and soccer players.[3] To date, no prior studies have compared leg dominance on tandem stance sway, only single leg. Our findings help provide preliminary support for a lack of leg

TABLE 3
mBESS Errors and Sway Index Mean ± SD During Single and Dual Tasks[a]

	Double-Leg Stance				Single-Leg Stance				Tandem Stance			
Level by Task	Errors	P	Sway Index	P	Errors	P	Sway Index	P	Errors	P	Sway Index	P
Overall sample												
Single task	0.01 ± 0.1	.99	1.22 ± 0.3	.19	1.69 ± 1.5	**.04**	2.91 ± 1.1	.69	0.70 ± 1.0	.63	2.15 ± 0.8	.53
Dual task	0.01 ± 0.1		1.18 ± 0.4		1.96 ± 1.7		1.91 ± 1.1		0.66 ± 1.0		2.14 ± 0.9	
Intercollegiate												
Single task	0.00 ± 0.0	.99	1.22 ± 0.2	**.04**	1.45 ± 1.4	.38	2.57 ± 0.8	.91	0.77 ± 1.2	.82	2.19 ± 1.1	.26
Dual task	0.00 ± 0.0		1.11 ± 0.3		1.73 ± 1.9		2.51 ± 0.9		0.78 ± 1.3		2.04 ± 0.8	
Collegiate club												
Single task	0.00 ± 0.0	.99	1.11 ± 0.2	.96	1.59 ± 1.5	.49	2.76 ± 1.0	.53	0.64 ± 0.9	.76	2.07 ± 0.6	.27
Dual task	0.00 ± 0.0		1.12 ± 0.3		1.77 ± 1.5		2.87 ± 1.1		0.62 ± 0.9		2.01 ± 0.8	
High school												
Single task	0.03 ± 0.1	.99	1.33 ± 0.5	.72	2.03 ± 1.5	.06	3.40 ± 1.2	.95	0.68 ± 1.0	.71	2.18 ± 0.7	.34
Dual task	0.03 ± 0.1		1.31 ± 0.4		2.38 ± 1.5		3.35 ± 1.2		0.60 ± 0.8		2.38 ± 0.9	

[a]Data are presented as mean ± SD during single and dual tasks. Bold values are statistically significant. Normal mBESS is nondominant limb only. mBESS, modified Balance Error Scoring System.

TABLE 4
1-Week Test-Retest Reliability and Change of mBESS Errors and Sway Index[a]

		Nondominant					Dominant				
		Statistics		% Change			Statistics		% Change		
Stance		r_s	P	Same	Decrease	Increase	r_s	P	Same	Decrease	Increase
mBESS errors											
Double leg	single	–0.009	.93	98.3	0.8	0.8	–		–	–	–
	dual	–0.009	.93	98.3	0.8	0.8	–		–	–	–
Single leg	single	0.508	<.001	34.7	31.4	33.9	0.576	<.001	36.4	31.4	32.2
	dual	0.623	<.001	33.9	39.0	27.1	0.651	<.001	42.4	38.1	19.5
Tandem	single	0.368	<.001	51.7	25.4	22.9	0.217	.02	56.8	24.6	18.6
	dual	0.449	<.001	59.3	28.0	11.9	0.296	.001	57.6	25.4	16.9
Sway index											
Double leg	single	0.442	<.001	1.7	45.8	52.5	–		–	–	–
	dual	0.615	<.001	2.5	52.5	44.9	–		–	–	–
Single leg	single	0.473	<.001	–	50.8	49.2	0.546	<.001	–	55.1	44.9
	dual	0.506	<.001	0.8	61.9	37.3	0.601	<.001	0.8	63.6	35.6
Tandem	single	0.389	<.001	0.8	55.1	44.1	0.246	.007	–	59.3	40.7
	dual	0.396	<.001	1.7	57.6	40.7	0.472	<.001	–	50.0	50.0

[a]Change is same, decrease, or increase in scores from initial testing to day 7 retesting. Dashes indicate not applicable. mBESS, modified Balance Error Scoring System.

dominance differences in that position. While some may expect better balance by athletes in their dominant leg due to increased use of that limb during functional activity, and thus more strength,[2] it is also possible that nondominant leg strength is equally improved due to the need to support body weight and stability when using the dominant leg.[3] It may also be possible that the lack of differences between legs is due to the static nature of the mBESS; however, more studies are needed, due to an absence of leg differences in dynamic tasks such as tandem gait and jump landing.[34] While the SCAT6 calls for administration using the nondominant foot for single and tandem stances, our findings suggest that either foot could be used, but only in the absence of lower extremity musculoskeletal injury and instability (eg, recent inversion ankle sprain, chronic ankle instability). If a patient has a history of chronic ankle instability in the nondominant foot, the dominant foot may provide the best utility for clinical evaluation and return-to-sports decision making.

Another major purpose of our study was to provide preliminary findings of the effects of a dual-task condition during the mBESS in a diverse sample of athletes. Our findings indicated mixed, weak findings for dual-task mBESS. Specifically, more errors were made in the single-leg stance during dual task in the overall sample, but no differences when stratified by level. Additionally, no group differences were observed for the overall sample on dual-task double-leg sway index; however, balance was improved during the dual task. No other differences were observed by task for double-leg errors, single-leg sway index, and tandem errors and sway index. The outcomes are partially supported by Ross et al[29] who reported no dual-task differences on the BESS in recreationally active college athletes. It is possible that our results may differ slightly due to the inclusion of a larger sample size across high school and collegiate athletes. As the mBESS is the nonfoam portion of the BESS, it is unlikely that the nature of the assessments mattered. However, our study counterbalanced task as well as leg dominance, where the prior-mentioned study completed dual task after single task, which may have elicited practice effects creating improved performance.[32] We believe the dual-task double-leg stance improvements may be coincidental among collegiate athletes. Likewise, with worse dual-task errors in single-leg stance, since no changes were observed in sway index, it is possible that these errors are not a result of worse bodily movement and stability but rather may be attributed to an athlete's preemptively committing an error, such as placing his or her nonbalancing foot down to stabilize a future excessive sway movement. It is also possible that errors were committed, in the absence of a sway index increase due to the shifting of CoP, such as lifting of the forefoot or toe. Our study also helps provide evidence by stance, rather than overall error score due to the nature of our counterbalancing. It would be difficult to truly provide a total score since double-leg stances were only completed once per task, to eliminate practice effects, unlike single and tandem stances, as they were repeated for dominant and nondominant legs. The incorporation of the dual task may not be specific enough to elicit changes, as the cognitive tasks may not have been challenging enough or dual task merely does not affect static measures of gait as effectively as dynamic movements. The hypothesis that dual-task conditions would produce worse errors was not supported, given the similarity in percentage change between single and dual tasks during both nondominant and dominant stances. Roughly one-third of the sample had the same decreasing and increasing errors on single-leg stance on both single and dual tasks, with similarities also apparent on tandem stance, with approximately half reporting the same error score and one-fourth reporting decreasing and increasing errors. Similar findings were also noted on sway index, but naturally with less likelihood of a similar score at retesting. Approximately half of the sample had increasing and the other half had decreasing scores at retesting. The theory of reinvestment states that directing attention internally to control movement enables the body to automatically control postural control,[35] since the focus is on the cognitive task rather than creating intentional and movement-specific corrections and control. It is possible that these athletes had improved stability during dual task due to the negated effects of intentionally compensating and controlling movements via neuromuscular activation.

The final purpose of this study was to examine the test-retest reliability over a 1-week period for both nondominant and dominant leg errors and sway index during single and dual tasks. Similar strengths were observed between initial and repeat testing of nondominant and dominant limbs, regardless of task. In both single- and dual-task balance, errors were weakly correlated in double-leg stance, fairly to moderately correlated in single-leg stance, and fairly correlated in tandem stance. Previous research noted moderate reliability (0.6) on total BESS errors in both single and dual tasks 14 days apart,[16,29] while mBESS at 6-month retest in military personnel was moderately reliable for double leg and single leg, and tandem stances were poor. Our reliability findings extended into sway index as well, with slightly weaker outcomes compared with findings on the Sway Balance Mobile Application at 2- and 3- week retesting in healthy adults.[6] Prior studies on the Sway Balance application revealed moderate coefficients for double-leg stance (0.72) and good reliability for single leg on both right and left (0.8) legs, with moderate and good reliability on tandem left (0.69) and right (0.8) foot, respectively.[6] Our difference in coefficient strength is likely due to the sensitivity of the BioSway force platform compared with a mobile application, as well as analyzing by leg dominance and in a sample of high school and collegiate athletes.

Strengths and Limitations

The inherent strength of the current study centers on the diverse, cross-sectional sample of athletes across a broad range of ages and skill levels representing a wide variety of sports. Additionally, there was no significant loss of patients to follow-up. The randomized assignment of athletes to test group controls for selection bias and the methodology for data measurement minimizes the effect of interrater variability. The clinical utility and efficiency of mBESS has been well-documented. The use of standardized, validated, objective measurements in the current study lends further credence to the value of the data and the potential impact on clinical practice.

However, this study was not without limitations. First, all participants were free of any lower extremity injury history, reconstruction, or instability, which may be pivotal in overall application of these findings, given the commonality of inversion ankle sprains in high school and collegiate athletics. Additionally, at the time of the study, the SCAT5 was the consensus-recommended balance assessment for sport-related concussion, in which the mBESS utilized a double-leg stance, followed by single-leg and then tandem. The tandem and single-leg stances have switched orders in the mBESS on the SCAT6, likely due to increasing difficulty over the test. While it is likely that this change in administration pattern would not influence errors, and thus sway, future research would help determine these effects. This study included a diverse sports sample across multiple levels of athletic competition but did not include every possible sport. Sports that vary between collegiate levels may provide differing values, such as field hockey and lacrosse, which vary between National Collegiate Athletic Association and club/recreational sanctioned sports programs. Future research should utilize similar methodology to determine the effects of lower extremity injury history and instability, as well as leg dominance effects on the foam surface of mBESS conditions.

CONCLUSION

Our study demonstrated that leg dominance does not appear to affect mBESS error or sway index in healthy, uninjured collegiate and high school athletes. The addition of a dual-task condition did not greatly influence single and tandem stance errors and sway, indicating emphasis should be placed on the optional foam surface to increase difficulty on the mBESS or that a multifaceted tandem gait should be used. Dual task may only be useful during dynamic tandem gait of the SCAT6 and the Sports Concussion Office Assessment Tool 6. Last, due to fair-to-moderate correlations between initial testing and follow-up assessments, caution is needed when administering the mBESS over a period of ≥1 week.

REFERENCES

1. Akoglu H. User's guide to correlation coefficients. *Turk J Emerg Med*. 2018;18(3):91-93.
2. Alonso AC, Brech GC, Bourquin AM, Greve JM. The influence of lower-limb dominance on postural balance. *Sao Paulo Med J*. 2011;129(6):410-413.
3. Barone R, Macaluso F, Traina M, Leonardi V, Farina F, Di Felice V. Soccer players have a better standing balance in nondominant one-legged stance. *Open Access J Sports Med*. 2010;2:1-6.
4. Bell DR, Guskiewicz KM, Clark MA, Padua DA. Systematic review of the Balance Error Scoring System. *Sports Health*. 2011;3(3):287-295.
5. Bressel E, Yonker JC, Kras J, Heath EM. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *J Athl Train*. 2007;42(1):42-46.
6. Caccese JB, Teel E, Van Patten R, Muzeau MA, Iverson GL, VanRavenhorst-Bell HA. Test-retest reliability and preliminary reliable change estimates for Sway Balance tests administered remotely in community-dwelling adults. *Front Digit Health*. 2022;4:999250.
7. Chan YH. Biostatistics 104: correlational analysis. *Singapore Med J*. 2003;44(12):614-619.
8. Dewan BM, Roger James C, Kumar NA, Sawyer SF. Kinematic validation of postural sway measured by Biodex Biosway (force plate) and SWAY Balance (accelerometer) technology. *Biomed Res Int*. 2019;2019:8185710.
9. Echemendia RJ, Brett BL, Broglio S, et al. Sport Concussion Assessment Tool 6 (SCAT6). *Br J Sports Med*. 2023;57(11):622-631.
10. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool 5th Edition (SCAT5): background and rationale. *Br J Sports Med*. 2017;51(11):848-850.
11. Guskiewicz KM. Assessment of postural stability following sport-related concussion. *Curr Sports Med Rep*. 2003;2(1):24-30.
12. Howell DR, Brilliant AN, Meehan WP 3rd. Tandem gait test-retest reliability among healthy child and adolescent athletes. *J Athl Train*. 2019;54(12):1254-1259.
13. Howell DR, Osternig LR, Chou LS. Single-task and dual-task tandem gait test performance after concussion. *J Sci Med Sport*. 2017;20(7):622-626.
14. Howell DR, Wilson JC, Brilliant AN, Gardner AJ, Iverson GL, Meehan WP 3rd. Objective clinical tests of dual-task dynamic postural control in youth athletes with concussion. *J Sci Med Sport*. 2019;22(5):521-525.
15. Hyong IH. The effects on dynamic balance of dual-tasking using smartphone functions. *J Phys Ther Sci*. 2015;27(2):527-529.
16. Kontos AP, Monti K, Eagle SR, et al. Test-retest reliability of the Vestibular Ocular Motor Screening (VOMS) tool and modified Balance Error Scoring System (mBESS) in US military personnel. *J Sci Med Sport*. 2021;24(3):264-268.
17. Manaseer TS, Whittaker JL, Isaac C, Schneider K, Roberts MR, Gross DP. The reliability of clinical balance tests under single-task and dual-task testing paradigms in uninjured active youth and young adults. *Int J Sports Phys Ther*. 2020;15(4):487-500.
18. Mazzella NL, McMillan AM. Contribution of the sural nerve to postural stability and cutaneous sensation of the lower limb. *Foot Ankle Int*. 2015;36(4):450-456.
19. McCrea M, Barr WB, Guskiewicz K, et al. Standard regression-based methods for measuring recovery after sport-related concussion. *J Int Neuropsychol Soc*. 2005;11(1):58-69.
20. Mohamadi S, Rahmani N, Ebrahimi I, Salavati M, Dadgoo M. The effect of leg dominance and group difference in Star Excursion Balance Test between individuals with chronic ankle instability, ankle sprain copers and healthy controls. *Arch Bone Jt Surg*. 2023;11(3):206-211.
21. Moran RN, Cochrane G. Preliminary study on an added vestibular-ocular reflex visual conflict task for postural control. *J Clin Transl Res*. 2020;5(4):155-160.
22. Moran RN, Meek J, Allen J, Robinson J. Sex differences and normative data for the m-CTSIB and sensory integration on baseline concussion assessment in collegiate athletes. *Brain Inj*. 2020;34(1):20-25.
23. Muehlbauer T, Mettler C, Roth R, Granacher U. One-leg standing performance and muscle activity: are there limb differences? *J Appl Biomech*. 2014;30(3):407-414.
24. Oldham JR, Difabio MS, Kaminski TW, Dewolf RM, Howell DR, Buckley TA. Efficacy of tandem gait to identify impaired postural control after concussion. *Med Sci Sports Exerc*. 2018;50(6):1162-1168.
25. Onofrei RR, Amaricai E, Petroman R, Surducan D, Suciu O. Preseason dynamic balance performance in healthy elite male soccer players. *Am J Mens Health*. 2019;13(1):1557988319831920.
26. Patricios JS, Schneider KJ, Dvorak J, et al. Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport-Amsterdam, October 2022. *Br J Sports Med*. 2023;57(11):695-711.
27. Rein S, Fabian T, Zwipp H, Mittag-Bonsch M, Weindel S. Influence of age, body mass index and leg dominance on functional ankle stability. *Foot Ankle Int*. 2010;31(5):423-432.
28. Ross JD, Hoch MC, Malvasi SR, Cameron KL, Roach MH. The relationship between human-rated errors and tablet-based postural sway during the Balance Error Scoring System in military cadets. *Sports Health*. 2023;15(3):427-432.
29. Ross LM, Register-Mihalik JK, Mihalik JP, et al. Effects of a single-task versus a dual-task paradigm on cognition and balance in healthy subjects. *J Sport Rehabil*. 2011;20(3):296-310.
30. Talarico MK, Lynall RC, Mauntel TC, Weinhold PS, Padua DA, Mihalik JP. Static and dynamic single leg postural control performance during dual-task paradigms. *J Sports Sci*. 2017;35(11):1118-1124.
31. Troester JC, Jasmin JG, Duffield R. Reliability of single-leg balance and landing tests in rugby union; prospect of using postural control to monitor fatigue. *J Sports Sci Med*. 2018;17(2):174-180.
32. Valovich TC, Perrin DH, Gansneder BM. Repeat administration elicits a practice effect with the Balance Error Scoring System but not with the Standardized Assessment of Concussion in high school athletes. *J Athl Train*. 2003;38(1):51-56.
33. Van Deventer KA, Seehusen CN, Walker GA, Wilson JC, Howell DR. The diagnostic and prognostic utility of the dual-task tandem gait test for pediatric concussion. *J Sport Health Sci*. 2021;10(2):131-137.
34. Wikstrom EA, Tillman MD, Kline KJ, Borsa PA. Gender and limb differences in dynamic postural stability during landing. *Clin J Sport Med*. 2006;16(4):311-315.
35. Wulf G, McNevin N, Shea CH. The automaticity of complex motor skill learning as a function of attentional focus. *Q J Exp Psychol A*. 2001;54(4):1143-1154.