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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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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Context: Dual-Task testing, which requires a person to perform both a cognitive and physical task simultaneously, has been suggested as an additional concussion assessment tool. Previous Dual-Task research has focused on various laboratory based tests and has not yet reached a consensus on a Dual-Task combination that can be utilized in the clinical setting for assessing sport-related concussions. **Design:** A randomized repeated-measure design. **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 one physical task and three cognitive tasks. Repeated Measure Analysis of Variance (ANOVA) and paired *t*-tests were performed on SPSS v22.0 with an alpha level of $p<0.05$. Intraclass Correlation Coefficient ($ICC_{2,1}$) was used to analyze test-retest reliability between sessions. **Interventions:** Testing involved one physical task [Expanded Timed Get-Up-and-Go (ETGUG)] and three cognitive tasks [Backward Digit Recall (BDR), Serial Sevens (SS), and Auditory Pure Switch Task (APST)]. Participants performed all tasks as Single-Task and all combinations of physical and cognitive tasks as Dual-Task in randomized order, with the same investigator recording each score. **Main Outcome Measures:** Time to completion for the ETGUG was recorded and Error, Digit Span, Accuracy, and Response Rate were recorded for each cognitive task were compared between Single- and Dual-Task testing conditions. **Results:** Repeated Measure ANOVA indicated that ETGUG time to completion significantly increased when paired with any of the three cognitive tasks [(BDR: 26.013 seconds, SS: 25.734 seconds, and APST: 22.302 seconds) vs. Single-Task ETGUG: 20.082 seconds ($p<0.001$)]. Among the three cognitive tasks, Response Rate for SS and APST significantly decreased when paired with ETGUG (SS: $p<0.01$; APST: $p=0.024$). Test-retest reliability (ICC) for the ETGUG ranged from 0.71 to 0.94. **Conclusions:** The current study utilized clinically practical physical and cognitive tests to develop Dual-Task combinations on a healthy population. Based on the results, 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. Future studies should include application of these Dual-Task tests to a concussed population to investigate the efficacy of the Dual-Task tests in identifying concussion deficits.
Word Count: 374

Table of Contents

List of Tables

List of Figures

Introduction

Thorough assessment of sport-related concussion is essential due to the potential long-term negative effects on learning and recovery [1]. The current National Athletic Trainers' Association position statement endorses the use of a multifaceted testing battery consisting of different types of screening tools that evaluate postural stability, neurocognitive function and self-reported symptoms. This battery is easily administered in a clinical setting and has been shown to be sensitive in identifying deficiencies in their respective areas [2, 3]. Dual-Task testing, which requires a person to perform both a cognitive and physical task simultaneously, has been suggested as an additional assessment tool for concussions. A previous case report using a motion analysis system in a gait laboratory has shown persistent neurocognitive and functional deficits indicated by Dual-Task testing in an athlete who was determined asymptomatic based on the current testing battery [4]. A new clinical assessment tool that is more sensitive in identifying both neurocognitive and functional deficits may be beneficial to athletic trainers in their assessment and management of concussions.

Dual-Task testing has been shown to predict fall risk in older adults [5-8]. Decreased executive function (a set of cognitive skills that are necessary to plan, monitor and execute a sequence of goal-oriented complex actions) has been associated with altered gait performance in older adults when a cognitive task is performed simultaneously [6, 9]. Executive function is one of many areas often affected by sport-related concussions [10]. Researchers have investigated the applicability of the Dual-Task test in the laboratory setting to assess gait in a concussed population and identified it as a valuable measure to incorporate into concussion management [4, 11-14]. However, these methods have used advanced laboratory equipment to investigate outcomes of Dual-Task testing that are not easily reproducible in the clinical setting [4, 5, 11-20].

The Timed Up and Go Test (TUG) is an established clinical test used to assess gait, as well as postural control [21, 22]. A study by Shumway-Cook et al. compared the TUG under Single- and Dual-Task conditions in an elderly population [21]. There was a significant decrease in gait speed during the TUG in a Dual-Task condition compared to Single-Task, although this difference was not associated with fall risk in daily life [21]. Slower gait speed with Dual-Task when performing a level-walking task similar to the TUG has also been reported [6, 7, 12, 13, 15, 23]. Using an established clinical test involving level walking, such as the TUG, is an appropriate choice for clinically practical Dual-Task tests. However, due to the athletic nature and age of the intended population that has a higher risk of concussion, the Expanded Timed Get-Up-and-Go test (ETGUG) was considered more appropriate due to a longer walking distance and has been validated in the intended population [24]. The increase in walking distance also allowed more time for the cognitive tasks to be performed.

Ideal combinations of tasks should consist of two different tests that are easily performed and administered simultaneously in the clinical setting. The selected tasks should not compete for the same specific input or output process (structural interference). For example, attempting to read a sign and catching a baseball both require input from visual cues. Performing these two tasks simultaneously limits the ability of the Dual-Task test to measure attention capacity [25]. Controlling for structural interference allows any deficiencies in Dual-Task performance to be attributed to the overload of the participant's attention capacity. Serial Sevens (SS), Auditory Pure Switch Task (APST), and Backward Digit Recall (BDR) are appropriate tasks to pair with the ETGUG. The SS and APST have previously been used in Dual-Task research and BDR is commonly used in on-field concussion assessment [12, 14, 18, 26, 27]. In addition, these tasks are number-based in order to minimize the influence of the participants' English fluency on the outcome measures as compared to word-based tasks.

To our knowledge, previous Dual-Task research has focused on various laboratory based tests, and has not yet reached a consensus on a Dual-Task combination that can be used in the clinical setting for assessing sport-related concussions. In order to establish the most appropriate combination of Dual-Task tests, it was necessary to investigate the effects of different Dual-Task combinations in a healthy population as well as their reliability. Therefore, the purpose of this study was twofold: first, to identify the effects of Dual-Task testing on outcome measures in healthy college-aged students, and second, to evaluate the reliability of these Dual-Task testing methods. The research hypothesis was that participants would have decreased outcome measures of either the physical or cognitive task when performing a Dual-Task test as compared to the Single-Task test.

Methods

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 tests were performed. Participants were assigned to one of two experienced examiners who administered and scored all tests for that participant. The independent variables were type of task (Single or Dual) and the testing session (Session 1 or Session 2). The dependent variables were the measured outcomes of the physical and cognitive tasks. The physical task for this study was ETGUG [24] and the three cognitive tasks were SS, APST, and BDR. All data collections were conducted in a quiet indoor facility with minimal distractions.

Instruments*:*

Expanded Timed Get-Up-and-Go (ETGUG):

One of the commonly used clinical tests to assess postural stability is the ETGUG [21, 22, 24]. Participants were instructed to sit upright with their back against an armless chair (seat height ~46 cm) located at the beginning of a 10-meter course, stand once they heard a verbal cue, walk to the other end of the course at a self-selected pace, walk around a cone placed at the 10-meter mark, walk back to the chair, and sit back down in the starting position (Figure 1). Each participant completed two trials and the measured outcome was the total time to complete the course. Time was recorded using a digital hand-held stopwatch.

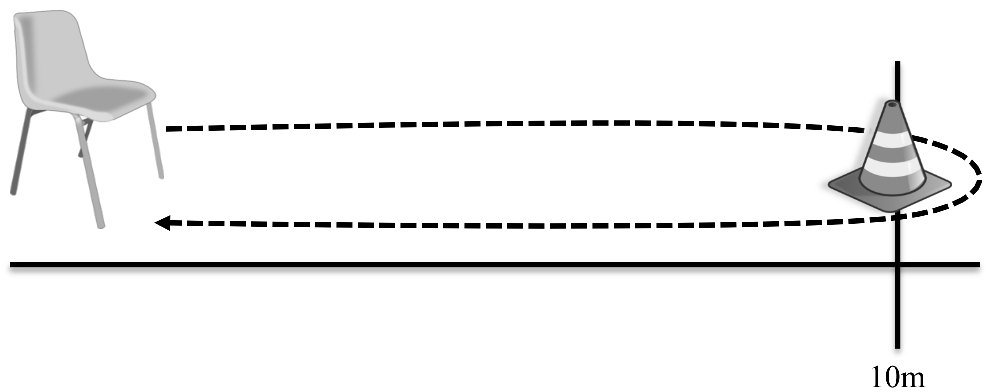

Figure 1. Expanded Timed Get-Up-and-Go Diagram

Cognitive Tasks:

Three different verbal mental tasks were administered as the cognitive component of this study: SS, APST, and BDR. Participants were given instructions, including an example, prior to each task. Instructions and scoring sheets for all three cognitive tasks can be found in the Appendices C and D. All cognitive tests were administered for 20 seconds during the Single-Task session to standardize the testing duration for all cognitive tasks.

<u>Serial Sevens:</u>

Participants were given a random number between 80 and 100 and instructed to subtract out loud by sevens [17]. Each subtraction was considered a unit and when participants failed to perform a correct subtraction, it was scored as an error. The measured outcomes for this task were the Number of Errors, the Percent Accuracy, and the Response Rate [29]. The calculations for Percent Accuracy and Response Rate are represented in Figure 2.

Auditory Pure Switch Task:

Participants were instructed to discriminate out loud between even and odd numbers as they were mentioned. The number set was comprised of random digits between one and eight [14, 18, 30]. Each number was given to participants immediately following the previous response. The measured outcomes for this task were the Number of Errors, the Percent Accuracy, and the Response Rate. The calculations for Percent Accuracy and Response Rate are represented in Figure 2.

Backward Digit Recall:

Participants were asked to repeat sets of numbers in the reverse order of that used by the examiners. The numbers included in this task were one through nine [31]. Each set of numbers was randomly selected with the following restrictions: no digits were present more than once in any set of numbers, immediate ascending or descending pairs were eliminated (e.g., 5-6 or 6-5), no double multiple jumps were included (e.g., 2-4-6 or 3-6-9), and no consecutive sequences began or ended with the same digit [32]. A baseline BDR was performed to determine the length of number sets used during Single- and Dual-Task trials. The baseline trials started from three digits and increased by one digit when the digits were repeated correctly until participants failed to respond correctly. The last set of numbers each participant repeated correctly was utilized as their number of digits used for the remaining trials [33]. The measured outcomes for this task were the Number of Errors, the Percent Accuracy, and the Response Rate. The calculations for Percent Accuracy and Response Rate are represented in Figure 2.

$$\% \ Accuracy = \frac{(\# \ of \ Responses - \# \ of \ Errors)}{\# \ of \ Responses} \times 100$$

$$ST \ Response \ Rate = \frac{\# \ of \ Responses}{20 \ seconds}$$

$$DT \ Response \ Rate = \frac{\# \ of \ Responses}{DT \ ETGUG \ Time \ to \ Completion \ (seconds)}$$

Figure 2. Equations for Percent Accuracy and Response Rate of Cognitive Tasks

Dual-Task Conditions:

The physical task was combined with a 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 those measured in the Single-Task condition.

Table 1. Combinations of Dual-Task tests

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

Participants:

Participants were 54 healthy individuals recruited from the university (Table 2). Exclusionary criteria for participants included: a history of diagnosed concussions, any lower extremity injury within the last 3 months, any diagnosed learning disability, any previous exposure to the tasks used in the current study, or any other condition that could affect the outcomes of the test. Of the 54 participants, two were unable to complete the second testing session due to lower extremity injury.

Table 2. Demographics of Participants for Session 1 and Session 2

	Gender	N	Age (Mean ± SD)
Session 1	Female	33	21.0 ± 1.7
	Male	21	20.9 ± 1.6
Session 2	Female	33	21.0 ± 1.7
	Male	19	20.8 ± 1.7

Procedure:

Data Collection:

This study consisted of two data collection sessions separated by an average of 18.0 ± 4.3 days in order to minimize any learning effects [19, 20]. Upon arrival for the first 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 A and B for Informed Consent Form and Demographic Questionnaire). Prior to the Single-Task trials, participants were asked to remove their shoes. Instructions were given prior to the start of each new testing trial; shortened instructions were provided for all additional trials with follow-up instructions provided as necessary (See Appendix C for instructions). Participants performed two trials for each Single- and Dual-Task combination during each testing session, with results analyzed using the mean of the two trails [20]. The first round of Single-Task trials were administered in a randomized order prior to the first round of Dual-Task trials. This sequence was then repeated for the second trial of both Single- and Dual-Tasks. 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.

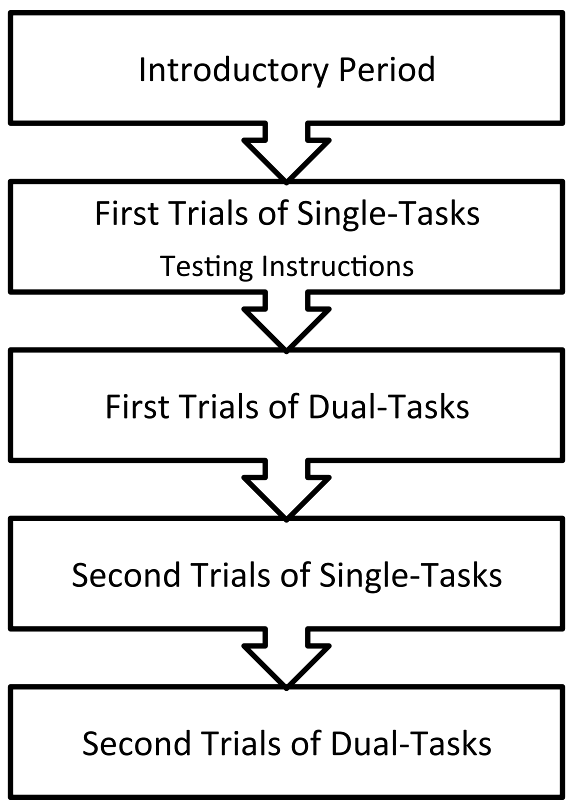

Figure 3. Order of Testing Trials

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 levels. Differences between each physical task in Single- and Dual-Task conditions were analyzed using a one-way ANOVA. Post-hoc analysis was performed using Bonferroni test to identify the relationship between groups. Differences between Single- and Dual-Task outcome measures of the cognitive tasks were analyzed using paired *t*-tests. Test-retest reliability of outcome measures for each task between testing sessions was analyzed using a two-way mixed Intraclass Correlation Coefficient ($ICC_{2,1}$). Intraclass correlation coefficients were interpreted as follows: poor reliability ICC< 0.40, fair to good reliability 0.40 ≤ ICC < 0.75, and excellent reliability ICC ≥ 0.75 [34].

Results

Differences between Single- and Dual-Task:

Completion times for the ETGUG were significantly increased for each Dual-Task combination when compared to the Single-Task condition for each testing session as seen in Figure 4 ($p < 0.001$ for all). Mean differences for Session 1 and Session 2 of each cognitive task Error, Response Rate, and Percent Accuracy are presented in Table 3. Response Rate was significantly decreased under Dual-Task conditions for SS and APST (SS: Session 1 $p < 0.001$, Session 2 $p = 0.02$; APST: Session 1 $p = 0.003$, Session 2 $p < 0.001$). Number of Errors for BDR and APST were significantly increased under Dual-Task conditions (BDR: Session 1 $p = 0.002$, Session 2 $p = 0.03$; APST: $p = 0.013$). Percent accuracy of APST was significantly decreased when performed with ETGUG ($p = 0.015$).

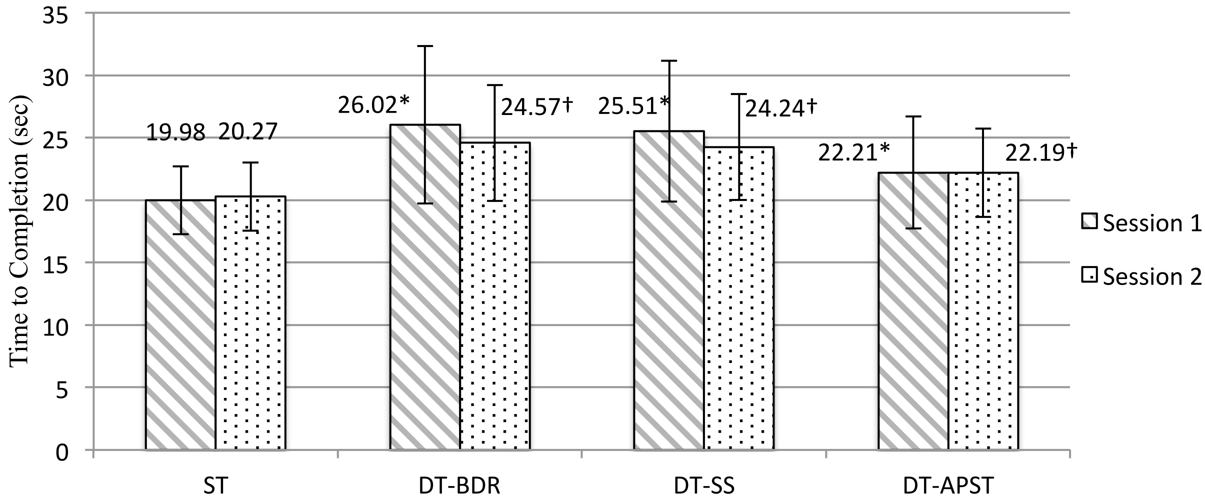

Figure 4. Expanded Timed Get-Up-and-Go **Time to Completion for Single- and Dual-Task Conditions in Session 1 and Session 2**
ETGUG = Expanded Timed Get-Up-and-Go test; ST = Single-Task; DT-BDR = ETGUG paired with Backward Digit Recall; DT-SS = ETGUG paired with Serial Sevens; DT-APST = ETGUG paired with Auditory Pure Switch Task
*Significant difference between Session 1 Single- and Dual-Task conditions ($p < .001$)
†Significant difference between Session 2 Single- and Dual-Task conditions ($p < .001$)

Table 3. Change in Means of all Cognitive Task outcomes between Single- and Dual-Task conditions during Session 1 and Session 2 (Dual-Task – Single-Task = Change in Mean)

		Error	Response Rate	Percent Accuracy
Session 1	BDR DT_{ETGUG}	0.35*	0.00	-3.54%
	SS DT_{ETGUG}	-	-0.12 *	-0.87%
	APST DT_{ETGUG}	0.06*	-0.03 *	-0.29% *
Session 2	BDR DT_{ETGUG}	0.26*	-0.01	-5.05%
	SS DT_{ETGUG}	0.16	-0.04*	-2.29%
	APST DT_{ETGUG}	-	-0.04*	-0.01%

* Significant difference between Single- and Dual-task conditions at $p < 0.05$ level
(DT = Dual-Task; ETGUG = Expanded Timed Get-Up-and-Go; BDR = Backward Digit Recall; SS = Serial Sevens; APST = Auditory Pure Switch Task)

Test-Retest Reliability and Differences between Sessions:

Expanded Timed Get-Up-and-Go:

Differences of mean ETGUG completion time between testing sessions were analyzed using paired *t*-tests for each outcome measure. Completion times for single-task ETGUG and ETGUG paired with APST were not significantly different between sessions for each examiner (Table 3). Completion time for ETGUG paired with BDR was significantly different between testing sessions for each examiner (Examiner 1: $p = 0.03$, Examiner 2: $p = 0.03$) and completion time for ETGUG paired with SS was significantly different only for Examiner 2 ($p = 0.01$). Test-retest reliability for each examiner is presented in Table 4 for each ETGUG combination. All ICC values for each examiner were good to excellent for all ETGUG conditions between sessions.

Table 4. Test-retest Reliability and Differences for Expanded Timed Get-Up-and-Go Completion Times between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
ETGUG	0.73	0.24 (-0.92 - 0.24)	0.90	0.36 (-0.86 - 0.32)
$ETGUG_{BDR}$	0.87	0.03* (0.12 - 2.14)	0.85	0.03* (0.14 - 2.78)
$ETGUG_{SS}$	0.71	0.09 (-0.20 - 2.59)	0.94	0.01* (0.31 - 1.87)
$ETGUG_{APST}$	0.77	0.05 (-1.57 - 0.01)	0.77	0.07 (-0.07 - 1.77)

*$p < 0.05$ (BDR = Backward Digit Recall; SS = Serial Sevens; APST = Auditory Pure Switch Task)

Backward Digit Recall:

Test-retest reliability and differences between sessions for BDR Error, Response Rate and Percent Accuracy are presented in Tables 5 through 7. Error for BDR had a poor to fair reliability (ICC 0.37-0.67) and significant differences were observed between sessions for Single-Task and Dual-Task conditions only for Examiner 1 ($p = 0.01$). Response Rate for BDR had excellent reliability between sessions (ICC 0.81-0.93) and significant differences were observed for the Single-Task condition (Examiner 1: $p = 0.03$, Examiner 2: $p = 0.01$). Percent Accuracy for BDR had good reliability for the Single-Task condition (ICC 0.71-0.74) but fair reliability under the Dual-Task condition (ICC 0.47-0.50). Percent Accuracy for BDR was significantly different between sessions for both Single- and Dual-Task conditions (p= 0.01–0.04).

Table 5. Test-Retest Reliability and Differences for Backward Digit Recall Error between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.62	0.01* (0.19 - 0.56)	0.67	0.22 (-0.13 - 0.52)
DT_{ETGUG}	0.37	0.01* (0.10 - 0.79)	0.42	0.18 (-0.16 - 0.82)

*$p \leq 0.05$ (DT_{ETGUG} = Dual-Task Backward Digit Recall with Expanded Timed-Get-Up-and-Go test)

Table 6. Test-Retest Reliability and Differences for Backward Digit Recall Response Rate between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.93	0.03* (-0.02 - -0.01	0.93	0.01* (-0.04 - -0.01)
DT_{ETGUG}	0.92	0.43 (-0.01 - 0.01)	0.81	0.10 (-0.04 - 0.01)

*$p \leq 0.05$ (DT_{ETGUG} = Dual-Task Backward Digit Recall with Expanded Timed-Get-Up-and-Go test)

Table 7. Test-Retest Reliability and Differences for Backward Digit Recall Percent Accuracy between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.71	0.01* (-0.19 - -0.07)	0.74	0.01* (-0.19 - -0.05)
DT_{ETGUG}	0.50	0.02* (-0.23 - -0.02)	0.47	0.04* (-0.25 - -0.01)

*$p \leq 0.05$ (DT_{ETGUG} = Dual-Task Backward Digit Recall with Expanded Timed-Get-Up-and-Go test)

<u>Serial Seven:</u>

Test-retest reliability and differences between testing sessions for SS Error, Response Rate, and Percent Accuracy are presented in Tables 8 through 10. Error for SS had an overall fair reliability between sessions with the Single-Task condition having a higher reliability than the Dual-Task condition (ICC 0.55 vs. 0.71). Differences for the Number of Errors between sessions were not significant except for the Single-Task condition by Examiner 2 (p=0.02). Response Rate for Single-Task SS had excellent reliability (ICC=0.75) while Response Rate for all Dual-Task conditions had poor to fair reliability (ICC= -0.04 to 0.43). Both Single-Task and Dual-Task conditions for SS Response Rate were significantly different between sessions (p= 0.01 for all). Reliability for SS Percent Accuracy was poor for the Single-Task condition (ICC= 0.07 to 0.18) and fair for the Dual-Task condition (ICC= 0.52 to 0.54). There were no significant differences between testing sessions for both Single- and Dual-Task SS Percent Accuracy (p = 0.11-0.82).

Table 8. Test-Retest Reliability and Differences for Serial Sevens Error between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.71	0.34 (-0.39 - 0.14)	0.67	0.02* (0.05 - 0.62)
DT $_{ETGUG}$	0.50	0.20 (-0.48 - 0.11)	0.55	0.71 (-0.28 - 0.41)

*$p \leq 0.05$ (DT $_{ETGUG}$ = Dual-Task Serial Sevens with Expanded Timed-Get-Up-and-Go test)

Table 9. Test-Retest Reliability and Differences for Serial Sevens Response Rate between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.72	0.01* (-0.11 - -0.04)	0.75	0.01* (-0.10 - -0.03)
DT $_{ETGUG}$	0.43	0.01* (-0.19 - -0.09)	-0.04	0.01* (-0.21 - -0.10)

*$p \leq 0.05$ (DT $_{ETGUG}$ = Dual-Task Serial Sevens with Expanded Timed-Get-Up-and-Go test)

Table 10. Test-Retest Reliability and Differences for Serial Sevens Percent Accuracy between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.07	0.70 (-0.05 - 0.08)	0.18	0.82 (-0.09 - 0.07)
DT $_{ETGUG}$	0.52	0.34 (-0.03 - 0.07)	0.54	0.11 (-0.13 - 0.02)

*$p \leq 0.05$ (DT $_{ETGUG}$ = Dual-Task Serial Sevens with Expanded Timed-Get-Up-and-Go test)

<u>Auditory Pure Switch Task:</u>

Test-retest reliability and differences between testing sessions for APST Error, Response Rate, and Percent Accuracy are presented in Tables 11 through 13. Due to a lack of variance, the reliability for APST Error could not be determined. No significant differences were found in APST Error between sessions (p =0.16-0.33). Reliability for APST Response Rate ranged from poor to good with the Single-Task condition having a higher reliability (Single-Task ICC = 0.58 to 0.78; Dual-Task ICC = 0.39 to 0.52). Auditory Pure Switch Task Response Rates were all significantly different between sessions (*p* =0.01 for all), except for the Dual-Task condition for Examiner 1 (*p* =0.41). Reliability for APST Percent Accuracy could not be determined for Examiner 1 while Examiner 2 had fair reliability for APST Percent Accuracy between sessions (ICC 0.47 to 0.50). Each condition had no significant differences between testing sessions (*p* =0.16-0.33).

Table 11. Test-Retest Reliability and Differences for Auditory Pure Switch Task Error between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	–	0.16 (-0.09 - 0.02)	–	0.33 (-0.07 - 0.02)
DT_{ETGUG}	–	0.16 (-0.09 - 0.02)	–	0.33 (-0.07 - 0.02)

*$p \leq 0.05$ (DT_{ETGUG} = Dual-Task Auditory Pure Switch Task with Expanded Timed-Get-Up-and-Go test)

Table 12. Test-Retest Reliability and Differences for Auditory Pure Switch Task Response Rate between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	0.78	0.01* (-0.05 - -0.01)	0.58	0.01* (-0.08 - -0.02)
DT_{ETGUG}	0.39	0.41 (-0.07 - 0.03)	0.52	0.01* (-0.09 - -0.03)

*$p \leq 0.05$ (DT_{ETGUG} = Dual-Task Auditory Pure Switch Task with Expanded Timed-Get-Up-and-Go test)

Table 13. Test-Retest Reliability and Differences for Auditory Pure Switch Task Percent Accuracy between Session 1 and Session 2

	Examiner 1		Examiner 2	
	ICC	Paired *t*-test *p* value (95% CI)	ICC	Paired *t*-test *p* value (95% CI)
Single-Task	–	0.16 (-0.01 - 0.01)	0.47	0.17 (-0.01 - 0.01)
DT $_{ETGUG}$	–	0.33 (-0.01 - 0.01)	0.50	0.33 (-0.01 - 0.01)

*$p \leq 0.05$ (DT $_{ETGUG}$ = Dual-Task Auditory Pure Switch Task with Expanded Timed-Get-Up-and-Go test)

Discussion

The ETGUG results revealed significant and consistent deficits in performance level under Dual-Task conditions compared to Single-Task conditions in a healthy population. Completion times for the ETGUG task were significantly increased under all Dual-Task conditions indicating a slower walking speed. These results support previous findings in laboratory based Dual-Task research with a concussed population [12, 13, 15]. Slower walking speed during Dual-Task conditions can be attributed to a prioritization of attention based on the difficulty of the tasks [35]. When two tasks are performed simultaneously, individuals voluntarily allocate more attention to the task that is perceived as being more difficult [35]. The results suggest that participants allocated less attention to ETGUG under dual-task conditions resulting in slower walking speed. The differences in completion times for the ETGUG (mean differences = 1.92 to 6.04 sec) are considered clinically significant and easily detectable in the clinical setting by a hand-held stopwatch.

Decreases in cognitive task performance level varied depending on the task and outcome measures. The majority of the significant differences were indicated in the outcome measures of Error and Response Rate; however, the changes in means were not considered clinically significant due to the mean differences being less than a discrete unit of the test. Conversely, an average increase of 3.78 to 5.30 in Error for APST during Dual-Task conditions has been shown in previous research with varying physical tasks [14, 18]. These physical tasks involved longer testing durations (average of 5.5 min) and a more attention-demanding task that involved maintaining the step-up/step-down cadence while maintaining balance. The shorter testing duration (average of 20 sec) and simplicity of the ETGUG compared to the physical tasks utilized in the previous studies might explain the lack of differences in cognitive performance in the current study. Deficits in cognitive outcome measures were relatively small compared to that of ETGUG performance in the Dual-Task condition. The results indicated that participants were devoting more attention to the cognitive task rather than the physical task.

Test-retest reliability for the Single-Task ETGUG completion time ranged from good to excellent (ICC 0.73 to 0.90). This is comparable to the reliability of the Expanded Timed Up-and-Go test, a similar test that used a chair with arm rests and a 3-meter walkway, with a reported ICC range from 0.91 to 0.97 [36]. No significant difference was found in Single-Task ETGUG completion time between testing sessions, indicating that no practice effect occurred and participants were able to maintain the same walking speed for both testing sessions. This indicates that the ETGUG is an appropriate physical task to be used for a Dual-Task test.

Test-retest reliability for the Dual-Task ETGUG time to completion also ranged from good to excellent (ICC 0.71 to 0.94). When paired with BDR, ETGUG completion time had excellent reliability between testing sessions with ICCs ranging from 0.85 to 0.87. Although reliability was excellent, the completion times were significantly improved in Session 2 by an average of 1.29 seconds. The learning effect was also seen in BDR Error and Percent Accuracy indicated by significantly decreased BDR Error and increased Percent Accuracy in Session 2, suggesting that the participants were becoming more familiar with the BDR task. This learning effect of the cognitive task could have caused the participants to perceive the task as being less difficult resulted in less attention necessary to complete the task, which allowed more attention to be allocated to the physical task resulting in decreased completion times during Session 2.

The Dual-Task APST is the only combination that was not associated with a practice effect in the ETGUG performance with excellent test-retest reliability for ETGUG completion time (ICC 0.77). Overall, the learning effects for physical and cognitive tasks were minimal in the combination of ETGUG and APST. Since the APST is one of the simplest forms of cognitive task, there may be limited area for improvement and thus resulted in it having smallest learning effect of the cognitive task. Simplicity of the APST may cause participants to perceive the task to be the least difficult compared to BDR and SS, which may allow the consistent allocation of attention to both cognitive and physical tasks for Session 1 and Session 2.

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

The current study demonstrated decreases in ETGUG performance level when paired with BDR, SS, or APST in a healthy population, indicating that these tasks are challenging enough to overload the participants' attention capacity. The test-retest reliability of the ETGUG time to completion was excellent under Dual-Task conditions. Based on the results of the difference between Single- and Dual-Task and test-retest reliability, the combination of ETGUG and APST with ETGUG time to completion as the outcome measure is the most appropriate combination as a Dual-Task test in the clinical setting. Further examination of the effects of Dual-Task on adolescent population is warranted as older individual have a greater attention capacity and more efficient strategies for allocating attention during Dual-Task testing [37]. Additionally, applicability of this Dual-Task test in a concussed population has yet to be determined and requires further development.

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Literature Review

Introduction

The assessment of concussions in sports has always been changing as more research is being done about this serious injury. Currently, concussion assessment involves testing neurocognitive status, postural stability, and self-reported symptoms from the athlete [3, 27]. This assessment protocol has been the standard for the past eight years with an overall sensitivity of 80% of detecting athletes with concussions [2]. Even with this reliable concussion assessment protocol, researchers are continually trying to improve it.

One testing methodology that is a possible concussion assessment tool is Dual-Task testing. Rather than having the athlete perform one test at a time in current concussion assessment, Dual-Task testing involves performing a physical and cognitive task simultaneously. This method is commonly used to assess risk of falls in the geriatric population. Recent concussion research has looked at how Dual-Task testing can be applied to a younger, more athletic population for concussion assessment.

The purpose of this review of literature is to evaluate the application of Dual-Task testing methodology as a concussion assessment tool. It will address what a concussion is and what the current standard is for concussion assessment. Then it will discuss clinical applications for the Dual-Task paradigm that are already being used. Previous research of Dual-Task methodology in concussion assessment will then be discussed.

What is a Concussion?

Defining what a concussion is has been in much debate over the years. Until recently, a panel of concussion experts at the fourth international conference on concussion defined a concussion as a complex pathophysiological process affecting the brain, induced by biomechanical forces [27]. The panel continues to say that the acute clinical symptoms reflect more of a functional disturbance rather than a structural injury to the brain. Giza et al. in a 2001 study collected data from and reviewed 100 articles related to the functions, post injury pathophysiology, and recovery of concussion [38]. This study defines the functional disturbance of concussion as a neurometabolic cascade. The neurometabolic cascade is when there is an abrupt increase in excitatory transmitters, such as glutamate, causing an imbalance of potassium and calcium being diffused across the cell's membrane [38]. The sodium-potassium pump must now work harder to compensate for this sudden change in ions, requiring more energy from glucose. An energy crisis in the brain develops because there is a lowered amount of glucose in the area of injury, while at the same time more is required by the sodium-potassium pump. The increase in calcium can lead to a worsened energy crisis, interfere with neural connectivity, and potentially cell death. This neurometabolic cascade can lead to impaired coordination, attention, memory and cognition.

Signoretti et al. uses the same definition of a concussion in a study done in 2011. They looked at the neurometabolic cascade as well, summarizing what happens during a concussion, but they also make clinical implications based on the pathophysiology of concussions. A previous study by Vagnozzi et al. is discussed on the possibility of using *N*-acetylaspartate (NAA) as a metabolic marker to assess the brain's metabolic dysfunction after concussion [39]. Patients had a significant change in NAA at three days post injury with a gradual recovery up to 15 days post injury. Complete recovery was at 30 days post injury implying that metabolic recovery occurs after patients self-declare they are asymptomatic [40]. Until this is further studied, concussion will continue to be assessed through neurocognitive and postural stability tests.

Current Recommendations for Concussion Assessment

As previously stated, current concussion assessment involves testing neurocognitive status, postural stability, and self-reported symptoms from the athlete. The National Athletic Trainers' Association (NATA) published a position statement in 2004 of what the standard is for concussion assessment [3]. The position statement makes recommendations on concussion management starting with evaluating and making the return-to-play (RTP) decision. After an athlete suffers a concussion, the certified athletic trainer (ATC) assessing the athlete must rule out cervical spine pathology, monitor vital signs and level of consciousness every five minutes, and record self-reported symptoms by the athlete. When making the RTP decision, a battery of tests is recommended for postural stability and neurocognitive status. Once the athlete is asymptomatic and test scores return to baseline, the athlete is ready to begin a gradual return to activity. The assessment tools recommended for the RTP process depends on which tests are available to the ATC. Some examples are the Standardized Concussion Assessment (SAC) for neurocognitive testing, the Balance Error Scoring System (BESS) for postural stability, and computerized neuropsychological testing programs when available. Baseline testing for athletes is recommended to establish what is "normal" for the athlete.

More recently, the 2012 Zurich consensus statement on concussion also establishes what is recommended in assessment of concussions [27]. This article also states that immediate evaluation must occur by the ATC or designated healthcare provider and repeated monitoring symptoms and vital signs over the first few hours is essential. The NATA position statement recommended using the SAC for neurocognitive testing, but the Zurich article also recommends using the Sports Concussion Assessment Tool V.3 (SCAT3). This test incorporates the SAC test, but includes assessment of symptoms, state of consciousness, coordination, and balance.

Both the NATA article and the Zurich article recommend using the BESS test and neuropsychological tests as tools to determine RTP timeline for an athlete. Although these articles agree on the tools used to conduct a proper concussion assessment, they differ on how to determine the RTP timeline.

The NATA discusses three different approaches in determining concussion severity when making the RTP decision: the first is grading the concussion at the time of injury using the American Academy of Neurology Concussion Grading Scale, the second grading the concussion based on presence and severity of symptoms using the Cantu Evidence-Based Grading Scale, and the third is to not use a grading scale at all. This third approach focuses on the athlete's recovery using the assessment tools and monitoring symptoms. The Zurich article recommends using the third approach with the management of the athlete's recovery rather than grading the severity of the injury. Although there are differences concerning the management of concussions, these two statements agree on what is needed for proper concussion assessment. As future concussion research is done, concussion assessment will always be changing to the best possible method.

The Dual-Task Paradigm

The Dual-Task methodology originally was utilized to assess fall risk in the elderly population. Lundin-Olsson et al. conducted a study to see what might be a reliable predictor of falls in elderly people [8]. They used the sign "stops walking when talking" as their predictor and studied this with 58 elderly people, 72% who were women. Common diagnoses among this group were dementia (n=26), depression (n=25), and history of stroke (n=20) but all subjects were able to walk with or without aids. To observe how each subject walked and talked, a physiotherapist walked with them to the assessment room and recorded whether or not the subject had to stop when a conversation was started. Lundin-Olsson et al. reported 12 subjects who stopped walking when a conversation was started and during a six-month follow-up, ten of those subjects had an incidence of falling. The results had an 83% positive predictive value for the "stops walking while talking" sign making this a possible protocol to predict fall risk in the elderly.

Another study looking at fall risk in the elderly population using the Dual-Task paradigm was by Shumway-Cook et al [21]. The purpose of the study was to test single-versus Dual-Task methodology with the Timed Up & Go Test (TUG) to identify risk of falling. The TUG requires the subject to stand up from a chair, walk three meters, turn 180 degrees, walk back to the chair, and then sit back down. They studied 15 adults with an average age of 78 years with no fall history and 15 adults with an average age of 86.2 years who had two or more falls in the previous six months. The subjects had to perform three tests: the TUG, the TUG with a simultaneous subtraction task, and the TUG while carrying a filled cup of water. The results showed that the TUG had 87% sensitivity and 87% specificity when identifying elderly people who were prone to falls. When adding a secondary task, there was no difference than the TUG when identifying those prone to falls. This study found that the TUG is a sensitive and specific measure to identify fall risk in the elderly population as a single-task.

Both Lundin-Olsson et al. and Shumway-Cook et al. used elderly subjects during their studies to investigate what is a valid method to identify risk of falls in that population. A different study by Condron et al. used a balance task paired with a cognitive task to see if there was a difference in healthy elderly population versus an elderly population with a mild increase in fall risk [41]. Condron et al. also looked at how age affects balance performance in this study. This study used three groups of subjects: 20 healthy young adults with a mean age of 26.4 ± 6.1

years, 20 healthy older adults with mean age of 73.8 ± 6.0 years, and 20 older adults with risk of falls with a mean age of 74.8 ± 7.3 years. The subjects performed a balance task using the Chattecs Balance System under three conditions: stable platform, dynamic platform with forward-backward tilting, and dynamic platform with side-to-side tilting. Incorporating the Dual-Task methodology, the subjects performed the balance test as a single-task as well as with a cognitive task of subtracting backwards by three. The results were that the forward-backward condition with the cognitive task was most effective in discriminating between the three groups. This condition had specificity of 0.8 and sensitivity of 0.8 when classifying the different older-adult groups showing that using the forward-backwards condition with a cognitive task is a reliable measure to discriminate between healthy older adults and those at risk of falling.

A study using the Dual-Task methodology to differentiate between fallers and non-fallers using a single-leg balance and a gait task was conducted by Toulotte et al [7]. The subject population was divided into two groups, 21 fallers and 19 non-fallers. During the single-leg balance, fallers placed their foot on the ground three times more than non-fallers under the eyes open condition and twice as much under the eyes closed condition. Gait parameters were measured during the walking task. The Dual-Task condition was walking with a glass of water in hand. There was a significant difference in gait parameters between fallers and non-fallers under Dual-Task conditions.

A more recent study by McCulloch et al. in 2009 investigated the Walking and Remembering Test (WART) as a new clinical measure using Dual-Task methods to assess fall risk in the elderly population [42]. Subjects used in this study were 25 college students, seven males and 18 females, with a mean age of 24.2 ± 3.0 years and 25 active older adults, 15 male and 10 female with a mean age of 75.9 ± 5.7 years. Subjects were required to walk along a narrow path six meters long as a single-task and Dual-Task measure. The cognitive task used in the Dual-Task condition was a digit-span test where the subject would hear a set of digits at the beginning of the path, start walking, and then repeat the digits at the end of the path. The results showed that the older adults had slower walking times, remembered shorter digit spans, and had greater Dual-Task deficits than younger adults. The WART is a reliable clinical measure of Dual-Task memory and walking to use with the elderly population, but more research is needed with an older population with a wider range of walking abilities.

These studies are only a few that use the Dual-Task method for assessment of fall risk in the elderly population. The tasks used in these studies varied, with Lundin-Olsson et al., Shumway-Cook et al., and McCulloch et al. using tests that required subjects to walk on a level surface while Condron et al. used three different dynamic balance conditions as the test. Toulotte et Al used both a balance and a walking task. The goal for these studies was focused on fall risk in the elderly population, but with the more recent studies, younger populations were used as well. This application of the Dual-Task method in the elderly population has shown that the effect of Dual-Task testing can show differences in physical and mental status among groups. From these findings, researchers are investigating the use of the Dual-Task method in the assessment of concussions.

Dual-Task Paradigm In Concussion Assessment

Using the Dual-Task method in concussion assessment is a new concept in concussion research with studies occurring within the last decade. Broglio et al. did a study looking at balance performance with a cognitive task in a healthy population of young adults [5]. The balance test used was the NeuroCom Smart Balance Master assessment protocol with four balance conditions and the cognitive test used was a visual processing test where subjects had to respond to a letter-digit pair in a two-by-two matrix. Subjects then had to judge whether the number was odd or even if it appeared in the top row, or if the letter was a consonant or vowel if it was in the bottom row. They were tested on two days, the first introducing the subjects to the test and the second involving the single-task testing and the Dual-Task testing trials. The results found in this study were that subjects improved on three out of the four balance conditions and three out of the four reaction times for the cognitive task. More research is needed to see if this protocol can detect changes in balance and cognitive status in the concussed population.

The same year Broglio et al. did their study, Parker et al. conducted a different study on the effect of divided attention on gait following concussion [17]. This study used ten concussed subjects with a Grade 2 concussion with ten matched controls by age, height, weight, and activity level. The tasks used was level-walking on a ten meter path with the subjects barefoot and the cognitive tasks used were spelling five-letter words backwards, subtraction by sevens, and reciting the months of the year in reverse order. Gait variables were taken using 25 reflective markers placed at anatomical landmarks on the upper and lower body. A six-camera motion analysis system was used to capture and reconstruct the subjects' gait and whole-body center of mass motion and velocity. The results showed that during the Dual-Task condition, the concussed group showed greater medio-lateral sway than the healthy group. This study suggested that concussed individuals have a lessened ability to control medio-lateral sway during divided attention.

Catena et al. took a different approach on implementing Dual-Task methods, studying immediate and long-term effects of concussion on balance control with different gait tasks [26]. This longitudinal study examined dynamic balance throughout one-month post concussion using previously reported gait protocols to see which one can detect changes in a concussed population. 30 concussed subjects and 30 matched controls participated in this study and were required to perform level walking, walking while avoiding an obstacle, and walking with cognitive tasks. These tasks were spelling five-letter words backwards, reciting the months of the year in reverse order, and continuously subtracting by a certain number. An eight-camera motion capture system was used to track 29 markers attached to each subject during test trials to analyze center of mass and center of pressure motion. They found that single-task level-walking showed no differences between groups, but walking with a cognitive task showed differences immediately following a concussion and walking while avoiding an obstacle showed differences further along in recovery from a concussion. This study indicates that more than one testing protocol assessing dynamic balance should be utilized in recovery from concussion.

The same authors followed up with another study in 2011 assessing the effects of attention capacity on dynamic balance control [16]. This was also a longitudinal study testing subjects one-month post concussion. Ten subjects with concussion were tested with ten matched controls. Unlike the previous study, Catena et al. decided to use one gait task and one cognitive task. The gait task was level walking and the cognitive task was an auditory Stroop test with reaction time and percent accuracy being measured. Center of mass and center of pressure were analyzed with an eight-camera motion analyses system tracking 29 reflective markers placed at anatomical landmarks on each subject. Results showed that concussed subjects had conservative balance control and returned to normal at 28 days post concussion. Within a testing session, concussed subjects showed deficits with center of mass and pressure control during gait as well as slower reaction times with the auditory Stroop test. This study helps to understand attention capacity changes after concussion while the previous study found what type of task is more sensitive in detecting deficits in balance during concussion recovery.

Based on methods done by Broglio et al., Resch et al. conducted a study as a continuation of the Dual-Task paradigm [18]. Using the same population of healthy young adults, Resch et al. used the same balance test with the NeuroCom Smart Balance Master, but with all six conditions rather than only four used by Broglio et al. Since two of the six conditions require the eyes closed, the cognitive task was an auditory switch task to allow all six conditions to be used. The subjects performed single-tasks of each test for baseline scores and then two days later performed the Dual-Task tests. Balance improved in two of the six conditions with scores of the cognitive task worsening during Dual-Task conditions. This study showed that posture was maintained or improved and took priority over cognitive function. This differs from the results found by Broglio et al. where balance and cognitive function improved from single-task to Dual-Task conditions.

The Dual-Task paradigm is in the beginning stages of how it can be used in concussion assessment and with research being done in the laboratory setting, it now needs to be applied to the clinical setting where concussion assessment occurs. Ross et al. did a study testing the reliability and feasibility of two different Dual-Task protocols [19]. The subjects chosen for this study were 30 healthy college-aged students who were required to perform two testing sessions, 14 days apart. The tests used in this study to assess balance were the BESS and all six conditions of the NeuroCom Sensory Organization Test (SOT). To assess cognition, a procedural reaction time test and a procedural auditory task were used. Each subject performed single-task trials and Dual-Task trials in each of the two testing sessions. Subjects improved on the SOT and the procedural reaction time, but no differences were seen with the BESS test and the procedural auditory task. Resch et al. concluded that the BESS test is a more reliable and clinically applicable test to be used in Dual-Task assessment of concussion.

One recent study conducted in 2012 by Teel et al. also looked at the possibility of clinical Dual-Task concussion assessment [20]. 23 healthy participants were used to complete four conditions of the SOT balance test and an incongruent Stroop test for the cognitive task. The measured outcomes were the balance score for the SOT and reaction time for the Stroop test. Balance scores only improved on one of the four balance conditions during the Dual-Task condition and reaction times were significantly longer under Dual-Task conditions. They concluded that using these two tasks for Dual-Task assessment of concussions are appropriate, but more research is needed in a concussed population.

All of these studies have utilized the Dual-Task methodology in a concussed population with results indicating it can be a useful tool in the clinical setting. With Dual-Task as a possible assessment tool for concussions, an appropriate method must be developed for the clinical setting.

Dual-Task Methodology

Since young adults are a common population to suffer from concussions, these studies have focused on seeing the effects of Dual-Task testing on this group. One inconsistency though on populations used in these studies is whether or not to incorporate concussed individuals as well as healthy individuals. Broglio et al., Resch et al., Ross et al., and Teel et al. used only healthy participants in their research while Parker et al. and both studies by Catena et al. used concussed individuals with matched controls. Ideally, research should use a concussed population since that is the population this research will ultimately benefit; however, in order to see if Dual-Task testing will show any differences of balance or cognitive status, it is important to first use a healthy population. Once that is established in previous literature, testing on concussed individuals is appropriate.

Physical tasks used in previous studies varied when looking at Dual-Task methodology. A common physical task used was the NeuroCom Smart Balance Master with either four or all six conditions used. Broglio et al. and Teel et al. used only four conditions since the cognitive task they used required the subject's eyes to be open. The two conditions requiring the eyes to be closed were not used. Resch et al. used all six conditions because the auditory switch task he used as the cognitive task allowed subjects to complete it with their eyes closed. Ross et al. also used this physical task, but also included the BESS test in the study. Parker et al. and Catena et al. used level walking to assess gait changes rather than static balance used in the other studies previously discussed. Catena also had subjects avoid an obstacle during level walking.

The use of a level-walking task is an easy choice in a Dual-Task method. Level walking performance has been correlated to a person's executive function [6, 9]. Springer et al studied and compared Dual-Tasking effects of gait in three subject groups: healthy young adults, healthy older adults, and idiopathic elderly fallers. Gait parameters were measured as well as executive function and memory. Results showed that there was a significant difference in swing time variability between fallers and non-fallers under Dual-Task conditions. Non-fallers had a significantly lower measure of executive function when compared to healthy older adults, but the memory scores showed no differences between groups.

Another study done by Coppin et al showed this same correlation between gait performance and executive function. This study used 737 community-dwelling older adults and performed simple and complex walking tasks. Executive function was measured and gait speed was the measured outcome for the walking tasks. Results showed that subjects with slower gait speed had lower measure of executive function. Since executive function is affected by concussions, level walking is an appropriate choice as a physical task in Dual-Task methodology [10].

To develop a Dual-Task methodology using level walking, a test already established in the clinical setting is an ideal choice. The Timed Up & Go test (TUG) measure gait and postural sway requiring the subject to walk on a level surface [21, 22]. Shumway-Cook et al used the TUG in a Dual-Task method comparing older adults with no history of falls with those with a history of falls. Subjects with a history of falls had slower TUG times than the other group when a secondary task was added. Whitney et al studied the TUG with subjects who had vestibular diagnoses. Results showed that a slower TUG time correlated with reports of falls in people with vestibular dysfunction.

Based on these studies, the TUG is an ideal choice to use in a Dual-Task methodology; however, it is intended for use with older adults. A test that is similar to the TUG is the Expanded Timed Get-Up-and-Go test (ETGUG) [24]. The TUG has a walking distance of only three meters, but Wall et al increased the distance for the ETGUG to ten meters to have a better measurement of each component of the test. The different components were to stand up from an armless chair, walk ten meters, turn around, walk back to the chair and sit back down. Results showed that the elderly subjects at risk of falling had higher times than the elderly control group. The times for each component were also high for the at-risk group, but further research is needed to identify if the components indicate specific functional deficits.

Cognitive tasks also varied in previous Dual-Task research. These studies have used either visual or auditory switch tasks, the Stroop test, or simple mental tasks such as spelling five-letter words backwards, reciting months in reverse order, and subtracting continuously by a certain number. The cognitive task chosen for a Dual-Task test should be appropriate for the physical task being used. Abernethy described the criteria necessary for developing a Dual-Task methodology and how to select an appropriate secondary task [25]. When choosing a secondary task, in this case a cognitive task, it is important to limit the amount of structural interference it may cause with the primary, or physical, task. It is not ideal to have two tasks being performed simultaneously, for example reading a sign and catching a ball, since they both require visual input. It is also important to consider the timing of the two tasks being used. When two tasks need to be performed simultaneously, both tasks should coincide completely so the Dual-Task method is being implemented throughout the testing trial [5].

Considering the criteria necessary when selecting a cognitive task, there were a few available tests from previous research. Parker et al used Serial Sevens as one of the cognitive tasks in Dual-Task research with concussions [17]. This test requires the participant to subtract by sevens from a random number given by the researcher. It is easy to administer and already used in mental status exams to assess attention and concentration. Another test is an Auditory Pure Switch Task, which has been used in previous Dual-Task research [14, 18, 30]. The participant is required to determine if each number given in a series is an even or odd number. In the previous research, this cognitive task was administered using laboratory equipment, however in this study it was given verbally by the researcher to make it more appropriate for the clinical setting. The last cognitive task is Backward Digit Recall, which has been used in previous on-field concussion assessment [27]. This task has been established and used as a part of the Sport concussion Assessment Tool (SCAT 2) making it a familiar and easy test to administer for clinicians. These three cognitive tasks do not need any additional equipment to administer and can be given verbally making them a good match with the ETGUG in a Dual-Task methodology.

Data Processing

Each task used in the current study required the same outcome measures, which were total error, percent accuracy, and Response Rate allowing comparisons to be made directly between each task. However in previous literature different measures have been used to compare results from Dual-Task testing. Dual-Task cost (DTC) is a common measure previously reported as it adjusts single-task performance to compare results between individuals and changes in single-task performance over time [43]. Since the population of this study consisted of only a healthy group, DTC were not necessary as group means were only taken into account. The purpose of this study was to investigate differences between tasks combinations, not individuals. This is seen in previous Dual-Task literature when only a healthy population is used [5, 18-20].

Statistical Analysis

In previous Dual-Task research there were a variety of methods chosen for statistical analysis. In this study, since a comparison was made using one physical task with three different cognitive tasks, a 3 by 1 ANOVA was used. This is modeled after Ross et al who also compared different combinations of Dual-Task tests [19]. Paired *t*-tests were also used to compare cognitive differences between single- and Dual-Task conditions as well as reliability across testing sessions of cognitive and physical tasks.

Conclusion

The Dual-Task paradigm started to be used in assessing the risk of falling in the elderly population. As more research has discovered how it can show differences in balance and cognitive status among groups, it has recently been applied to concussion assessment. Although research has only been done within the past decade with concussions, a lot has been discovered. From these studies, it is shown that under Dual-Task conditions, there are differences compared to single-task testing; however, more research is needed to see exactly what kind of difference are expected. Also, further research is needed to determine the best combination of physical and mental tasks to use for concussion assessment. The Dual-Task paradigm can be a future testing condition that can make concussion assessment even more accurate than current assessment protocols. Until this is found and tested, concussion assessment should continue to follow the current recommended protocol.

Appendix A. Informed Consent Form

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

VII. **<u>Compensation</u>**: 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. **<u>Confidentiality</u>**: 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. **<u>Contact Information</u>**: 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.

____

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

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

<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 B. 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 with 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

Appendix C. Testing Instructions

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 D. 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

BESS + 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			

<u>Single-Task Trial 2</u>

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