PRELIMINARY INVESTIGATION OF THE EFFICACY OF CLINICALLY PRACTICAL DUAL-TASK TESTS AS A CONCUSSION ASSESSMENT TOOL: A COMPARISON OF SINGLE- AND DUAL-TASK TESTS ON HEALTHY YOUNG ADULTS

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ABSTRACT

Preliminary Investigation of the Efficacy of Clinicaly Practical Dual-Task Tests as a Concussion Assessment Tool: A Comparison of Single- and Dual-Task Tests on Healthy Young Adults.

Objective: To develop Dual-Task tests using clinically practical physical and cognitive tasks. The effect of Dual-Task tests was investigated by comparing the outcome measures to that of Single-Task tests on healthy subjects. **Method**: 54 healthy participants were recruited. Testing involved Modified Balance Error Scoring System (mBESS) and three cognitive tasks [Backward Digit Recall (BDR), Serial Sevens (SS), and Auditory Pure Switch Task (APST)]. Repeated Measure Analysis of Variance, paired *t*-tests, Intraclass Correlation Coefficients were performed on SPSS v22.0 with an alpha level of $p<0.05$ **Results:** Total mBESS score increased under Dual-Task combination with SS compared to its Single-Task score ($p=0.01$). Accuracy for BDR, Digit Span for SS and APST showed significant decrease under Dual-Task task with single-leg stance on foam ($p<0.05$). **Conclusions:** These Dual-Task combinations had similar effects as shown in previous research and may show promise as part of developing a practical, clinically based Dual-Task test for assessing concussion.

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Introduction

Concussion management has radically evolved in the past 20 years; subsequently the perception of the injury has changed from simply "getting dinged" to being a potentially life-altering event. A battery testing method is a multifaceted approach incorporating several different assessment tools to evaluate the concussion in its entirety. Utilization of multiple assessment tools has been shown to be more sensitive in detecting different aspects of the impairments caused by concussion compared to utilizing any single tool.[1] The current testing battery is designed to assess neurocognitive function, postural stability, and symptoms of concussion. Commonly, the computerized and/or pen-and-paper based tests are used to assess neurocognitive function, the Balance Error Scoring System (BESS) is used to assess postural stability, and the Graded Symptom Checklist (GSC) is used to assess post-concussion symptoms.[2] These tests aid Certified Athletic Trainers (ATs) in ensuring concussed student athletes are deficit-free prior to resuming physical activities. While these tools provide important information to ATs regarding the return-to-play decision making process, non-concurrent performance of each test may not appropriately replicate the complex interactions of neurocognitive function and physical tasks required by sports participation.

Dual-Task testing involves concurrent performance of neurocognitive and postural stability tests, and is the closest approximation of sports participation available in the clinical setting.[3-6] Continued dysfunction was detected with Dual-Task testing in a concussed athlete even after the neurocognitive test scores had returned to baseline in a single case report.[6] Previous research has investigated several combinations of Dual-Task test in a laboratory setting using reaction time and postural sway as the outcome measures.[3-7] Resch et al. and Broglio et al. utilized Sensory Organization Test (SOT) for physical task and combined it with cognitive task for their Dual-Task study.[5,7] Both authors found the SOT score was better under Dual-Task condition but reaction times for cognitive task were significantly slower in Dual-Task.[5,7] While valid, these tests require expensive and bulky equipment not commonly found in the clinical setting. To our knowledge, no previous study has investigated a reliable combination for Dual-Task testing that is feasible in a clinical setting.

The BESS was developed as a clinical field test that can be used to assess a concussed athlete's postural stability.[8,9] It is widely utilized by ATs as a part of sports-related concussion assessment.[2,10] Several studies have analyzed postural stability using the BESS and have found that the score for the double-leg stances on the firm and foam surfaces was consistently low regardless of injury.[9,11,12] One study indicated that excluding both firm and foam surface double-leg stances [modified BESS (mBESS)] resulted in greater reliability.[13] The established clinical practice of the BESS and mBESS make it a suitable task for including in a clinical-based Dual-Task test.

Serial Sevens (SS) has previously been utilized to assess detailed concentration and attention capability for concussed athletes in both Single- and Dual-Task conditions.[14,15] Auditory Pure Switch Task (APST), which measures cognitive flexibility, attention, and information-processing speed, has been commonly applied in studies utilizing a Dual-Task condition. [5,7,16,17] For this task, participants were instructed to listen to a series of numbers and, for each number, respond whether it is either an even or odd number.[16] Backward Digit Recall (BDR) was modified from the digit span task in the Wechsler Intelligence Scales. One study showed that Backward Digit Recall was more suitable than forward digit recall to assess complex span measure of working memory and it was more sensitive to the effects of cognitive dysfunction than forward digit recall.[18] All of these cognitive tasks are auditory based, thus limiting structural interference with the physical tasks, and do not require complex and expensive equipment. Word-based cognitive tasks are not appropriate since they can only be used effectively by a native speaker of that particular language.[19]

The purpose of this study was to establish the most appropriate combination of Dual-Task tests that can be performed in the clinical setting. The effect of Dual-Task combinations on cognitive and physical function was investigated in healthy college-aged students along with the reliability of each Dual-Task combination. The research hypothesis for this study was that cognitive and physical function would decrease during the Dual-Task tests as compared to the Single-Task tests.

Method

Research Design:

This study utilized a randomized repeated-measure design consisting of two separate testing sessions (two to three weeks apart) during which both Single-task and Dual-Task test were performed. Participants were assigned to one of two experience examiners who administered and scored all test for that participant. The independent variables were type of task and the testing session. The dependent variables were the measured outcomes of the physical and cognitive tasks. The physical task for this study was the mBESS, and the three cognitive tasks were BDR, SS, and APST. All the data collections were conducted in a quiet indoor facility with minimal distractions.

Physical Task:

Modified Balance Error Scoring System (mBESS)

The mBESS is designed to assess an individual's balance ability following a concussion. This test consisted of balance performance in four conditions: single-leg stable firm surface (SL), tandem leg stance stable firm surface (TAN), single-leg unstable foam surface (SLF), and tandem leg stance unstable foam surface (TANF) (Figure 1).

The floor of the testing site was utilized as the stable firm surface and a 50cm x 41cm x 6cm medium-density Airex pad (Alcan Airex, Aaragu, Switzerland) was utilized as the unstable foam surface. Participants were instructed to hold the balance position for 20 seconds with their eyes closed (see Figure 1 for balance positions). Time was measured using a gym timer (TITLE Platinum, Kansas, US). The examiner recorded Errors made during each stance. The Error criteria included: opening eyes, hands coming off of the hips, being out of position more than five seconds, falling out of position, stepping down with the foot, and abducting the hip more than 30 degrees.[13] If two or more errors occurred simultaneously, it was scored as only a single error. Another error was not scored until after participants had returned to the testing position. Participants were instructed to set their foot down and to return to the testing position as quickly as possible if they felt they were losing their balance. If participants stayed out of the testing position for longer than five seconds, the maximum score of ten was recorded for that stance. Participants were not made aware of the criteria for errors. A single trial included all four conditions with the measured outcomes being the number of Errors for each stance as well as the total number of Errors. Verbal instructions and scoring sheets for the mBESS can be found in Appendices A and B.

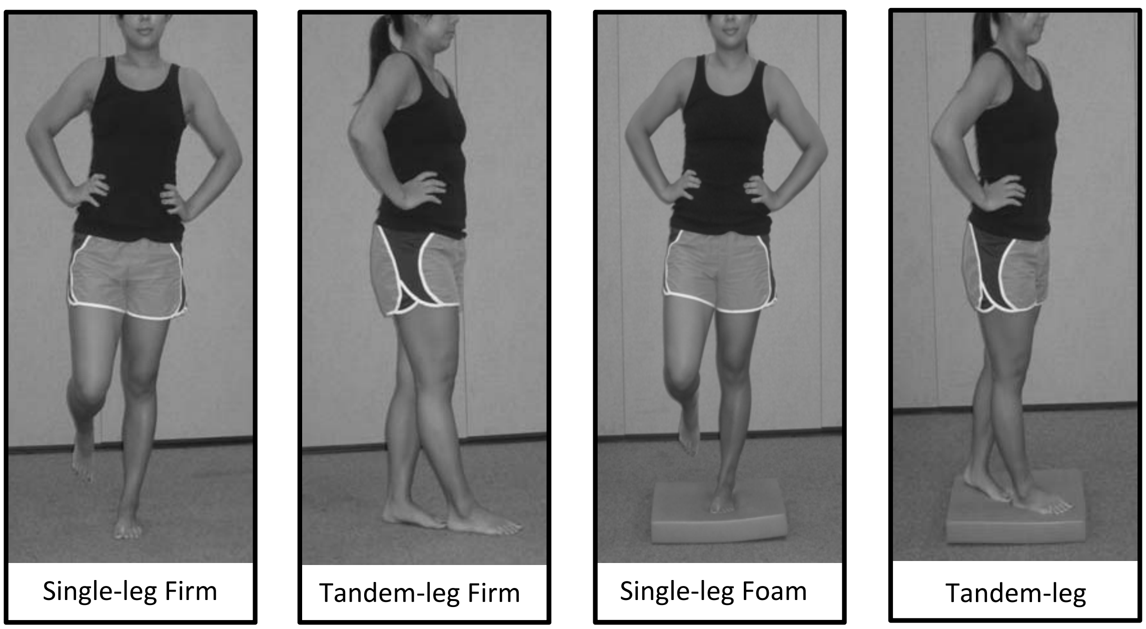

Figure 1. Modified Balance Error Scoring System

Cognitive Tasks:

Three different verbal mental tasks were administered as the cognitive component of this study: BDR, SS, and APST. Participants were given instructions, including an example, prior to each task. Instructions and scoring sheets for all three cognitive tasks can be found in Appendices A and B. All cognitive tests were administered for 20 seconds during Single-Task session in order to standardize the time period with the physical task. The outcome measures for cognitive tasks were the following: the number of incorrect response (Error), the total number of attempted (Digit Span), and Accuracy. Accuracy was calculated as $\frac{Digit\ Span - Error}{Digit\ Span}$.

Backward Digit Recall (BDR)

Participants were instructed to repeat sets of numbers, consisting of digits one through nine, given by the researcher in reverse order.[18] Each set of numbers was randomly selected with the following restrictions: digits were only present once in any individual set of numbers, with no immediate ascending or descending pairs (e.g., 5-6 or 6-5), no double multiple jumps (e.g., 2-4-6 or 3-6-9), and no consecutive sequences began or ended with the same digit.[20] A baseline Backward Digit Recall was performed to standardize the length of number sets used during Single- and Dual-Task trials for each individual. The baseline trial started at three digits; when the participant responded correctly, the next number set given was increased by one digit. The last set of number each participant repeated correctly was utilized as their standardized number of digits used for the remaining trials.[21] The total number of sets attempted was considered as Digit Span; total number of sets incorrect response was recorded as Error.

Serial Sevens (SS)

Participants were given a random number between 80 and 100 and instructed to subtract by sevens.[14] When participants failed to perform a correct subtraction, it was considered as an Error. The total number of incorrect calculations was recorded as Error and total number of calculations attempted was counted as Digit Span.[22] For example, if participants responded with the following, 100…93…86…79…72…70, the measured outcome would be 4 incorrect answers with a Digit Span of 5.

Auditory Pure Switch Task (APST)

Participants were instructed to differentiate between even and odd numbers as they were given by the examiner. The number set was comprised of random digits between one and eight. [5,16,17] Each number was given to participants immediately following the previous response. The total number of incorrect response was recorded as Error and the total number of responses attempted was Digit Span.

Dual-Task Conditions:

The physical task was combined with each cognitive task to create three distinct Dual-Task conditions. These combinations can be seen in Table 1. The measured outcomes of each component of the Dual-Task conditions remained the same as measured outcomes in the Single-Task condition.

Table 1. Combinations of Dual-Task Test (mBESS = modified Balance Error Scoring System)

		Physical Task
		mBESS
Cognitive Tasks	Serial Sevens (SS)	mBESS + SS
	Backward Digit Recall (BDR)	mBESS + BDR
	Auditory Pure Switch Task (APST)	mBESS + APST

Participants:

Participants were 54 healthy individuals (21 male: 20.9 ± 1.6 y/o, 33 female: 21.0 ± 1.7 y/o) recruited from the local college population. Exclusionary criteria for participants included: a history of concussions, any lower extremity injury within the last 3 months, any diagnosis of learning disabilities, knowledge of any of the tasks in the current study, or any other condition that could affect the outcomes of the test. Of 54 participants, two participants were not able to complete the second testing session due to lower extremity injury. Three participants' video data from the second testing session were excluded due to a technical difficulty and therefore were not included in live and filmed mBESS Accuracy analyses.

Procedure:

Data Collection

This study consisted of two data collection sessions separated by two to three weeks in order to control for learning effects.[4,23] Upon arrival for their first study session participants completed an informed consent form approved by the university's Human Studies Program Institutional Review Board along with a demographic questionnaire (See Appendices C and D for the informed consent and the questionnaire). Prior to the

Single-Task trials, the baseline Backwards Digit Recall was completed. All trials were completed barefoot. Instructions were given prior to the start of the first trial of each task; shortened instructions were provided for all subsequent trials with follow up instructions provided as necessary (See Appendix A for instructions). Participants performed two rounds of trials for each Single- and Dual-Task during each testing session. The first round of Single-Task trials (mBESS, SS, APST, and BDR) were administered in a randomized order prior to the first round of Dual-Task trials. This sequence was then repeated for the second round of both Single- and Dual-Tasks trials. The testing order of Single- and Dual-Task trials is demonstrated in Figure 3. Session two consisted of the same procedure as session one with the exception of the introductory period. All trials were recorded on a digital video recorder (Handycam DCR-SR68, Sony, Japan) in order to verify the live scoring conducted during the trial.

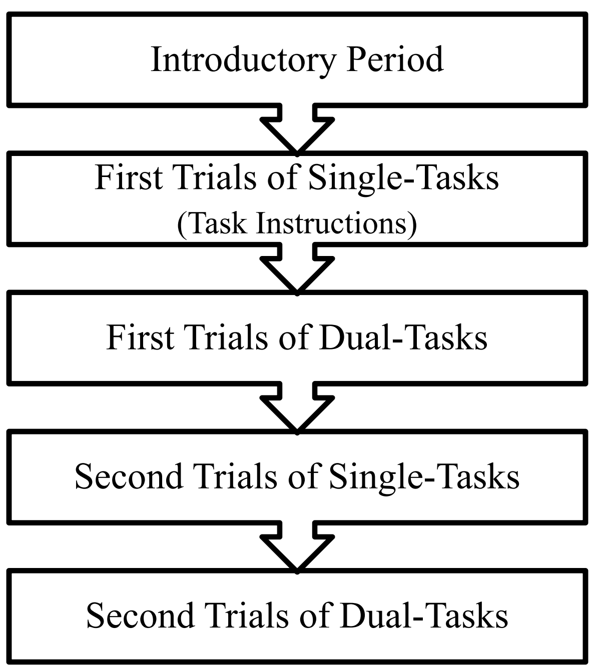

Figure 2. Order of Testing Trials

Statistical Analysis:

Data were analyzed using SPSS Statistical Analysis Software Version 22 (IBM, Armonk, New York, USA). Statistical significance was set at a $p < 0.05$ probability level. The mean of the two trials for each outcome measures for both sessions were used for analyses [4]. Differences between each physical task in Single- (mBESS) and Dual-Task (mBESS+BDR, mBESS+SS, and mBESS+APST) conditions were analyzed using a one-way repeated measures ANOVA with post-hoc analysis using Bonferroni test to identify the relationship between the groups. The same analysis method was utilized to analyze differences between each mBESS stances in Single- and Dual-Task conditions (mBESS SL + BDR, mBESS TAN + BDR, mBESS SLF + BDR, mBESS TANF + BDR; mBESS SL + SS, mBESS TAN+ SS, mBESS SLF + SS, mBESS TANF + SS; mBESS SL + APST, mBESS TAN +APST, mBESS SLF + APST, mBESS TANF + APST). Differences between Single- and Dual-Task outcome measures of the cognitive tasks (BDR in mBESS SL, TAN, SLF, TANF; SS in mBESS SL, TAN, SLF, TANF; APST in mBESS SL, TAN, SLF, TANF) were analyzed utilizing repeated measures ANOVA as well. Accuracy of live and video scores was examined utilizing paired *t*-test for each stance and total mBESS score. Reliability of mBESS scoring between session one and two was examined for each examiner by calculation of $ICC_{(2,1)}$ and paired *t*-tests. Intraclass correlation coefficients were interpreted as follows: excellent reliability $ICC \geq 0.75$, fair to good reliability $0.40 \leq ICC < 0.75$, and poor reliability $ICC < 0.40$.[24]

Results

Physical Task:

Repeated measures ANOVA revealed significant increase in mBESS total score when paired with SS compared to its Single-Task condition only during session one (live score: $p = 0.037$, video score: $p = 0.009$) (Table 2). There were no significant differences in mBESS total score between live and video scoring. The mBESS total scores were broken down into four stances (SL, TAN, SLF, and TANF) in order to analyze the effect of Dual-Task on each individual stance. For each stance, there were no significant differences between Single- and Dual-Task conditions for all combinations (Table 4). Paired *t*-tests revealed no significant differences between live score and video in all Dual-Task conditions for each stance ($p > 0.05$). Means and SD for mBESS total score and scores for each stance in Single- and Dual-Task conditions for each cognitive test are provided in Tables 2 - 5.

Table 2. Results of mBESS Total Scores for Live and video Scoring in All Testing Conditions (Mean ± SD)

		Single-Task	Dual-Task with Backward Digit Recall	Dual-Task with Serial Seven	Dual-Task with Auditory Pure Switch Task
Live scoring	Session 1	11.39 ± 5.26	12.28 ± 7.25	13.46 ± 7.11[a]	12.67 ± 7.02
	Session 2	12.81 ± 6.56	13.64 ± 8.16	13.75 ± 8.41	12.52 ± 7.76
Video Scoring	Session 1	11.73 ± 5.38	12.59 ± 7.08	13.91 ± 7.27[a]	12.61 ± 7.27
	Session 2	12.13 ± 5.91	13.42 ± 7.90	13.98 ± 7.73	12.24 ± 7.72

mBESS: modified Balance Error Scoring System
[a] Significant difference between Single-Task and Dual-Task ($p < 0.05$).
[b] No significant differences were found between live score and video score.

Table 3. Reslts of each mBESS Stance for Single-Task and Dual-Task with Backward Digit Recall in Session 1 and Session 2 (Mean ± SD)

Stance	Single-Task		Dual-Task	
	Session 1	Session 2	Session 1	Session 2
Single-leg firm	1.45 ± 1.43	2.02 ± 2.55	1.45 ± 2.29 [a]	2.05 ± 2.40 [a]
Tandem firm	0.42 ± 0.64	0.51 ± 0.67	0.56 ± 1.16 [a]	0.76 ± 1.49 [a]
Single-leg foam	6.59 ± 2.60	6.83 ± 2.45	7.00 ± 2.96 [a]	7.45 ± 2.68 [a]
Tandem foam	3.00 ± 2.93	3.46 ± 3.19	3.11 ± 3.37 [a]	3.38 ± 3.55 [a]

mBESS: modified Balance Error Scoring System
[a] No significant differences were found between Single-Task and Dual-Task.

Table 4. Results of each mBESS Stance for Single-Task and Dual-Task with Serial Seven in Session 1 and Session 2 (Mean ± SD)

Stance	Single-Task		Dual-Task	
	Session 1	Session 2	Session 1	Session 2
Single-leg firm	1.45 ± 1.43	2.02 ± 2.55	1.93 ± 2.33 [a]	1.87 ± 2.31 [a]
Tandem firm	0.42 ± 0.64	0.51 ± 0.67	0.63 ± 1.36 [a]	0.83 ± 1.67 [a]
Single-leg foam	6.59 ± 2.60	6.83 ± 2.45	7.60 ± 2.45 [a]	7.48 ± 2.95 [a]
Tandem foam	3.00 ± 2.93	3.46 ± 3.19	3.24 ± 3.27 [a]	3.63 ± 3.82 [a]

mBESS: modified Balance Error Scoring System
[a] No significant differences were found between Single-Task and Dual-Task.

Table 5. Results of each mBESS Stance for Single-Task and Dual-Task with Auditory Pure Switch Task in Session 1 and Session 2 (Mean ± SD)

Stance	Single-Task		Dual-Task	
	Session 1	Session 2	Session 1	Session 2
Single-leg firm	1.45 ± 1.43	2.02 ± 2.55	1.45 ± 2.16 [a]	1.94 ± 2.59 [a]
Tandem firm	0.42 ± 0.64	0.51 ± 0.67	0.47 ± 0.98 [a]	0.46 ± 1.14 [a]
Single-leg foam	6.59 ± 2.60	6.83 ± 2.45	7.48 ± 2.70 [a]	7.43 ± 2.69 [a]
Tandem foam	3.00 ± 2.93	3.46 ± 3.19	3.23 ± 3.41 [a]	2.78 ± 3.30 [a]

mBESS: modified Balance Error Scoring System
[a] No significant differences were found between Single-Task and Dual-Task.

Cognitive Tasks:

Repeated measures ANOVA revealed a significant decrease in BDR Accuracy under Dual-Task SLF condition compared to Single-Task ($p = 0.019$) (Table 6). Digit Span for both SS and APST under Dual-Task SLF condition significantly decreased compared to each Single-Task condition ($p = 0.042$ and $p < 0.001$ respectively) (Tables 7 and 8). Digit Span for BDR under Dual-Task SLF condition also decreased compared to Single-Task but did not reach statistical significance ($p = 0.055$) (Table 6). Digit Span for APST under Dual-Task TANF condition significantly decreased compared to Single-Task condition ($p = 0.003$) (Table 8).

Table 6. Results of Backward Digit Recall for All Testing Conditions (Mean ± SD)

	Error	Digit Span	Accuracy
Single-Task	0.99 ± 0.85	3.47 ± 1.44	0.69 ± 0.25
Dual-Task with mBESS SL	0.89 ± 0.87	3.65 ± 1.25	0.70 ± 0.29
Dual-Task with mBESS TAN	1.04 ± 1.02	2.50 ± 1.39	0.66 ± 0.28
Dual-Task with mBESS SLF	1.17 ± 1.05	3.22 ± 1.27	0.58 ± 0.28[a]
Dual-Task with mBESS TANF	0.85 ± 0.86	3.43 ± 1.29	0.68 ± 0.26

mBESS: modified Balance Error Scoring System, SL: Single-leg firm, TAN: Tandem, SLF: Single-leg foam, TANF: Tandem foam

[a] Significant difference between Single-Task and Dual-Task ($p < 0.05$).

Table 7. Results of Serial Sevens for All Testing Conditions (Mean ± SD)

	Error	Digit Span	Accuracy
Single-Task	0.54 ± 0.66	5.85 ± 2.14	0.89 ± 0.14
Dual-Task with mBESS SL	0.52 ± 0.64	5.98 ± 2.48	0.89 ± 0.16
Dual-Task with mBESS TAN	0.44 ± 0.49	5.60 ± 2.48	0.89 ± 0.15
Dual-Task with mBESS SLF	0.49 ± 0.56	5.27 ± 2.34[a]	0.87 ± 0.17
Dual-Task with mBESS TANF	0.31 ± 0.44	5.75 ± 2.37	0.93 ± 0.10

mBESS: modified Balance Error Scoring System, SL: Single-leg firm, TAN: Tandem, SLF: Single-leg foam, TANF: Tandem foam

[a] Significant difference between Single-Task and Dual-Task ($p < 0.05$).

Table 8. Results of Auditory Pure Switch Task for All Testing Conditions (Mean ± SD)

	Error	Digit Span	Accuracy
Single-Task	0.01 ± 0.07	16.37 ± 1.38	1.00 ± 0.01
Dual-Task with mBESS SL	0.01 ± 0.07	16.15 ± 1.54	1.00 ± 0.01
Dual-Task with mBESS TAN	0.06 ± 0.16	16.35 ± 1.50	1.00 ± 0.01
Dual-Task with mBESS SLF	0.06 ± 0.23	15.32 ± 1.74[a]	1.00 ± 0.02
Dual-Task with mBESS TANF	0.03 ± 0.12	15.77 ± 1.61[a]	1.00 ± 0.01

mBESS: modified Balance Error Scoring System, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

[a] Significant difference between Single-Task and Dual-Task ($p < 0.01$).

Reliability Analysis

Modified Balance Error Scoring System:

Intraclass Correlation Coefficients (ICC) and paired *t*-tests were utilized to analyze reliability between session one and two within each examiner (Examiner 1: n=28, Examiner 2: n=24) for mBESS for both Single- and Dual-Task conditions. For all Single-Task conditions, both examiners' ICCs for mBESS total score indicated fair to good reliability (Examiner 1: ICC = 0.71, Examiner 2: ICC = 0.67). Reliability for each stance of Single-Task mBESS for Examiner 1 indicated good reliability except TANF stance, which indicated poor reliability (SL ICC = 0,54, TAN ICC = 0,45, SLF ICC = 0.45, TANF ICC = 0.35). Examiner 2 indicated good reliability for SL and SLF stances while poor reliability for TAN and TANF (SL ICC = 0.62, SLF ICC = 0.49, TAN ICC = 0.38, TANF ICC = 0.30). Paired *t*-tests indicated no significant improvements in Single-Task mBESS total score and score of each stance in the second session.

For all of the Dual-Task conditions, both examiners' ICCs for mBESS total scores indicated fair to good reliability (Examiner 1: BDR combination ICC = 0.71, SS combination ICC = 0.60, APST combination ICC = 0.70, Examiner 2: BDR combination

ICC = 0.76, SS combination ICC = 0.54, APST combination ICC = 0.65) (Table 9). There was a significant difference between sessions in mBESS total score with BDR combination indicating increased Error in the second session (Examiner 1: $p = 0.01$, 95% CI: 5.64 to 0.79, Examiner 2: $p = 0.02$, 95% CI: 5.03 to 0.56). There were no significant differences in SS and APST combinations between sessions for both examiners. All Dual-Task mBESS stances with BDR indicated fair to good reliability for both examiners (Examiner 1: SL ICC = 0.58, TAN ICC = 0.51, SLF ICC = 0.43, TANF ICC = 0.60, Examiner 2: SL ICC = 0.63, TAN ICC = 0.65, SLF ICC = 0.44, TANF ICC = 0.59). There were no significant differences between sessions in all stances except for SL in Examiner 1, which indicated a significant increase in amount of Error (Examiner 1: SL $p = 0.02$, 95% CI: 2.23 to 0.20). Test-retest reliabilities for each stance in Dual-Task with SS ranged from poor to good; there were no significant differences between sessions in all stances (Examiner 1: SL ICC = 0.37, TAN ICC = 0.29, SLF ICC = 0.36, TANF ICC = 0.50, Examiner 2: SL ICC = 0.42, TAN ICC = 0.63, SLF ICC = 0.30, TANF ICC = 0.38). Test-rest reliabilities for each stance in Dual-Task with APST ranged from poor to good with the majority of the stances indicating poor reliability; there were no significant differences between sessions in all stances (Examiner 1: SL ICC = 0.58, TAN ICC = 0.31, SLF ICC = 0.20, TANF ICC = 0.48, Examiner 2: SL ICC = 0.67, TAN ICC = 0.17, SLF ICC = 0.25, TANF ICC = 0.31). Among the three cognitive task outcome measures, only Digit Span indicated good to excellent reliability (Examiner 1: BDR ICC > 0.91, SS ICC > 0.72, APST ICC > 0.71; Examiner 2: BDR ICC > 0.90, SS ICC > 0.74, APST ICC > 0.65) for both examiners in all mBESS stances.

Table 9. Results of Intraclass correlation Coefficient (ICC) and Paired *t*-test for mBESS in All Testing Conditions for Each Examiner

Testing Conditions	Examiner 1(n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test
	Session 1	Session 2		P value (95% CI)	Session 1	Session 2		P value (95% CI)
Single-Task	12.54 ± 5.30	15.07 ± 6.72	0.71 (0.46 to 0.85)	0.01 (4.33 to 0.74)	11.71 ± 5.21	14.15 ± 6.31	0.67 (0.38 to 0.84)	0.02 (4.41 to 0.46)
Dual-Task with BDR	13.64 ± 7.65	16.86 ± 8.79	0.71 (0.47 to 0.86)	0.01 (5.64 to 0.79)	12.52 ± 7.41	15.33 ± 8.00	0.76 (0.53 to 0.89)	0.02 (5.03 to 0.56)
Dual-Task with SS	15.27 ± 7.77	16.25 ± 9.00	0.60 (0.29 to 0.79)	0.50 (3.91 to -1.95)	13.94 ± 7.23	14.54 ± 7.64	0.54 (0.12 to 0.77)	0.68 (3.60 to -2.40)
Dual-Task with APST	14.75 ± 7.55	15.93 ± 8.46	0.70 (0.45 to 0.85)	0.32 (3.57 to -1.22)	13.40 ± 6.66	14.60 ± 6.98	0.65 (0.34 to 0.83)	0.31 (3.61 to -1.20)

CI: Confidence Interval mBESS: modified Balance Scoring System, BDR: Backward digit recall, SS: Serial sevens, APST: Auditory pure switch task

Backward Digit Recall:

For BDR Digit Span, ICC indicated excellent reliability (ICC > 0.90) in both Single- and Dual-Task testing conditions for both examiners. Paired *t*-tests revealed significant improvements in BDR Digit Span for the second session for all combinations except for the TANF combination for Examiner 1, and the SLF and TANF combinations for Examiner 2 (Table 10). The BDR Error and Accuracy reliability in all testing conditions ranged from poor (ICC = 0.12) to excellent (ICC = 0.76); Error significantly decreased in the second session in SLF condition for both examiners, and significant improvements in Accuracy for the second session were indicated for SL and SLF conditions for both examiners (Tables 11 and 12).

Serial Seven:

For SS Digit Span, ICCs indicated excellent reliability for all Dual-Task conditions (Examiner 1: ICC > 0.77, Examiner 2: ICC > 0.77) and good reliability for Single-Task (Examiner 1: ICC=0.72, Examiner 2: ICC=0.74). Paired *t*-tests indicated significant improvements in Digit Span for second session for all testing conditions (Table 13). For SS Error, ICC indicated fair to good reliability (Examiner 1: ICC > 0.48, Examiner 2: ICC > 0.57) for all conditions except for Dual-Task TAN (Examiner 1: ICC = 0.31, Examiner 2: ICC = 0.15); significantly less Error in the second session was indicated for the SFL condition only in Examiner 1. For SS Accuracy, ICC indicated poor reliability (Examiner 1: ICC > 0.03, Examiner 2: ICC > 0.03) for all conditions except for Dual-Task TAN for Examiner 1 (ICC = 0.45); significant improvements in the second session were indicated for SLF for Examiner 1 and TAN for Examiner 2 (Tables 14 and 15).

Auditory Pure Switch Task:

For APST Digit Span, ICC indicated good to excellent reliability (ICC > 0.71) in all testing conditions. Paired *t*-tests indicated significant differences in Digit Span between sessions for all conditions (Table 16). In most testing conditions for APST Error and APST Accuracy, ICC tests were not applicable due to a lack of variance in the data set (Tables 17 and18).

Table 10. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Digit Span of Backward Digit Recall in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28) Total Score (Mean ± SD) Session 1	Session 2	ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)	Examiner 2 (n=24) Total Score (Mean ± SD) Session 1	Session 2	ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)
Single-Task	3.43 ± 1.21	3.64 ± 1.43	0.93 (0.85 to 0.97)	0.03 (0.41 to 0.02)	3.44 ± 1.28	3.61 ± 1.52	0.93 (0.85 to 0.97)	0.12 (0.40 to -0.05)
Dual-Task with SL	3.55 ± 1.15	3.80 ± 1.30	0.91 (0.82 to 0.96)	0.02 (0.45 to 0.05)	3.52 ± 1.22	3.80 ± 1.39	0.94 (0.85 to 0.97)	0.01 (0.49 to 0.08)
Dual-Task with TAN	3.30 ± 1.20	3.50 ± 1.21	0.92 (0.82 to 0.96)	0.05 (0.39 to 0.01)	3.28 ± 1.28	3.52 ± 1.33	0.93 (0.84 to 0.97)	0.03 (0.45 to 0.02)
Dual-Task with SLF	3.13 ± 1.04	3.34 ± 1.16	0.91 (0.81 to 0.96)	0.03 (0.40 to 0.03)	3.15 ± 1.11	3.37 ± 1.22	0.90 (0.78 to 0.96)	0.06 (0.44 to -0.01)
Dual-Task with TANF	3.32 ± 1.13	3.48 ± 1.23	0.91 (0.82 to 0.96)	0.10 (0.35 to -0.03)	3.39 ± 1.22	3.46 ± 1.33	0.93 (0.84 to 0.97)	0.54 (0.27 to -0.14)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 11. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Error of Backward Digit Recall in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28) Total Score (Mean ± SD) Session 1	Session 2	ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)	Examiner 2 (n=24) Total Score (Mean ± SD) Session 1	Session 2	ICC $_{(2,1)}$ (95% IC)	Paired *t*-test P value (95% CI)
Single-Task	1.02 ± 0.66	0.64 ± 0.43	0.62 (0.33 to 0.81)	0.01 (0.19 to 0.56)	0.98 ± 1.08	0.78 ± 0.74	0.67 (0.37 to 0.85)	0.22 (-0.13 to 0.52)
Dual-Task with SL	0.93 ± 0.77	0.68 ± 0.43	0.20 (-0.18 to 0.53)	0.12 (-0.06 to 0.56)	0.94 ± 0.79	0.72 ± 0.74	0.12 (-0.30 to 0.50)	0.31 (-0.22 to 0.65)
Dual-Task with TAN	1.04 ± 0.79	0.89 ± 0.66	0.13 (-0.25 to 0.47)	0.44 (-0.23 to 0.52)	1.04 ± 1.02	0.91 ± 0.91	0.44 (0.04 to 0.72)	0.55 (-0.31 to 0.57)
Dual-Task with SLF	1.16 ± 0.79	0.75 ± 0.59	0.50 (0.17 to 0.74)	0.01 (0.14 to 0.68)	1.35 ± 1.05	0.78 ± 0.94	0.76 (0.51 to 0.89)	0.01 (0.26 to 0.87)
Dual-Task with TANF	0.95 ± 0.57	0.77 ± 0.80	0.37 (0.01 to 0.65)	0.16 (-0.08 to 0.79)	1.00 ± 1.17	1.04 ± 1.17	0.66 (0.35 to 0.84)	0.80 (-0.40 to 0.31)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 12. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Accuracy of Backward Digit Recall in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test
	Session 1	Session 2		P value (95% CI)	Session 1	Session 2		P value (95% CI)
Single-Task	0.66 ± 0.25	0.79 ± 0.17	0.71 (0.47 to 0.86)	0.01 (0.19 to 0.07)	0.66 ± 0.27	0.78 ± 0.18	0.74 (0.48 to 0.88)	0.01 (0.19 to 0.05)
Dual-Task with SL	0.69 ± 0.31	0.81 ± 0.16	0.48 (0.13 to 0.72)	0.02 (0.22 to 0.02)	0.67 ± 0.33	0.81 ± 0.18	0.51 (0.14 to 0.76)	0.01 (0.26 to 0.03)
Dual-Task with TAN	0.65 ± 0.28	0.71 ± 0.27	0.32 (-0.06 to 0.61)	0.33 (-0.19 to 0.06)	0.70 ± 0.27	0.69 ± 0.29	0.50 (0.12 to 0.75)	0.88 (-0.11 to 0.13)
Dual-Task with SLF	0.59 ± 0.29	0.73 ± 0.25	0.61 (0.31 to 0.80)	0.01 (0.24 to 0.05)	0.55 ± 0.29	0.73 ± 0.26	0.64 (0.32 to 0.83)	0.01 (0.27 to 0.07)
Dual-Task with TANF	0.66 ± 0.26	0.73 ± 0.25	0.70 (0.44 to 0.85)	0.08 (-0.15 to 0.01)	0.64 ± 0.28	0.73 ± 0.26	0.73 (0.46 to 0.87)	0.05 (-0.17 to 0.01)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 13. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Digit Span of Serial Sevens in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test
	Session 1	Session 2		P value (95% CI)	Session 1	Session 2		P value (95% CI)
Single-Task	5.54 ± 2.14	7.92 ± 3.15	0.72 (0.49 to 0.86)	0.01 (2.26 to 0.71)	5.23 ± 2.14	6.92 ± 3.34	0.74 (0.49 to 0.88)	0.01 (2.54 to 0.83)
Dual-Task with SL	5.59 ± 2.62	6.73 ± 3.00	0.81 (0.64 to 0.91)	0.01 (1.81 to 0.48)	5.40 ± 2.77	6.65 ± 3.22	0.82 (0.63 to 0.92)	0.01 (2.01 to 0.49)
Dual-Task with TAN	5.27 ± 2.44	6.80 ± 3.02	0.79 (0.59 to 0.90)	0.01 (2.23 to 0.84)	5.08 ± 2.52	6.73 ± 3.26	0.80 (0.60 to 0.91)	0.01 (2.42 to 0.87)
Dual-Task with SLF	4.71 ± 2.42	6.29 ± 3.14	0.77 (0.56 to 0.89)	0.01 (2.31 to 0.83)	4.52 ± 2.52	6.23 ± 3.33	0.77 (0.54 to 0.89)	0.01 (2.55 to 0.87)
Dual-Task with TANF	5.50 ± 2.31	6.76 ± 2.73	0.80 (0.61 to 0.91)	0.01 (1.89 to 0.63)	5.23 ± 2.53	6.67 ± 2.88	0.80 (0.60 to 0.91)	0.01 (2.16 to 0.72)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 14. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Error of Serial Sevens in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)
	Session 1	Session 2			Session 1	Session 2		
Single-Task	0.34 ± 0.43	0.46 ± 0.51	0.71 (0.47 to 0.86)	0.34 (0.39 to -0.14)	0.81 ± 0.79	0.48 ± 0.87	0.67 (0.38 to 0.84)	0.02 (0.05 to 0.62)
Dual-Task with SL	0.41 ± 0.49	0.48 ± 0.74	0.48 (0.13 to 0.72)	0.66 (0.40 to -0.26)	0.67 ± 0.79	0.58 ± 0.76	0.57 (0.23 to 0.79)	0.58 (0.22 to -0.39)
Dual-Task with TAN	0.45 ± 0.44	0.45 ± 0.52	0.31 (-0.06 to 0.61)	1.00 (0.20 to -0.20)	0.46 ± 0.55	0.25 ± 0.36	0.15 (-0.26 to 0.52)	0.12 (0.05 to -0.46)
Dual-Task with SLF	0.45 ± 0.53	0.20 ± 0.39	0.61 (0.31 to 0.80)	0.02 (0.04 to 0.46)	0.54 ± 0.61	0.44 ± 0.71	0.58 (0.24 to 0.79)	0.41 (0.15 to -0.36)
Dual-Task with TANF	0.32 ± 0.42	0.30 ± 0.38	0.70 (0.44 to 0.85)	0.60 (0.16 to -0.27)	0.33 ± 0.48	0.44 ± 0.65	0.57 (0.22 to 0.79)	0.35 (0.33 to -0.12)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 15. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Accuracy of Serial Sevens in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test P value (95% CI)
	Session 1	Session 2			Session 1	Session 2		
Single-Task	0.92 ± 0.13	0.91 ± 0.13	0.07 (-0.31 to 0.42)	0.70 (0.05 to -0.08)	0.91 ± 0.13	0.92 ± 0.17	0.18 (-0.23 to 0.54)	0.82 (0.09 to -0.07)
Dual-Task with SL	0.89 ± 0.16	0.90 ± 0.15	0.03 (-0.34 to 0.40)	0.77 (0.09 to -0.07)	0.88 ± 0.16	0.89 ± 0.15	-0.03 (-0.42 to 0.37)	0.73 (0.11 to -0.08)
Dual-Task with TAN	0.87 ± 0.16	0.91 ± 0.13	0.45 (0.10 to 0.70)	0.24 (0.09 to -0.02)	0.86 ± 0.17	0.95 ± 0.08	0.23 (-0.18 to 0.57)	0.01 (0.16 to 0.02)
Dual-Task with SLF	0.86 ± 0.19	0.95 ± 0.11	0.15 (-0.23 to 0.49)	0.04 (0.17 to 0.01)	0.86 ± 0.20	0.91 ± 0.19	-0.03 (-0.42 to 0.37)	0.40 (0.16 to -0.07)
Dual-Task with TANF	0.93 ± 0.09	0.95 ± 0.8	0.05 (-0.33 to 0.42)	0.35 (0.07 to -0.03)	0.93 ± 0.10	0.91 ± 0.17	0.29 (-0.12 to 0.61)	0.57 (0.05 to -0.09)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 16. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Digit Span of Auditory Pure Switch Task in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC (2,1) (95% CI)	Paired *t*-test	Total Score (Mean ± SD)		ICC (2,1) (95% CI)	Paired *t*-test
	Session 1	Session 2		P value (95% CI)	Session 1	Session 2		P value (95% CI)
Single-Task	16.21 ± 1.34	16.89 ± 1.58	0.78 (0.57 to 0.89)	0.01 (1.06 to 0.30)	16.31 ± 1.35	17.02 ± 1.61	0.76 (0.52 to 0.89)	0.01 (1.14 to 0.27)
Dual-Task with SL	16.07 ± 1.61	16.61 ± 1.85	0.71 (0.47 to 0.86)	0.04 (1.05 to 0.02)	16.19 ± 1.59	16.98 ± 1.65	0.73 (0.47 to 0.88)	0.01 (1.29 to 0.29)
Dual-Task with TAN	16.09 ± 1.59	16.80 ± 1.84	0.85 (0.70 to 0.93)	0.01 (1.08 to 0.35)	16.38 ± 1.42	17.19 ± 1.56	0.82 (0.63 to 0.92)	0.01 (1.19 to 0.43)
Dual-Task with SLF	14.84 ± 1.78	15.88 ± 2.10	0.73 (0.50 to 0.87)	0.01 (1.59 to 0.48)	15.15 ± 1.56	16.27 ± 1.94	0.65 (0.34 to 0.83)	0.01 (1.75 to 0.50)
Dual-Task with TANF	15.48 ± 1.65	15.93 ± 2.15	0.81 (0.64 to 0.91)	0.05 (0.90 to -0.01)	15.79 ± 1.45	16.40 ± 1.84	0.76 (0.52 to 0.89)	0.02 (1.09 to 0.12)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 17. Results of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Error of Auditory Pure Switch Task in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC (2,1) (95% CI)	Paired *t*-test	Total Score (Mean ± SD)		ICC (2,1) (95% CI)	Paired *t*-test
	Session 1	Session 2		P value (95% CI)	Session 1	Session 2		P value (95% CI)
Single-Task	0.00 ± 0.00	0.04 ± 0.13	N/A	0.16 (0.09 to -0.02)	1.00 ± 0.01	1.00 ± 0.01	N/A	0.33 (0.06 to -0.02)
Dual-Task with SL	0.00 ± 0.00	0.02 ± 0.09	N/A	0.33 (0.05 to -0.02)	1.00 ± 0.01	1.00 ± 0.01	N/A	N/A
Dual-Task with TAN	0.05 ± 0.16	0.02 ± 0.09	-0.06 (-0.42 to 0.32)	0.33 (0.04 to -0.11)	1.00 ± 0.01	1.00 ± 0.01	N/A	0.16 (0.02 to -0.10)
Dual-Task with SLF	0.00 ± 0.00	0.04 ± 0.13	N/A	0.16 (0.08 to -0.02)	1.00 ± 0.02	1.00 ± 0.01	N/A	N/A
Dual-Task with TANF	0.00 ± 0.00	0.00 ± 0.00	N/A	N/A	1.00 ± 0.01	1.00 ± 0.01	N/A	N/A

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Table 18. Resutls of Intraclass Correlation Coefficient (ICC) and Paired *t*-test for Accuracy of Auditory Pure Switch Task in All Testing Conditions for Each Examiner

Testing Condition	Examiner 1 (n=28)				Examiner 2 (n=24)			
	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test	Total Score (Mean ± SD)		ICC $_{(2,1)}$ (95% CI)	Paired *t*-test
	Session 1	Session 2		P value (95% CI)	Session 1	Session 2		P value (95% CI)
Single-Task	1.00 ± 0.00	1.00 ± 0.01	N/A	0.16 (0.01 to -0.01)	1.00 ± 0.01	1.00 ± 0.01	0.47 (0.09 to 0.73)	0.17 (0.01 to -0.01)
Dual-Task with SL	1.00 ± 0.00	1.00 ± 0.01	N/A	0.33 (0.01 to -0.01)	1.00 ± 0.01	1.00 ± 0.01	-0.43 (-0.43 to 0.36)	0.90 (0.01 to -0.01)
Dual-Task with TAN	1.00 ± 0.01	1.00 ± 0.01	-0.06 (-0.42 to 0.31)	0.39 (0.01 to -0.01)	1.00 ± 0.01	1.00 ± 0.01	0.16 (-0.26 to 0.52)	0.87 (0.01 to -0.01)
Dual-Task with SLF	1.00 ± 0.00	1.00 ± 0.00	N/A	0.16 (0.01 to -0.01)	1.00 ± 0.02	1.00 ± 0.01	-0.03 (-0.42 to 0.37)	0.16 (0.01 to -0.01)
Dual-Task with TANF	1.00 ± 0.00	1.00 ± 0.00	N/A	N/A	1.00 ± 0.01	1.00 ± 0.01	-0.10 (-0.48 to 0.30)	0.33 (0.01 to -0.01)

CI: Confidence Interval, SL: Single-leg firm, TAN: Tandem firm, SLF: Single-leg foam, TANF: Tandem foam

Discussion

In the current study, healthy collegiate participants demonstrated an inconsistent decrease in performance level when physical and cognitive tasks were performed simultaneously. The total mBESS score increased only under Dual-Task SS condition indicating decreased balance ability as compared to the mBESS Single-Task condition. Decreases in cognitive ability under the Dual-Task condition were also inconsistent. When the effect of each mBESS stance on cognitive ability was analyzed individually, SLF was the only stance that influenced all three cognitive tasks indicated by decreased Digit Span for BDR, SS and APST, as well as decreased Accuracy for BDR. Since the mBESS consists of four different stances, the same cognitive task needed to be administered during each stance; requiring participants to repetitively perform the same cognitive task four times within a single mBESS test. Although the total score of all four stances is conventionally utilized as the mBESS score to indicate balance ability, an isolated use of SLF for Dual-Task combined with Digit Span as a Dual-Task outcome measure may be recommended.

Total scores of mBESS were compared between live scoring and video scoring to examine the accuracy of the scores recorded by the examiners. Since mBESS scoring requires constant attention, conducting and scoring the cognitive tests while scoring mBESS could be difficult and the examiners' ability to accurately score mBESS was of concern. No significant differences between live and video scores were found in all conditions, indicating high accuracy of mBESS scoring while simultaneously conducting the cognitive tests. However, simultaneous scoring of mBESS and cognitive tasks requires the examiner to be highly skilled, and multiple practice sessions are recommended in order to become proficient. Our results suggest that the live scoring can be performed accurately if the examiners are familiar and proficient with simultaneous scoring of both the mBESS and the cognitive tests. Filming Dual-Task mBESS tests will allow the examiners to score the mBESS separately and more accurately, which may be recommended if the examiners are not familiar with the Dual-Task testing protocol.

Overall practice effect for the mBESS was examined by comparing the mBESS total scores and scores of each stance between the two sessions. There were no significant improvements in Single-Task mBESS total scores between two sessions, although its *p* value approaches significant level ($p = 0.054$). Likewise, there were no significant improvements in mBESS total scores and scores for each stance between sessions in all three Dual-Task conditions. The results suggest that there are no practice effects for the mBESS in healthy active individuals under Single- and Dual-Task conditions when the mBESS is conducted two to three weeks apart, which is consistent with the findings of Ross et al. (2011) who reported no practice effect of Dual-Task BESS performance when BESS was performed 14 days apart.[23]

Test-retest reliability was analyzed for mBESS in both Single- and Dual-Task conditions utilizing ICC and paired *t*-test for each examiner separately. Total mBESS scores in Single-Task condition indicated ICC of 0.71 for Examiner 1, and 0.67 for Examiner 2, which is comparable to mBESS ICC reported by Hunt et al.[13] (ICC = 0.73). On the other hand, the test-retest reliability of mBESS total scores under Dual-Task conditions varied. The highest reliabilities of mBESS total score were indicated for the BDR Dual-Task combination for both examiners (Examiner 1: ICC = 0.71, Examiner 2: ICC = 0.76), while fair to good reliabilities of mBESS total scores for SS and APST combinations were indicated for both examiners.

When reliability was analyzed for each mBESS stance in Dual-Task condition, the BDR combinations also indicated the overall highest reliability (fair to good) compared to the SS and APST combinations, with TANF for Examiner 1 (ICC = 0.60) and SL for Examiner 2 (ICC = 0.66) being the highest among all stances.

Test-retest reliability and learning effect between sessions for cognitive tests indicated overall high ICCs for Digit Span for both examiners in all three cognitive tasks. Digit Span for BDR indicated excellent reliability for all testing conditions in both examiners (Examiner 1: ICC > 0.91, Examiner 2: ICC > 0.90), however, most conditions were associated with a significant learning effect; TANF was the only stance that did not have a leaning effect in both examiners. Digit Span for SS indicated excellent reliability (ICC > 0.77) for all Dual-Task testing conditions in both examiners, yet all testing conditions indicated significant learning effects. Digit Span for APST under Single-Task, and TAN and TANF Dual-Task conditions indicated excellent reliabilities (ICC > 0.76) while Dual-Task SL and SLF indicated fair reliabilities (ICC > 0.65); there were significant learning effects for all APST conditions. Most of the cognitive tasks under Dual-Task condition were associated with learning effects as indicated by significant improvements in the outcome measures for the second session. Broglio et al.[7] and Ross et al.[23] also reported significant improvement in the reaction time of cognitive task under Dual-Task condition when sessions were separated by one to three days. Based on the test-retest reliability analyses, Digit Span was the most reliable outcome measure for all cognitive tasks in Dual-Task conditions; however, the leaning effect must be appropriately addressed in order for it to be used in a test-retest model.

Limitations of this study included the inconsistent amount of distraction that occurred during the testing sessions. Although distractions were minimized, there were unavoidable distractions such as other faculty and students walking through the room during testing as well as noticeable outside noise. However, the amount of distractions was no greater than a typical clinic and/or athletic training room.

Conclusion

Previous Dual-Task studies have proposed the potential of Dual-Task testing to be a more sensitive tool in detecting deficits caused by concussion.[3,9,21] Currently, battery testing is widely utilized among athletic trainers to make a return-to-play decision following a concussion. However, battery testing involves isolated administration of cognitive and physical tests, limiting the ability of the athletic trainer to mimic the sport environment that requires athletes to divide their attention between cognitive and physical tasks. In order to make more reliable and conservative decision regarding concussions, a clinically practical Dual-Task test might be beneficial for athletic trainers. The current study explored the effect of Dual-Task on healthy collegiate participants with the aim of developing a Dual-Task concussion assessment tool. Our study utilized clinically practical physical and cognitive tasks that do not require extensive lab equipment; the overall results are consistent with previous studies, which reported decreased performance level under Dual-Task conditions in a healthy active population.[5,7,14] Based on the result of the current study, we recommend further analysis of the Dual-Task combination consisting of SLF stance and BDR using Accuracy or Digit Span as the outcome measure and methods for addressing the leaning effects. Further examination of the effects of Dual-Task methodology on adolescent population is warranted as older individuals have a greater attention capacity and more efficient strategies for allocating attention during Dual-Task testing.

Future studies should also investigate the applicability of these Dual-Task tests in detecting sports-related concussions.

Review of Literature

Introduction

The National Athletic Trainers' Association position statement on concussion recommends utilizing multiple assessment tools to more accurately evaluate sports-related concussion.[25] Management of concussions has to be done conservatively, since each individual reacts to concussion differently and it is difficult to detect the damages from concussion. Although a battery of concussion assessment tools are sensitive to concussion, they all do not emulate physical and cognitive functions that sports participation requires.[1] A Dual-Task is a concussion assessment methodology which allows health care providers to assess concussed athletes in the closest environment of participation in sports. The purpose of this review is to present the current issues regarding concussion assessments.

Definition and Epidemiology

At the 4th International Conference on Concussion in Sport, concussion was defined as "a complex pathophysiological process affecting the brain, induced by biomechanical forces."[10] Although a mild traumatic brain injury is the term used interchangeably with concussion in US literature, each term refers to different injury constructs.[10] Bakhos et al found that over 500,000 concussion related emergency department visits were made between 2001 and 2005.[26] The Center for Disease Control and Prevention estimated that there are between 1.6 and 3.8 million concussive injuries due to sports participation every year.[27] This estimated number of concussion cases may be under reported due to lack of proper diagnosis and recognition. Lincoln et al. found that the concussion incident rate increased more than 4.2-fold in an 11-year period (1997 to 2008) in the high school student-athlete population.[28] In this study, 2651 concussion occurred over the 11-year period and football was accounted for more than half of concussion incidence.[28] Schulz et al. studied the incident rate of concussions among high school student-athletes and discovered that 'the rate' of concussion was more than double the rate in student-athletes with history of concussion(s) than athletes without a history of concussion.[29]

Concussion Assessment Tools

Several concussion assessment tools are available for health care providers to manage concussion injuries. These tools are utilized by certified athletic trainers (ATC) for return to play decision regarding concussion. In order to establish a score to be compared to post-injury performance, gathering baseline scores for each assessment tool was advised during the 4th International Conference on Concussion Sport held in Zurich.[10]

The trend of methods to assess concussion utilized by ATCs were investigated by Covassin et al.[30] They had conducted a web based questionnaire study in which 513 ATCs completed the survey of which methods were often utilized for return to play decisions after concussion. The study revealed that symptom checklist, SAC, Neuropsychological computerized test, and BESS were often utilized by ATCs.[30]

A battery testing method was also recommended during the 4th International Conference on Concussion in Sport.[10] This method allows the examiner to assess attention and memory function and it has been studied to show its practicality and effectiveness. One goal of the battery testing method is to assess multiple aspects of functions that are affected by concussion. This assessment method should be utilized to aid in clinical decision-making on return to play for concussed athletes.

Broglio et al. studied the sensitivity of the battery testing method as a concussion assessment.[1] Participants were 75 collegiate student-athletes who were diagnosed with a concussion between 1998 and 2005. The researchers had compared the post-concussion results of each assessment tool with its baseline results and analyzed the sensitivity to concussion. The areas of the concussion assessment tools covered were postural control, neurocognitive function, and concussion symptom. For the result, when ImPACT, postural control, and symptom assessments scores were coupled, it was 95.7% sensitive to concussion.

Dual-Task Method

The Dual-Task method requires subjects to perform two different tasks simultaneously.[31] Dual-Task methodology has been studied mostly among the elderly population to predict risk of fall.[32,33] To predict fall in elderly population, various gait and mobility tests have been utilized. Verghese et al. focused on the effect of cognitive impairment on fall risk.[19] Walking while talking (WWT) test was selected for Dual-Task in their study with recruiting elderly population older than 65 years old. After 12 months of follow up, they observed that WWT test strongly predicted fall risk in this population. From this result, they recommended to add cognitive task to the current fall risk tests to assessing fall risk. Some researchers have investigated the Dual-Task method among concussed population.

Cantin et al. conducted Dual-Task tests on both healthy and concussed population.[3] In the study, physical task was walking task and several kind of tasks were selected for cognitive task such as Trail Making Test, Stroop Test, and Spatial and Digit Span Tests. Concussed participants performed poorly compared to healthy participants in both physical task and cognitive tasks during Dual-Task test condition.[3] This results agreed with Dual-Task study by Parker et al.[14]

Parker et al. recruited 10 concussed college students and 10 healthy students for their study.[14] Physical task for this study was walking and cognitive tasks were spelling a word in reverse, serial sevens, and months in reverse order. Gait velocity was slower in Dual-Task conditions for both groups and stride length was significantly shorter in concussed group. The authors did not report the changes in cognitive tasks but they observed greater medio-lateral center of mass sway.

Other Dual-Task studies have looked at balancing tasks as a physical task and combined with cognitive tasks. Broglio et al. is the one of these examples with balance task Dual-Task.[7] Healthy young adults were recruited for the study. The physical test was conducted utilizing SOT and cognitive task was switch task of even/odd and vowel/consonant judgment. Under the Dual-Task, response time to the stimulus was longer but physical task was improved. It might be due to the instructions from the examiner included to focus on the balance task, and also the cognitive task being too simple that attention was divided more to physical task.

Resch et al. also studied balance performance, with Dual-Task methodology in healthy college-age students.[5] The tasks for this study were the same as Broglio's study, SOT for physical task and switch task for cognitive task. Their result agreed with Broglio et al. that response time of cognitive task became longer under Dual-Task condition.[5] Some of the stances of SOT improved under Dual-Task conditions as well.[5]

Catena et al. and Teel et al. also selected the same tasks for their Dual-Task study.[4,34] The physical task was conducted with SOT and Stroop task was chosen for cognitive task. Catena et al. recruited both healthy and concussed population for their study but Teel et al. did not include concussed population for their participants. Catena et al. observed that under Dual-Task condition, concussed participants presented longer reaction time for cognitive task and smaller sagittal plane movement was observed for SOT performance. Even though Teel et al. did not include concussed participants, they have observed the similar trend for healthy participants.

Dual-Task was studied among Army population as well. May et al. have studied Dual-Task condition with or without wearing a backpack that weigh 30% of participants' body weight. In their study, SOT was utilized for the physical task and switch task was selected for cognitive task.[17] Their 20 healthy participants presented poor balance score and slow reaction time under Dual-Task and with wearing backpack.

One of the Dual-Task literatures studied Dual-Task methodology on a concussed athlete and compared the Dual-Task test score to Single-Task tests score and followed up for 30 days. Fait et al. conducted several neuropsychological tests as well as gait analysis individually and also Dual-Task methodology on several time points.[6] They observed that even after post-concussion symptoms resolved and series of neuropsychological testing returned to baseline value, Dual-Task tests revealed deficits at 30 days post-concussion.

The following are the physical and cognitive tasks utilized in the current research study. The physical task used was the mBESS, a variation of the BESS. The three cognitive tasks were the Backwards Digit Recall, APST, and Serial Sevens.

Balance Error Scoring System

The Balance Error Scoring System (BESS) is one of the widely used postural concussion assessment tools utilized by ATCs.[2,10,30] It was developed as a postural stability assessment tool which does not require complex or expensive lab equipment.[35]

Riemann et al. studied the efficacy of a clinical balance testing tool for detecting mild head injury in athletes.[8] Sixteen athletes were recruited for this study and all of them sustained a mild head injury during practice or game situation. The researchers evaluated participants with both the BESS and the Sensory Organization Test (SOT) at day 1, 3, 5 postinjury. The results suggested that the BESS may be a useful clinical concussion assessment tool in return-to-play decision making for athletes.

Wilkins et al. and Fox et al. studied the effect of fatigue to the BESS score.[9,36] Both studies recruited Division I collegiate athletes and included exercise protocol to investigate the effect of exercise/fatigue on the BESS scores. The results from both studies agreed with each other that participants made more Errors after the exercise/fatigue protocol. Fox et al. did multiple post exercise BESS trials and studied how long the fatigue effect lasts on the BESS score. The result showed that fatigue lasted up to 13 minutes after the exercise protocol, therefore, the study suggested administering BESS at least 13 minutes after exercise.

Guskiewicz et al.[37] studied the difference in postural stability and neuropsychological testing scores between 36 concussed collegiate athletes and 36 healthy control participants. Postural stability and neuropsychological testing were administered on day 1, 3, and 5 of postinjury, and they were compared to its baseline. The BESS and Sensory Organization Test (SOT) scores on day 1 postinjury were significantly worse than that of the control group.

Valovich et al. studied the learning effect of the BESS.[11,12] Healthy young athletes went through repeated administration of the BESS. Compared to the baseline score, athletes scored lower when they were testing repeatedly on day 5 and 7. When athletes were tested 30 days after the baseline testing, the score did not show significant learning effect.

Hunt et al. investigated the reliability of the modified BESS (mBESS).[13] The BESS without both double-leg stances was called the modified BESS. The subjects were 144 high school football athletes and the data was collected before their season started. The reliability of the regular BESS was 0.60 compared to that of the modified BESS was 0.71.

Previous studies have shown that the BESS is an effective clinical postural stability test.[8,9,36,37] The BESS does not require expensive and complicated machines and can be easily conducted by athletic trainers at a clinical setting. For the current study, mBESS was selected to aim for higher reliable results.[13]

Backward Digit Recall

The Backward Digit Recall (BDR) is a testing tool which measures short-term memory, working memory, and attention.[9] Subjects were instructed to repeat a list of random single digit numbers in reverse order. The highest number of list of numbers repeated in reverse is considered as their Digit Span. Standard Assessment of Concussion (SAC) also utilizes BDR as a part of its neurocognitive testing tool.

Leung et al. investigated BDR in cognitive impairment screening among over 75 years old subjects.[38] Digit Span test (forward and backward digit recall) was conducted to differentiate between dementia and delirium in the older population as a one of the mental tasks. As a result, BDR was more sensitive than forward digit recall in detecting cognitive impairment.

Likewise, St Clair-Thompson et al. studied the differences between forward and backward digit recall test.[18] They stated that both tasks require short-term phonological storage but BDR is classified as a complex span measure of working memory. From the five experiments conducted among healthy college-age students, they concluded that their participants performed poorly in BDR compared to forward digit recall.

Sheridan et al. had selected Digit Span test as one of the mental tasks in their Dual-Task study.[21] They have recruited subjects with possible Alzheimer's disease for this study. The subjects were instructed to walk at their self-selected pace while performing one of the mental tasks. As a result, the researchers found that the subjects walk slower when they perform a mental task together.

Digit Span test was analyzed among children with learning disability as well. Torgesen et al. conducted Digit Span test on children with learning disabilities.[20] As expected, children with learning disabilities struggled with this task compared to children without learning disabilities. In this study, they described how they came up with the set of numbers for this task. The restrictions were the following: no digits were present more than once in any span trial, immediate ascending or descending pairs were eliminated, no double multiple jumps were included, and no consecutive sequences began or ended with the same digit.

Guskiewicz et al.[37] investigated the differences in neuropsychological testing scores between 36 concussed collegiate athletes and 36 healthy control participants. They have included Trail-Making Test A, Trail-Making Test B, Weschsler Digit Span Test (WDST), Stroop Color Word Test, and Hopkins Verbal Learning Test. The result showed the Trail-Making Test B and WDST revealed significant differences between the control group and concussed group at postinjury day 1, 3, and 5. The scores of the Trail-Making Test B and BDR among concussed participants were significantly worse than that of control participants at postinjury day 1.

Based on previous studies, BDR has proven to be an effective cognitive task in Dual-Task methodology.[21,37] Compared to forward digit recall of the Digit Span test, Leung et al. found that BDR was more sensitive in detecting cognitive impairment.[38] Additionally, ATCs are familiar with BDR as a part of SAC in concussion assessment.

Serial Sevens

Serial Sevens (SS) started implementing as an intellectual measurement for psychiatric patients.[39] Parker et al. and Peterson et al. utilized SS in their Dual-Task studies as a cognitive task.[14,40] Both studies utilized concussed population as well as control group and a walking task for their physical task. When the subjects performed the walking task along with the cognitive task, the concussed subject's walking velocity was slower and had a shorter stride length.[14,40]

Auditory Pure Switch Task

The switch task requires participants to response in a specific manner associated with each stimulus. Okumura et al. stated that the switch task can be conducted in two different types: pure condition and mixed condition.[16] Pure condition is when participants were instructed to discriminate within the same category. In contrast, mixed condition type requires participants to discriminate from alternating categories such as number and letter. The switch task can be administered via computer screen (visual) or auditory.

Statistical Analysis

Analysis of variance and/or *t*-test has been utilized in the previous Dual-Task studies.[5,7,14,23,34,37,40] These tests were utilized to investigate the score variance of each task in Single- and Dual-Task conditions with each individual. Test-retest reliability was analyzed utilizing Intraclass Correlation Coefficient (ICC) and paired *t*-test between session 1 and 2. The ICC model and type were selected based on the current study design which each participant had the same examiner administer and score the tasks for both testing sessions. Therefore, ICC model was two-way mixed and type was consistency with 95% confidence interval.[41] ICCs were categorized as follows: excellent reliability $ICC \geq 0.75$, fair to good reliability $0.40 \leq ICC < 0.75$, and poor reliability $ICC < 0.40$.[42]

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Appendix A: Instruction Sheet

Single-Task Testing Instructions

Introduction

"I will ask you to perform several tasks. There will be 2 physical and 3 mental tasks. The testing session will be divided into two parts: a single test session and a double test session, which will take about 50 minutes. For the single task session, you will perform all tasks individually, and for the double task session, you will be asked to perform 2 tasks at the same time."

mBESS

"This test requires you to perform 2 different stances on the floor and also on the blue pad. The blue pad is soft so that it will be harder to balance on, so let's practice all the stances on the pad.

The first stance is a single-leg stance. Pick up the leg that you use to kick a ball with (dominant leg goes up). Do not touch the other leg. Pick up your leg so that your foot is at least above the height of your standing ankle. Then put your hands on your hips and close your eyes. The other stance is a heel-to-toe stance. For this stance, turn 45 degrees to your left. Put whatever leg was in the air for the single-leg stance, so your dominant leg, directly in front of the other foot to make a diagonal line on the pad. Make sure your heel and toe are touching. Place your hands on your hips and close your eyes.

Each stance lasts 20 seconds. You will hear a beep (demonstrate the beep) so you know when to start. You can stop when you hear the second beep. During that time, you want to hold the stance the best you can. If you feel like you are losing your balance, do not hop around or swing your leg, just set your foot down and return to the stance right away."

ETGUG

"For this task, you will start sitting with your back against the chair. When I say 'Go' you will stand up, walk at your normal speed, walk around the cone, come back to the chair, and return to the starting position. Ok, now let's do a practice trial."

Serial Sevens

"For this task, you will subtract by 7s out loud from a random number I give you. For example, if I give you the number 65, you will say 58, 51, 44, etc. The task will start when you hear a beep and you will continue this task until you hear a second beep."

Backward Digit Recall

"For this task, I will give you a string of numbers. Remember these numbers and repeat them in reverse order. After you repeat them back to me, I will give you another string of numbers and you will again repeat them back to me. For example, when I say 5-8-3, you will say 3-8-5. The task will start when you hear a beep and you will continue this task until you hear a second beep."

Auditory Pure Switch Task

"For this task, I will give you a series of numbers. For each number, you will be asked to say whether it is even or odd. The task will start when you hear a beep and you will continue this task until you hear a second beep."

Dual-Task Testing Instructions

Introduction

"Now, we will move on to the double testing session. For this session, you will be asked to perform one of the physical tasks and one of the mental tasks at the same time. I will tell you which combination you will perform every time. Nothing new, all the tasks are from the single task session we already did. Before we start each combination of tasks, I will give you brief instructions for the tasks."

mBESS + SS

"This combination is BESS testing and serial 7's. For each stance, I will give you a random number to start subtracting with. When you hear the beep, you will start subtracting and stop when you hear the second beep."

mBESS + BDR

"For this combination, you will perform the BESS test and the Backward Digit Recall task. Before the first beep of each stance, I will give you a string of numbers. After you hear the beep, you will repeat them back to me in reverse order. I will continue to give you strings of numbers, which you repeat back to me until the second beep. "

mBESS + APST

"For this combination, you will perform the BESS test and the switch task. After you hear the first beep, I will start giving you a series of numbers. Like you did in the single testing session, you will be asked to say whether the number is even or odd. You will continue this until the second beep."

ETGUG + SS

"For this combination, you will perform both the ETGUG and serial 7's. I will let you know the starting number, and when I say 'GO', you will start subtracting by 7's until you sit back down. "

ETGUG + BDR

"For this combination, you will perform both the ETGUG and Backward Digit Recall. Before I say 'GO', I will give you a string of numbers. After I say 'GO', you will start the TUG and repeat those numbers back to me in reverse order. After you repeat the first string of numbers, I will continue to give you strings of numbers until you sit back down."

ETGUG + APST

"For this combination, you will perform both the ETGUG and the switch task. After I say 'GO', I will give you a series of numbers and for each number you will say whether it is an even or odd number. This will continue until you sit back down."

Appendix B: Scoring Sheet

Single Task Trial 1

mBESS

Single Leg Firm	Tandem Firm	Single Leg Foam	Tandem Foam	Total

APST

Number of Error	Number of sets

ETGUG

Time

SS

Number of Error	Digit Span

BDR

Number of Error	Number of sets

Dual-Task Trial 1

mBESS + BDR

	mBESS	**BDR**			
	Number of Errors	Number of Errors		Number of sets	
Single Leg Firm					
Tandem Firm					
Single Leg Foam					
Tandem Foam					
Total		Avg		Avg	

ETGUG + APST

ETGUG	**APST**	
Time	Number of Error	Number of sets

mBESS + SS

	mBESS	**SS**			
	Number of Errors	Number of Errors		Digit Span	
Single Leg Firm					
Tandem Firm					
Single Leg Foam					
Tandem Foam					
Total		Avg		Avg	

ETGUG + BDR

ETGUG	BDR	
Time	Number of Error	Number of sets

ETGUG + SS

ETGUG	SS	
Time	Number of Error	Digit Span

mBESS + APST

	mBESS	APST	
	Number of Errors	Number of Errors	Number of sets
Single Leg Firm			
Tandem Firm			
Single Leg Foam			
Tandem Foam			

Single-Task Trial 2

ETGUG

Time

APST

Number of Error	Number of sets

BDR

Number of Error	Number of sets

mBESS

Single Leg Firm	Tandem Firm	Single Leg Foam	Tandem Foam	Total

SS

Number of Error	Digit Span

Dual Task Trial 2

mBESS + BDR

	mBESS	BDR			
	Number of Errors	Number of Errors		Number of sets	
Single Leg Firm					
Tandem Firm					
Single Leg Foam					
Tandem Foam					
Total		Avg		Avg	

ETGUG + SS

ETGUG	SS	
Time	Number of Error	Digit Span

ETGUG + APST

ETGUG	APST	
Time	Number of Error	Number of Sets

mBESS + SS

	mBESS	SS			
	Number of Errors	Number of Errors		Digit Span	
Single Leg Firm					
Tandem Firm					
Single Leg Foam					
Tandem Foam					
Total		Avg		Avg	

ETGUG + BDR

ETGUG	BDR	
Time	Number of Error	Number of sets

mBESS + APST

	mBESS	APST			
	Number of Errors	Number of Errors		Number of sets	
Single Leg Firm					
Tandem Firm					
Single Leg Foam					
Tandem Foam					
Total		Avg		Avg	

Appendix C: Informed Consent

INFORMED CONSENT FORM

Department of Kinesiology and Leisure Science, University of Hawaii at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

I. **Principle Investigators:** Kaori Tamura, PhD, ATC; Christopher Stickley, PhD, ATC; Morgan Kocher, MS, ATC; Liana Finer, ATC; Ayaka Shimizu, ATC

II. **Title of Study**: A Comparison of Multiple Single- and Dual-Task Methodologies in Healthy Young Adults to Develop a Reliable Clinical Assessment Tool for Sport-Related Concussions

III. **Purpose of Research**: Current sport-related concussion testing involves the use of separate physical and mental tests that the patient must complete. Although this method is a good assessment of sport-related concussions, a new approach of using a combination of tests simultaneously, called Dual-Task testing, might be better in assessing sport-related concussion. The purpose of this study is two fold; first, to identify the effects of Dual-Task testing on outcome measures in healthy college-aged students, and secondly, to evaluate the reliability of these Dual-Task testing methods.

IV. **Expected Duration for Participants**: Two testing sessions that will be approximately two to three weeks apart. Each session will be about 45 minutes long.

V. **Description of Procedures**: You will be asked to complete two different testing sessions. Each testing session will include a series of mental and physical tasks to be performed.

Mental Tasks: For the current study, three different mental tasks were selected. These tasks will be in a question and answer format. The tester will give these mental tasks to you verbally.

Physical Tasks: Two different physical tasks will be used in this study. The first is a balance test that requires you to stand in two positions, each on a firm and foam surface, with your eyes closed. The second is a walking task that involves standing up from a chair, walking a short distance, turning around, and sitting back in the chair.

Each mental and physical task will be performed two times each during each session. After completing these tasks individually, you will then be asked to perform different combinations of mental and physical tasks simultaneously. There will be six different combinations of mental and physicals tasks performed two times each. Once all testing trials are completed, the session is done and you will be scheduled to return for the second testing session approximately two to three weeks later.

V. **Benefits**: There are no direct benefits for participating as a research subject.

VI. **Risks**: The physical tasks (the balance test and the walking test) may cause some soreness with lower extremities upon completion.

VII. **Compensation**: You will be given extra credit for participating in this study. Your course instructor will determine the amount of extra credit you will receive. If you are unable to complete the study, you will be given an alternative opportunity to receive extra credit.

VIII. **Confidentiality**: All personal information will be kept confidential to the extent allowed by law. Several public agencies with responsibility for research oversight, including the UH Human Studies Program, have authority to review research records. Research records will be kept in a locked file in the investigator's office for the duration of the study. All personal information will be destroyed upon completion of the research project.

IX. **Contact Information**: If you have any questions or concerns regarding your participation in this study, you may contact any of the primary investigators: Liana Finer at 707.484.1920, Ayaka Shimizu at 617.771.7611, or Morgan Kocher at 971.237.6903. For questions about your rights as a research participant, contact the University of Hawaii Human Studies Program by phone at 808.956.5007 or by email at uhirb@hawaii.edu.

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Print Name

____ __________________

Signature of Participant Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai'i at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

VIDEO IMAGING CONSENT

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<u>Title of Study</u>: A Comparison of Multiple Single- and Dual-Task Methodologies in Healthy Young Adults to Develop a Reliable Clinical Assessment Tool for Sport-Related Concussions

I understand that I will be video imaged as part of this study. The movement of face, hands, legs, body and how I speak will be taped. The video image will be stored in a locked file cabinet when not being viewed and will only be viewed by researchers directly involved with this study. Only my code number will be used to identify the image. The image will be destroyed after the results of the study are published or 2 years after completion of the study, whichever is first.

I understand that if I do not agree to be video imaged, I will not be able to take part in this study.

I give my consent to be video imaged as part of this project.

____________________	____________________	____________
Subject's Name (Print)	Signature	Date

____________________	____________________	____________
Researcher's Name (Print)	Signature	Date

Appendix D: Demographic Questionnaire

Questionnaire

Name: ______________________________ Age: ________ Gender: ________

Email: ______________________________ Phone: ____________________

Please answer the following questions. Circle the appropriate choice.

1. Have you ever been diagnosed with a concussion?

   Yes   No

2. Which one is your dominant leg? (Which leg do you use to kick a ball?)

   Right   Left

3. Have you ever been diagnosed as any of the following learning disabilities? Circle the appropriate heading(s).

   - ADD/ADHD
   - Autism
   - Dyslexia
   - Others

4. Have you sustained any lower extremity injuries in the past 6 months?

   Yes   No

5. How often do you exercise?

1x /Week   2x/ Week   3x/ Week   4x / Week   5x / Week   6x / Week   Every day   None

6. How long do you exercise?

Less than 30 min   30 min – 1 hour   1 hour – 1.5 hour   1.5 hour – 2 hours   More than 2 hours