ASSESSMENT OF CONCUSSION AND SUB-CONCUSSIVE BLOWS USING IMPACT AND DUAL-TASK TESTS DURING A HIGH SCHOOL FOOTBALL SEASON

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Abstract

Context: Laboratory-based Dual-Task (DT) tests have detected deficits from concussions past return to play using the current assessment battery. A clinically-viable DT test has yet to be investigated in the secondary school setting. Objective: (1) determine reliability and learning effects of DT testing in adolescents; and (2) examine effects of concussions on DT (ETGUG+APST). Design: Repeated measures. Setting: Local private secondary school. Participants: 118 athletes (12-17 years old) were used for between sport analysis, 18 multisport athletes were also identified, eight athletes were concussed. Interventions: Pre- and post-season and post-concussion DT and ImPACT tests were performed. The DT test consisted of the Expanded Timed-Get-Up-and-Go (ETGUG) and the Auditory Pure Switch Task (APST). Participants completed three trials of the ETGUG and APST separately before DT testing. Post-concussion DT data were collected with the ImPACT throughout the return to play protocol. Main Outcome Measures: ETGUG-time to completion; APST-percent accuracy and response rate; ImPACT-composite scores. Results: Overall, reliability trended upwards in all healthy athletes with fair to excellent reliability. Significant deficiencies were identified in concussed individuals in Single-Task A learning effect was identified through pre- and post-season assessment as well as multisport athletes 3 testing sessions. Response Rate (Baseline: .719±.076, Post-Concussion: .788±.094, p=.018) and DT Percent Accuracy (Baseline: .916±.051, Post-Concussion: .876±.067, p=.017). Conclusions: Results indicated that DT test identified deficits in athletes following concussion. Reliability increased in the older age groups. This clinically-viable DT test has the potential to be used for concussions assessment and management and is worthy of further investigation.

PART I

Introduction

The current understanding of concussions is constantly changing to reflect the most recent findings in this rapidly expanding area of research. Concussions are a complex pathophysiological process affecting the brain's ability to function. Induced by biomechanical forces, concussions may be caused by a direct blow to the head, face, neck, or elsewhere on the body and result in the rapid onset of short-lived impairment of neurological functions that generally resolve spontaneously within days. Signs and symptoms can occasionally take hours to develop following an injury [1].

The current National Athletic Trainers' Association (NATA) position statement suggests using a battery of tests in order to assess multiple aspects that a concussion could affect [2, 3]. This battery of tests has been effective in assessing neurocognitive function and motor control separately [3, 4]. Several studies have proposed the potential use of Dual-Task (DT) paradigm for concussion assessment [5-10]. A previous case study has reported that DT testing was able to identify cognitive and physical deficits after single-task assessments had returned to baseline levels in a college-aged athlete [11]. Dual-Task testing combines cognitive function and motor control into an assessment that will challenge multiple areas simultaneously. This type of assessment is considered to be more apt for an athletic population because of the need to adjust both motor and cognitive control concurrently during sports performance [12]. Previous research on the geriatric population has established that pairing a balance or gait assessment with a cognitive task has high validity for assessing vestibulocochlear disorder [13]. The expanded timed get up and go assessment (ETGUG), when paired with a cognitive test, such as the auditory pure switch task (APST), helps clinicians identify individuals at risk for a fall [13, 14].

The ETGUG and APST are fairly simple assessments to perform and are suitable for the clinical setting, such as in the clinic or on the field [15-17]. Unlike laboratory-based DT tests, a combination of ETGUG and APST constructs a DT test that does not require expensive equipment. The applicability of a DT test consisting of ETGUG and APST is worth investigating since DT tests are theorized to be valid in detecting deficits from concussions and may be more sensitive than a single-task assessment. While this DT test is valid in identifying elderly with high fall risk, to our knowledge, no studies have examined the validity in identifying individuals with a concussion. The reliability of this DT test on an adolescent population is unknown. Therefore, the purpose of this study was twofold: (1) to determine the reliability and learning effects of DT testing in adolescents; and (2) to examine the effects of concussions on DT (ETGUG+APST) performance.

Methods

Research Design

This research study used a repeated measures design to examine the test-retest reliability of DT tests over the course of a season (pre-season and post-season tests) using healthy adolescents, as well as the effects of concussion on the DT test outcome (baseline and post-concussion tests). When athletes sustained a concussion during the season, the school's athletic trainer administered the DT test along with the standard concussion management protocol as mandated by state law. In order to identify the potential influences of age and sports, especially with football deficits over the course of a season, sports level (varsity and intermediate football, varsity/junior varsity and intermediate basketball) were used as additional independent variables.

Participants

Athletes in this study consisted of 118 secondary school male athletes between the ages of 12 and 17 from football and basketball (Table 1). Athletes were on the eligible roster for the 2016-2017 school year. Signed informed consent and assent forms were collected from the parents and athletes, respectively, prior to the start of the season (Appendices A & B). Twenty-nine football and twelve basketball athletes had a history of at least one diagnosed concussion. Three athletes (two football, one basketball) were diagnosed Attention Deficit Disorder (ADD) or Attention Deficit Hyperactivity Disorder (ADHD). These athletes were allowed to participate in the study due to the repeated measured design. Exclusionary criteria included: any physical musculoskeletal injuries that influenced the athletes' walking ability. The Varsity football and Intermediate football teams were used as groups for collision sports and Varsity and Junior Varsity Basketball, as well as Intermediate basketball were utilized as groups for contact sports. Varsity and Junior Varsity basketball were combined into one group to have a larger number of athletes to compare to varsity football. The basketball team served as a control when examining the effects of sub-concussive blows for the football team. Healthy controls were matched for the concussed athletes from the same sport and team based on age, position, height, and body mass.

Table 1. Participant Demographics (Mean ± Standard Deviation)				
Team	n	Age (years)	Height (inches)	Body Mass (pounds)
Varsity Football	48	16.0±0.9	69.36±3.12	189.75±47.12
Intermediate Football	30	13.0±1.0	65.16±3.72	135.87±40.78
Varsity & Junior Varsity Basketball	24	15.5±1.1	68.52±3.24	153.33±25.17
Intermediate Basketball	16	13.3±0.8	64.92±2.88	131.13±22.44
Total	118	14.5±1.6	66.96±3.84	152.52±46.13

Test Procedures

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

The ImPACT assessment tool was used for comparison in this study as it's been shown to be the most reliable and well accepted standardized program for concussion assessment [18, 19]. The assessment was taken online on the athlete's laptop computer provided by the school and was supervised by the school's athletic trainer. The test took approximately 30 to 45 minutes to complete.

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

Athletes 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 hear 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. The measured outcome was the total time to complete the course from the verbal cue until the athlete was once again fully seated in the chair. Time was recorded using a digital hand-held stopwatch.

Auditory Pure Switch Task (APST)

Athletes were instructed to distinguish out loud between even and odd numbers as they were stated out loud by the researcher. The number set was comprised of random digits between one and eight [7, 8, 10]. Each number was given to athletes immediately following the previous response. The outcome measures for this task were the percent accuracy $\left(\frac{Total\ Responses\ Correct}{Total\ Responses\ Attempted}\right)$ and the response rate$\left(\frac{Total\ Responses\ Attempted}{Time}\right)$. The single-task APST was performed for 20 seconds.

Dual-Task:

The dual-task assessment involved concurrent performance of the ETGUG and APST. As the athlete stood to begin the ETGUG, they began the APST, which lasted the duration of the ETGUG. The outcome measures were the same as for the ETGUG and APST. Dual-Task Cost (DTC) was calculated as $\frac{-(DT-ST)}{ST} * 100$ for ETGUG and $\frac{DT-ST}{ST} * 100$ for APST to standardize the differences between DT and ST performances (percentage change between Single- and Dual-Task) [20]. The DTC is used to assess task prioritization; for example, increased motor task DTC with decreased cognitive task DTC indicates smaller ST to DT deficits in the cognitive task, suggesting the prioritization of the cognitive task over the motor task. Athletes performed three trials each of the single-task ETGUG and APST, which served as familiarization trials prior to performing the three DT trials.

Data Collection Procedure

The ImPACT, ETGUG, APST, and DT (ETGUG + APST) were collected at pre-season as a baseline, as well as at post-season for the non-concussed athletes. The pre-season baselines were measured during the summer camp of football and during preseason workouts for basketball (within two weeks of the start of the practices). All healthy athletes completed a post-season ImPACT and DT assessment within two weeks of the completion of the season.

If an athlete was diagnosed with a concussion by a certified athletic trainer in accordance with the school's concussion assessment protocol during the season, a series of post-concussion data collections were conducted under the same protocol as the baseline testing. The concussed athlete completed the ETGUG, APST, and DT in the same order as their baseline once every three to five days until they were cleared to start the gradual return to play protocol, which was determined by a neuropsychologist based on the post injury ImPACT score. The gradual return to play protocol was supervised by Board certified athletic trainers at the school. The athlete continued to perform DT assessment once every 72 hours until they were cleared for practice without restrictions.

Statistical Analysis

Data were analyzed using the SPSS Statistical Analysis Software Version 24 (IBM, Armonk, New York, USA) with the alpha level set at $p \leq 0.05$. A Shapiro-Wilk test was used to analyze the normality of the data. The ImPACT Memory Verbal composite score and Cognitive Efficiency Index for the concussed group were not normally distributed; therefore, non-parametric methods were used. The rest of the data were deemed normally distributed and parametric methods were used. A mixed method repeated measures analysis of variance (ANOVA) was used to analyze the scores of ImPACT and DT test over time (pre-season and post-season) and between groups (varsity football, intermediate football, varsity/junior varsity basketball, and intermediate basketball). The test-retest reliability was assessed using intraclass correlation ($ICC_{2,1}$) and standard error of the measurement (SEM) and paired *t*-tests were used to compare pre- and post-season data to assess for learning effects. Single-task and Dual-task APST percent accuracy were not included in the analyses due to the lack of variability.

Results

The influence of multiple head impacts were examined by mixed method repeated measures ANOVA using sports level (varsity football, intermediate football, varsity/junior varsity basketball, and intermediate basketball teams) as the between-subjects variable and time (pre- and post-season) as the within-subjects variable. No interaction effects were found and significant main effect differences were found for time. Post-hoc analyses indicated significant changes over the course of the season in several variables for varsity football: ETGUG DT (25.23±4.30 sec vs. 23.83±3.29 sec, $p = 0.01$), ETGUG-DTC (-29.01±16.79% vs. -20.05±10.45%, $p<0.01$), RR-ST (0.79±0.09 vs. 0.83±0.08, $p=0.01$), RR-DTC (-2.68±6.86 vs. -6.22±7.58%, $p=0.01$), and ImPACT-VMS (36.37±6.36 vs. 38.66±6.70, $p<0.01$). Varsity basketball had three variables with significant differences (RR-DT: 0.70±0.05 vs. 0.74±0.08, $p=0.04$, ImPACT-VMS: 37.11±5.34 vs. 39.36±5.29, $p=0.02$, and ImPACT-RT 0.61±0.07 vs. 0.58±0.05, $p=0.01$). Intermediate basketball had four variables with significant differences (ETGUG ST: 21.89±2.19 vs. 20.19±2.11, $p<0.01$, ETGUG DT: 28.96±3.82 vs. 24.99±3.17, $p<0.01$, RR ST: 0.79±0.07 vs. 0.84±0.06, $p<0.01$, RR DT: 0.73±0.07 vs. 0.80±0.07, $p=0.02$). These data displayed a time effect with improvements in the post-season tests, which indicate no detrimental effects from repetitive head trauma for football athletes over the course of the season; therefore, the data from football and basketball teams were pooled together for further analyses.

Table 2. Single- and Dual-task and ImPACT Results by Sport and Grand Mean

		Football						Basketball						Grand Mean (n=118)		
		Varsity (n=48)			INT (n=30)			Varsity & JV (n=24)			INT (n=16)					
		Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*
ETGUG	ST (sec)	19.60 ±2.68	19.86 ±2.31	0.43	19.28 ±2.12	18.76 ±2.28	0.12	20.50 ±2.32	21.18 ±3.35	0.13	21.89 ±2.19	20.19 ±2.11	<0.01*	20.00 ±2.53	19.88 ±2.61	0.54
	DT (sec)	25.23 ±4.30	23.83 ±3.29	0.01*	24.57 3.39	23.99 ±3.50	0.31	24.75 ±2.66	25.12 ±3.51	0.47	28.96 ±3.82	24.99 ±3.17	<0.01*	25.49 ±3.94	24.28 ±3.38	<0.01*
	DTC (%)	-29.01 ±16.79	-20.05 ±10.45	<0.01*	-27.53 ±11.49	-27.91 ±10.22	0.88	-21.25 ±9.84	-19.38 ±12.13	0.33	-32.69 ±15.25	-24.18 ±14.04	0.07^	-27.73 ±14.43	-22.50 ±11.67	<0.01*
APST Percent Accuracy	DTC (%)	0.10 ±4.44	0.24 ±4.09	0.84	-0.41 ±3.24	-1.43 ±5.62	0.31	0.42 ±3.86	-1.04 ±3.70	0.14	-1.39 ±3.06	-0.88 ±4.56	0.63	-0.21 ±3.88	-0.59 ±4.53	0.35
APST Response Rate	ST (resp.·sec^{-1})	0.79 ±0.09	0.83 ±0.08	0.01*	0.76 ±0.07	0.77 ±0.08	0.54	0.79 ±0.04	0.79 ±0.18	0.97	0.79 ±0.07	0.84 ±0.06	<0.01*	0.78 ±0.08	0.81 ±0.11	0.02**
	DT (resp.·sec^{-1})	0.77 ±0.09	0.78 ±0.10	0.53	0.70± 0.07	0.72 ±0.10	0.43	0.70 ±0.05	0.74 ±0.08	0.04**	0.73 ±0.07	0.80 ±0.07	0.02**	0.73 ±0.08	0.76 ±0.10	0.01*
	DTC (%)	-2.68 ±6.86	-6.22 ±7.58	0.01*	-7.18 ±5.13	-6.56 ±6.82	0.67	-10.72 ±5.93	-10.35 ±5.51	0.81	-7.82 ±5.27	-5.71 ±6.82	0.34	-6.18 ±6.76	-7.05 ±7.03	0.23
ImPACT Composite Scores	Memory Verbal	81.38 ±9.43	80.92 ±10.45	0.79	76.48 ±13.45	71.39 ±15.84	0.11	81.95 ±9.05	84.05 ±8.78	0.22	80.69 ±16.23	84.69 ±9.93	0.38	79.45 ±12.71	80.09 ±12.25	0.83
	Memory Visual	73.88 ±12.86	74.83 ±12.84	0.62	70.61 ±10.04	64.22 ±16.21	0.08^	71.77 ±11.96	74.68 ±14.71	0.32	70.25 ±13.48	71.88 ±14.95	0.52	71.08 ±13.19	72.13 ±14.71	0.94
	Visual Motor Speed	36.37 ±6.36	38.66 ±6.70	<0.01*	30.25 ±6.45	30.23 ±9.20	0.99	37.11 ±5.34	39.36 ±5.29	0.02**	35.90 ±8.11	35.90 ±7.98	1.00	34.84 ±6.97	36.62 ±7.95	0.00*
	Reaction Time	0.64 ±0.08	0.63 ±0.10	0.88	0.68 ±0.11	0.67 ±0.17	0.74	0.61 ±0.07	0.58 ±0.05	0.01*	0.62 ±0.12	0.64 ±0.07	0.51	0.65 ±0.10	0.63 ±0.11	0.46
	Cognitive Efficiency Index	0.27 ±0.14	0.29 ±0.15	0.50	0.26 ±0.17	0.23 ±0.25	0.38	0.29 ±0.12	0.35 ±0.11	0.07^	0.31 ±0.15	0.34 ±0.10	0.50	0.27 ±0.15	0.29 ±0.17	0.37

* Significantly different from Preseason Value at p<.01, ** Significantly different from Preseason Value at p<.05, ^ Approached significance at p<0.10
ETGUG: Expanded Timed Get-up-and-Go, APST: Auditory Pure Switch Task, ImPACT: Immediate Post-Concussion Assessment and Cognitive Test, ST: Single-Task, DT: Dual-Task, DTC: Dual-Task Cost

Test-Retest Reliability and Learning Effect

The pooled data for pre-and post-season were used to calculate the ICC (Table 3). Overall, ETGUG-ST had an excellent $ICC_{2,1}$ at 0.78, with an SEM of 1.20, while ETGUG-DT ($ICC_{2,1}$=0.71, SEM=1.99) and RR-DT ($ICC_{2,1}$=0.64, SEM=0.06) had good reliability. The remaining four variables had fair reliability: RR-ST ($ICC_{2,1}$=0.46, SEM=0.07), ETGUG-DTC ($ICC_{2,1}$=0.47, SEM=9.59), APST-%ACC-DTC ($ICC_{2,1}$=0.49, SEM=3.00), and RR-DTC ($ICC_{2,1}$=0.42, SEM=5.24).

Paired *t*-tests indicated that the time to completion for ETGUG-DT as well as DTC improved significantly from pre- to post- season (ETGUG-DT 25.49±3.94 sec vs. 24.28±3.38 sec, $p<0.01$; ETGUG-DTC -27.73±14.43% vs. -22.50±11.67%, $p<0.01$). Single-task and dual-task RR also increased significantly (ST 0.78±0.08 vs. 0.81±0.11, $p=0.02$; DT 0.73±0.08 vs. 0.76±0.10, $p<0.01$). However, there were no significant differences in RR DTC (-6.18±6.76 vs. -7.05±7.03, $p=0.23$). Of all of the ImPACT composite scores, only Visual Motor Score (VMS) significantly improved (34.84±6.97 to 36.62±7.95, $p<0.01$).

Test-Retest Reliability and Learning Effect by Age Group

In order to examine the influence of age on reliability and learning effects, $ICC_{2,1}$ were calculated for each age group (Table 3). All age groups had good or excellent reliability in ETGUG-ST: 12 year olds (n= 14, $ICC_{2,1}$=0.75, SEM=1.25), 13 year olds (n=15, $ICC_{2,1}$=0.73, SEM=1.14), 14 year olds (n=19, $ICC_{2,1}$=0.87, SEM=0.98), 15 year olds (n=25, $ICC_{2,1}$=0.77, SEM=1.33), 16 year olds (n=25, $ICC_{2,1}$=0.86, SEM=0.99), and 17 year olds (n=20, $ICC_{2,1}$=0.70, SEM=1.38). The 12 year olds had fair reliability in RR-DT and RR-DTC ($ICC_{2,1}$=0.53, SEM=0.06 and $ICC_{2,1}$=0.40, SEM=4.80, respectively).

The 13 year olds had good reliability in ETGUG-DT and fair in % ACC-DTC ($ICC_{2,1}$=0.62, SEM=2.02 and $ICC_{2,1}$=0.55, SEM=2.17, respectively). The 14 year olds had an excellent reliability in ETGUG-DT ($ICC_{2,1}$=0.87, SEM=0.98) and good reliability in both ETGUG-DTC and % ACC-DTC ($ICC_{2,1}$=0.69, SEM=7.63 and $ICC_{2,1}$=0.60, SEM=2.80, respectively). The 15 year olds had good reliability in both ETGUG-DT ($ICC_{2,1}$=0.70, SEM=2.26) and RR-DT($ICC_{2,1}$=0.70, SEM=0.05), and fair reliability in RR-ST ($ICC_{2,1}$=0.43, SEM=0.06), % ACC-DTC($ICC_{(2,1)}$=0.60, SEM=2.56), and RR-DTC ($ICC_{2,1}$=0.50, SEM=5.255). The 16 year olds had excellent reliability in RR-DT ($ICC_{2,1}$=0.837, SEM=0.044) and good reliability in all other variables: RR-ST ($ICC_{2,1}$=0.66, SEM=0.054), ETGUG-DT ($ICC_{2,1}$=0.68, SEM=1.72), ETGUG-DTC($ICC_{2,1}$=0.63, SEM=7.894), and RR-DTC ($ICC_{2,1}$=0.65, SEM=4.49). The 17 year olds had excellent reliability in ETGUG-DT ($ICC_{2,1}$=0.77, SEM=1.54), good reliability in ETGUG-DTC ($ICC_{2,1}$=0.63, SEM=7.92), % ACC-DTC ($ICC_{2,1}$=0.641, SEM=2.54), and RR-DTC ($ICC_{2,1}$=0.60, SEM=4.41), and fair reliability in RR-ST (0.59, 0.04) and RR-DT ($ICC_{2,1}$=0.58, SEM=0.06). Overall, there was a trend of increased reliability in older age groups.

Table 3. Intraclass Correlation Coefficients, Standard Error of the Measurement and Paired *t*-tests by Age and Overall

		12 Year Olds				13 Year Olds				14 Year Olds				15 Year Olds				16 Year Olds				17 Year Olds				Grand Means			
		$ICC_{2,1}$	SEM	Mean Diff.	*p*	$ICC_{2,1}$	SEM	Mean Diff.	*p*	$ICC_{2,1}$	SEM	Mean Diff.	*p*	$ICC_{2,1}$	SEM	Mean Diff.	*p*	$ICC_{2,1}$	SEM	Mean Diff.	*p*	$ICC_{2,1}$	SEM	Mean Diff.	*p*	$ICC_{2,1}$	SEM	Mean Diff.	*p*
ETGUG	ST	0.75	1.25	0.96 ±2.16	0.12	0.73	1.14	1.06 ±1.94	0.06	0.87	0.87	0.62 ±1.80	0.15	0.77	0.77	0.3 ±2.41	0.54	0.86	0.99	-0.41 ±1.84	0.27	0.70	1.38	-1.22 ±2.28	0.03*	0.78	1.20	0.12 ±2.18	0.54
	DT	0.38	2.85	2.11 ±4.40	0.10	0.62	2.02	1.41 ±3.43	0.15	0.85	1.75	1.76 ±2.95	0.02*	0.70	2.26	1.86 ±3.76	0.02*	0.68	1.72	0.69 ±2.99	0.26	0.77	1.54	-0.42 ±2.80	0.52	0.71	1.99	1.20 ±3.40	<0.01*
	DTC	-2.45	21.87	-4.68 ±20.62	0.41	0.24	9.87	-0.09 ±14.56	0.98	0.69	7.36	-4.30 ±12.66	0.16	0.31	12.04	-7.65 ±18.29	0.05*	0.63	7.89	-6.47 ±12.89	0.02*	0.63	7.92	-4.81 ±13.31	0.13	0.47	9.59	-5.11 ±15.24	<0.01*
APST	RR ST	0.39	0.06	-0.04 ±0.09	0.13	0.18	0.15	0.05 ±0.22	0.39	0.39	0.39	-0.04 ±0.08	0.06	0.43	0.43	-0.06 ±0.09	<0.00*	0.66	0.05	-0.03 ±0.09	0.09	0.59	0.04	0.01 ±0.07	0.75	0.71	1.99	1.20 ±3.40	<0.01*
	RR DT	0.53	0.06	-0.04 ±0.10	0.11	0.34	0.06	0.01 ±0.10	0.65	-0.02	0.08	-0.04 ±0.12	0.16	0.70	0.05	-0.04 ±0.08	0.02*	0.84	0.04	-0.02 ±0.08	0.36	0.58	0.06	-0.01 ±0.10	0.78	0.64	0.06	-0.02 ±0.09	0.01*
	RR DTC	0.40	4.80	-1.03 ±7.65	0.62	0.05	4.38	2.04 ±6.21	0.24	-0.53	9.28	-0.45 ±11.59	0.87	0.50	5.26	2.14 ±8.54	0.22	0.65	4.49	2.01 ±7.69	0.20	0.60	4.41	-0.04 ±7.54	0.98	0.42	5.24	0.93 ±8.34	0.23
	% ACC ST	0.40	0.03	0.00 ±0.05	0.78	0.66	0.03	0.02 ±0.04	0.17	0.23	0.23	0.01 ±0.04	0.29	0.41	0.41	0.00 ±0.04	0.82	0.52	0.03	-0.01 ±0.05	0.54	0.57	0.03	-0.01 ±0.05	0.57	0.48	0.03	0.00 ±0.05	0.65
	% ACC DT	0.41	0.05	0.02 ±0.08	0.30	0.79	0.03	0.02 ±0.04	0.08	0.76	0.02	0.01 ±0.04	0.51	0.62	0.03	0.00 ±0.04	0.83	0.55	0.03	0.00 ±0.05	0.70	0.67	0.02	0.00 ±0.04	0.96	0.64	0.03	0.01 ±0.05	0.24
	% ACC DTC	0.28	4.32	2.14 ±6.43	0.24	0.55	2.17	0.42 ±3.56	0.67	0.60	2.80	0.43 ±4.78	0.70	0.60	2.56	0.03 ±4.36	0.97	0.11	3.87	0.41 ±5.64	0.72	0.64	2.54	0.81 ±4.38	0.43	0.49	3.00	0.42 ±4.88	0.35

ICC: intraclass correlation coefficient, SEM: Standard Error of the Measurement, ST: Single-Task, DT: Dual-Task, ETGUG: Expanded Timed Get-Up-and-Go, APST: Auditory Pure Switch Task, ACC: Accuracy, RR: Response Rate

* indicates significant differences at the $p<0.05$ level

Learning Effects over Three Testing Sessions

There were 18 athletes that competed in both football and basketball during the school year. These multi-sport athletes completed three data collections: pre-football, inter-season (post-football/pre-basketball), and post-basketball. These data were used to further examine the learning effects over the three testing sessions (Table 4). The mean time between pre-football and inter-season testing sessions was 133±5.7 days and the mean time between inter-season and post-basketball was 95±8.5 days. The overall mean days between pre-football to post-basketball was 228±12.7 days. No significant changes in ETGUG-ST were indicated, while significant improvement was indicated in ETGUG-DT from pre-football to post-basketball (24.79±3.95sec vs. 22.77±4.09sec, p=0.03). Dual-Task Cost ETGUG approached significance from inter-season to pre-football (-29.82±13.74% to -21.87±10.39%, p=0.06) and significantly improved from pre-football to post-basketball (-29.82±13.74% to -19.02±10.00%, p<0.01). The RR-ST and RR-DT significantly improved from pre-football to post-basketball (0.76±0.11 to 0.84±0.08, p<0.01 and 0.74±0.12 vs. 0.81±0.10, p=0.02, respectively).

Table 4. Single- and Dual-Task Results over Three Data Collections

Football & Basketball Player Three Session Data n=18			Pre-Football season	Inter-season	Post-Basketball season
Physical	ETGUG	ST (sec)	19.08 ±2.18	19.38 ±2.06	19.15 ±3.20
		DT (sec)	24.79 ±3.95	23.58 ±2.90	22.77 ±4.09*
		DTC (%)	-29.82 ±13.74	-21.87 ±10.39^	-19.02 ±10.00*
Cognitive	APST-% ACC	DTC (%)	0.68 ±5.32	-0.92 ±3.32	1.17 ±4.55
	RR-ST	ST (resp.·sec^{-1})	0.76 ±0.11	0.80 ±0.11	0.84 ±0.08*
		DT (resp.·sec^{-1})	0.74 ±0.12	0.74 ±0.13	0.81 ±0.10*^
		DTC (%)	-3.53 ±7.72	-7.61 ±7.89	-3.06 ±7.72
ImPACT	Composite Scores	Memory Verbal	79.11 ±11.63	80.67 ±9.94	81.11 ±8.62
		Memory Visual	73 ±12.66	74.78 ±9.55	69.72 ±15.51
		Visual Motor Speed	33.06 ±7.51	33.83 ±6.77	34.84 ±6.85
		Reaction Time (sec)	0.65 ±0.06	0.64 ±0.09	0.62 ±0.10
		Cognitive Efficiency Index	0.24 ±0.14	0.31 ±0.11*	0.31 ±0.11^

Data presented as mean±standard deviations; * indicates significantly different from preseason value (p=0.05); ^ indicates approaching significantly different from preseason value (p<0.10). ETGUG: Expanded Timed Get-up-and-Go, APST: Auditory Pure Switch Task, ImPACT: Immediate Post-Concussion Assessment and Cognitive Test, ST: Single-Task, DT: Dual-Task, DTC: Dual-Task Cost, resp: responses, sec: second

Effects of Diagnosed Concussion

Eight athletes sustained a concussion during the football season and completed a series of post-concussion data collections. Their data from baseline (pre-football), initial post-concussion test (PC1), at the time of return to light activity (RTA), and at the time of full return to participation (RTP) were used for analysis (Table 5). The ETGUG-DTC significantly decreased (-32.19±9.63% vs. -24.55±10.48%, p=0.01) from baseline to PC1, and remained decreased through RTA and RTP (-21.04±3.59%, p=0.02 and -20.07±6.75%, p=0.08, respectively) indicating the deficits between ST and DT became smaller (improved) over time. Conversely, % ACC-DTC at PC1 (-11.99±7.33%, p=0.05) and the RR DTC at RTA and RTP were significantly increased (-11.74±6.76%, p=0.03 and -12.62±8.93%, p=0.01, respectively) compared to the baseline % ACC-DTC (-0.53±5.70%) and RR DTC (-6.86±6.70%), indicating the deficits between ST and DT became larger (worsened). The RR DT indicated that their responses were given at a slower rate during PC1 compared to baseline (0.67±0.07 vs. 0.59±0.09, p=0.06). From the ImPACT data, the Memory Visual composite score decreased significantly from baseline to PC1 (69.08±8.54 to 57.71±15.32, p=0.03), while the Reaction Time significantly improved from baseline to RTP (0.65±0.05 vs. 0.60±0.07, p=0.04).

All concussed athletes were matched to a healthy control by age, sport, position, height and body mass to compare the concussed group to the healthy control at baseline and following concussion (Table 6). At baseline, no between group differences were found. At PC1, RR-DT (0.77±0.10 vs. 0.59±0.09, p<0.01), RR-DCT (-.17±6.68 vs. -12.20±7.77, p=0.04), and %ACC-DTC (0.80±6.06 vs. -11.99±7.33, p=0.01) were significantly different between groups indicating decreased cognitive performance in concussed group compared to control group. At RTP, RR-DT (0.77±0.10 vs. 0.69±0.12, p=0.04) and RR-DTC (-.17±6.68 vs. -12.62±8.93, p=0.01) were significantly decreased in the concussed group compared to control group.

Table 5. Results of Repeated Measures ANOVA of Concussed Athletes Data Comparing to Baseline to Various Time Points During Recovery (n=8)

		n	Baseline	PC1		RTA		RTP	
				Mean ±SD	*p*	Mean ±SD	*p*	Mean ±SD	*p*
ETGUG	ST (sec)	8	20.35 ±3.33	21.71 ±4.01	0.25	21.16 ±3.55	0.30	20.63 ±3.47	0.90
	DT (sec)	8	26.90 ±4.80	26.97 ±4.75	0.80	25.59 ±4.27	0.14	24.79 ±4.46	0.17
	DTC (%)	8	-32.19 ±9.63	-24.55 ±10.48	0.01*	-21.04 ±3.59	0.02*	-20.07 ±6.75	0.08^
APST	%ACC DTC (%)	8	-0.53 ±5.70	-11.99 ±7.33	0.05*	-4.04 ±7.90	0.39	-4.10 ±7.77	0.25
	RR ST (resp.$\cdot$sec^{-1})	8	0.72 ±0.08	0.68 ±0.12	0.43	0.75 ±0.09	0.31	0.79 ±0.09	0.11
	RR DT (resp.$\cdot$sec^{-1})	8	0.67 ±0.07	0.59 ±0.09	0.06^	0.67 ±0.11	0.93	0.69 ±0.12	0.60
	RR DTC (%)	8	-6.89 ±6.70	-12.20 ±7.77	0.24	-11.74 ±6.76	0.03*	-12.62 ±8.93	0.01*
ImPACT	Memory Verbal	8	79.40 ±18.30	70.71 ±11.15	0.19	70.63 ±8.37	0.13	80.57 ±8.40	0.77
	Memory Visual	8	69.08 ±8.54	57.71 ±15.32	0.03*	64.63 ±10.57	0.24	72.71 ±14.28	0.35
	Visual Motor Speed	8	33.65 ±7.44	31.00 ±5.50	0.24	37.46 ±9.61	0.17	37.52 ±10.17	0.20
	Reaction Time (sec)	8	0.65 ±0.05	0.70 ±0.12	0.36	0.64 ±0.08	0.83	0.60 ±0.07	0.04*
	Cognitive Efficiency Index	8	0.30 ±0.15	0.23 ±0.07	0.16	0.23 ±0.07	0.36	0.25 ±0.12	0.41

* Significant from baseline at p<.05; ^ Approaches significance (p<0.10). ETGUG: Expanded Timed Get-up-and-Go, APST: Auditory Pure Switch Task, ImPACT: Immediate Post-Concussion Assessment and Cognitive Test, ST: Single-Task, DT: Dual-Task, DTC: Dual-Task Cost, resp: responses, sec: second

Table 6. Comparisons Between Concussed and Healthy Controls at Various Time Points

		Baseline			Post-Season	Post-Concussion 1		Return to Activity		Return to Play	
						Compared to Post-Season Controls					
		Controls	Concussed	*p*	Controls	Concussed	*p*	Concussed	*p*	Concussed	*p*
ETGUG	ST	19.70 ± 1.96	20.35 ± 3.33	0.75	19.90 ± 1.95	21.71 ± 4.01	0.40	21.16 ± 3.55	0.32	20.63 ± 3.47	0.65
	DT	25.45 ± 3.97	26.90 ± 4.80	0.35	25.49 ± 2.37	26.97 ± 4.75	0.45	25.59 ± 4.27	0.83	24.79 ± 4.46	0.94
	DTC	-30.67 ± 26.69	-32.19 ± 9.63	0.53	-28.40 ± 9.74	-24.55 ± 10.48	0.40	-21.04 ± 3.59	0.07	-20.07 ± 6.75	0.20
APST	% ACC DTC	-0.75 ± 2.24	-0.53 ± 5.70	0.56	0.80 ± 6.06	-11.99 ± 7.33	0.01*	-4.04 ± 7.90	0.15	-4.10 ± 7.77	0.09
	RR ST	0.79 ± 0.07	0.72 ± 0.08	0.13	0.77 ± 0.08	0.68 ± 0.12	0.07	0.75 ± 0.09	0.85	0.79 ± 0.09	0.40
	RR DT	0.74 ± 0.08	0.67 ± 0.07	0.09^	0.77 ± 0.10	0.59 ± 0.09	<0.01*	0.67 ± 0.11	0.23	0.69 ± 0.12	0.04*
	RR DTC	-5.89 ± 3.69	-6.89 ± 6.70	0.92	-0.17 ± 6.68	-12.20 ± 7.77	0.04*	-11.74 ± 6.76	0.08	-12.62 ± 8.93	0.01*
ImPACT	Memory Verbal	81.50 (79.0, 87.50)	88.00 (66.25, 91.75)	0.89	70.25±17.58	70.71 ± 11.15	0.79	76.13 ± 8.92	0.49	72.86 ± 15.83	0.70
	Memory Visual	74.50±14.49	69.08 ±8.54	0.26	63.25±17.98	57.71 ±15.32	0.37	64.63 ±10.57	0.87	70.00 ± 17.18	0.63
	Visual Motor Speed	31.35±7.61	33.65 ±7.44	0.60	30.00±15.44	31.00 ±5.50	0.72	37.46 ±9.61	0.51	37.52 ±10.17	0.32
	Reaction Time	0.69±0.18	0.64±0.05	0.41	0.59 (0.53, 0.62)	0.65 (0.61, 0.76)	0.24	0.63 (0.58, 0.84)	0.58	0.65 (0.54, 0.77)	0.80
	Cognitive Efficiency Index	0.32 (0.16, 0.42)	0.39 (0.16, 0.41)	0.58	0.15 ± 0.33	0.23 ± 0.07	0.45	0.33 ± 0.12	0.21	0.27 ± 0.17	0.27

ETGUG: Expanded Timed Get-Up-and-Go, APST: Auditory Pure Switch Task, ImPACT: Immediate Post, ST: Single-Task, DT: Dual-Task, DTC: Dual-Task Task, % ACC: Percent Accuracy RR: Response Rate

Discussion

This study is one of the first to examine the applicability of a clinically viable DT test consisting of ETGUG and APST as a concussion assessment tool for adolescent athletes. Comprehensive test-retest reliability analyses were conducted to examine the consistency of the DT test when applied to this specific population. The results indicated that the overall reliability for DT test outcomes ranged from good to fair. While acceptable reliabilities were indicated overall, further analyses of reliability was conducted to assess the differences in reliability per age group due to the possible influence of cognitive development occurring in our sample population (12-17 years old). These results indicated that the DT test reliability increased as the athlete's age increase. Previous research examining the age effect on DT performance has reported that high school athletes performed significantly lower than collegiate athletes, indicating collegiate athletes had higher ability to multitask [21]. Children have been found to have significantly decreased postural control when multiple cognitive tasks were administered [22]. The comparison by sports levels (varsity football: 16 years old, intermediate football: 13 years old, varsity and junior varsity basketball: 15.5 years old, intermediate basketball 13.3 years old) in the current study did not indicate significant main effects, therefore, the effect of age on DT ability remains inconclusive. However, the lower reliabilities in the younger athletes were clearly displayed in our results. These suboptimal reliabilities of the DT test in the younger athletes, especially 12, 13, and 14 year olds, indicate that the DT test may not be applicable for these age groups.

Learning effects were also identified in the current study. Overall, significant improvements were indicated for DT-ETGUG, ETGUG-DTC, and DT-RR. This learning effect was further confirmed by the analyses of multi-sports athletes who underwent three data collection sessions, indicating significant improvements from football pre-season to the basketball post-season in the same three variables. Interestingly, analyses of learning effects per age group revealed that the significant differences were mostly associated with 15 year olds, indicating significant improvements in both DT-ETGUG and DT-RR, possibly suggesting that the development of multitasking skills occurred at this age; however, further investigation is warranted to determine the factors influencing the reliability of this DT test.

Data collected from the concussed athletes allowed further analyses to determine the applicability of this DT test for identifying deficits resulting from concussion. Eight football athletes sustained a concussion during the season (age range: 12 to 17 years old). Of those eight athletes, five were on the intermediate football team and three were from the varsity team. Five of the eight concussed athletes had a history of at least one prior concussion. It has been reported that having a history of concussion makes the brain more susceptible to sustaining additional brain injuries and be associated with long-term deficits in executive functions [23, 24].

Athletes were scheduled to be assessed every three to five days post-concussion for both DT and ImPACT; however the average time between testing sessions was 5.58 days. The majority of the athletes were told by physicians or parents to stay home from school for a number of days following their concussion, which kept them from being assessed. Athletes in the current study took an average of 26.6 days to return to play, which is consistent with previous findings [25]. Data were compared at baseline, PC1, RTA and RTP in order to analyze differences between the major time points during the return to play protocol. When PC1 was compared to baseline measures, significant decrease in performance was indicated for % ACC-DTC and ImPACT-Memory Visual, and RR-DT approached significance (*p*=0.06), while significant improvement was indicated for ETGUG-DTC. At RTA and RTP, there was a significant increase in RR-DTC and decrease in ETGUG-DTC when compared to baseline. These results indicate a consistent pattern of decreases in cognitive task and improvement in the motor task outcome. Compared to the matched controls, the concussed group showed significantly higher %ACC-DTC and RR-DTC at PC1, confirming that these increases in DTC were unique to the concussed athletes. In addition, RR-DT was significantly decreased in the concussed group compared to controls indicating the concussed group responded to APST at a slower rate. Previous findings state that concussed individuals were significantly worse on laboratory-based DT assessment than matched controls for up to two weeks following concussion [26-28]. Our results agree with the previous findings that the concussed individuals showed decreased performance during DT, which was highlighted in the outcome associated with cognitive task.

More attention was allocated for the cognitive task resulting in improved performance of the cognitive task and decreased performance of the motor task [20, 29]. In the current study, the athletes were not given specific instruction on which task to prioritize, however, our results of increased % ACC-DTC and RR-DTC with decreased ETGUG-DTC indicate that the concussed athletes prioritized the ETGUG performance over APST. Although this prioritization of the motor task is shown to be unique to the concussed athletes, as it was not indicated for the healthy control, in the current study it is unclear whether this shift in prioritization is indicative of abnormal function.

The limitations in the study include variability in data collection time points. Although athletes were instructed to report to the athletic trainer at a standardized time interval, this was often delayed due to physician advice to stay out of school for upwards of one week. The average time to PC1 following concussion was 6.6 days, and it is possible that the acute concussion signs and symptoms had resolved by this time. The lack of standardization of task prioritization may have caused increased within and between subject variability in the DT outcomes. Variability of the testing environment could have influenced the outcome, as these tests were conducted in the school's gym, cafeteria, or hallway to obtain a ten-meter walkway. These locations were practical, but not ideal due to the presence of distractions.

In conclusion, this study indicated that the clinically viable DT test has potential to identify the deficits caused by a concussion. Decreases in performance following concussion were related to cognitive outcomes, as indicated by decreased RR, and increased %ACC-DTC and RR-DTC. However, the interpretation of the changes in DTC indicating prioritization of the motor task warrants further investigation. Additionally, our results indicate that the DT paradigm may not be suitable for younger athletes due to lower reliability. Further research should focus on age influence on reliability and learning effects of DT tests.

PART II

Literature Review

In recent years, the understanding of concussions has greatly improved. More research is being performed on identifying reliable methods of detecting signs and symptoms of concussion, as well as managing these symptoms as the present themselves. This is especially important for younger populations due to the continuing development of the brain. Another area of interest is sub-concussive blows, which do not present symptoms in the same way that concussions do, but the effects of this repetitive trauma have been found in athletes upon post-mortem. With all of the new information surrounding these brain injuries, clinicians must adapt to accommodate for new assessments or findings in research. Previously validated single-task tests are being combined to assess neurocognitive and motor function simultaneously with a dual-task (DT) test. Most of the literature on this topic has been performed in the geriatric population in order to identify those at risk for falls, but recently these studies have also been used to assess the symptoms of a concussion in a young-athletic population.

Concussion Knowledge

Athletic trainers and other healthcare professionals continue to do research to learn more about the effects of sport-related concussions. The high rate of concussion in athletic competition, specifically contact sports, puts the athletes at risk for serious brain injury. Understanding the signs and symptoms that present after absorbing an external force to the brain can help decrease the number of concussions in sports.

This article by McCrory et al. [1] is an update of the prior guidelines set during the first through third International Conference on Concussion in sport. These took place in 2001, 2004, and 2008 in Vienna, Prague, and Zurich, respectively. The definition of concussion is constantly evolving and this conference was intended to revise the previous guidelines to increase the knowledge and capability of clinicians while handling concussions and related symptoms. A more conservative approach was suggested for return to play (RTP) when approaching management of a concussion in adolescents when compared to the adult population. Due to the longer recovery time and different physiological response, diffuse cerebral swelling for example, school and home activities may need to be modified in the child's everyday life. The panel agreed that no child is to return to sport or activity until they can successfully go through school with no symptoms, this will allow for cognitive rest and more complete healing. It was also discussed that pre-participation concussion screenings must happen and be thorough as to the athlete's concussion history. Not solely how many concussions they had, but how long did it take to recover, what symptoms were observed, and more.

Brenner et al. [2] reviewed the research on football-related injuries, looked at the possible impacts of delaying or properly educating on tackling in youth sports. The majority of concussions in football are related to tackling or being tackled, specifically when head-to-head contact occurs. In the studies that were reviewed, about 40% of the injury incidence was due to tackling in player-to-player contact, with about 64% of concussions happening while tackling or being tackled [3]. When comparing high school to college aged athletes, high school football players experienced a higher yearly incidence rate of catastrophic head injury. This data presented as .67 (high school) versus .21 (college) per 100,000 participants. [4]

As presented by the research, the definition of a concussion is constantly changing and as healthcare professionals, it is necessary to keep looking for new information. Collaboration of the greatest minds in the field must continue to occur every couple of years so that the most recent data can be collected into one informational document. Setting up guidelines and rules for tackling properly could help decrease the number of youth concussions in football. Effects of a concussion can continue to linger in people after they sustain a concussion, especially when the brain is in an important phase of growth.

Sub-Concussive Blows

The effect of sub-concussive blows is a newer concept that is now becoming more popular as the brains of former National Football League athletes have been observed during autopsies. The brains of these players presented with signs of what was named, Chronic Traumatic Encephalopathy (CTE). More information is being collected on the subject and how sub-concussive blows from contact sports may be the cause. American football has typically been the focus in most of the research on sub-concussive blows, but Matser et al. [5] observed soccer for any effects of brain trauma. Heading the ball in soccer occurs very frequently throughout a game or practice. Between September 1997 and May 1998, 33 amateur soccer players with 27 controls were compared. Two middle-distance running teams and one middle-distance swimming team were used as the controls. A total of 14 tests were administered to the participants and the means were compared using a t-test with 1-talied P values. The average number of balls headed in a match was 8.5, 9 players reported 1 soccer-related concussion, and 7 players reported 2 to 5 soccer-related concussions in their career. Soccer players performed significantly worse in the planning and memory sections of the tests. These findings suggest that amateur soccer players do exhibit symptoms from sub-concussive blows. Because soccer is so popular worldwide, it is important observe for any other signs or symptoms to improve safety.

In an unpublished study from the University of Hawaii, sub-concussive blows in a varsity football team were observed. Prior to this research, only one other study had used the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) to examine the effects of sub-concussive head impacts. This study used a repeated measures research design. The independent variables were group (experimental and control) and test (preseason, midseason, postseason). Dependent variables were the ImPACT composite test scores. The n-size was 88 athletes ages 14-18. When comparing pre and postseason data, significant decreases were seen within the experimental group in the Verbal Memory composite score. Statistically significant differences were also seen between the experimental and control group's postseason Verbal Memory score.

This data presents evidence that varsity football players at the high school level do, in fact, absorb many sub-concussive blows throughout a season that negatively affect certain functions. [6]

As CTE has been presented and discussed in the public eye recently, sub-concussive blows have been research more frequently. A study by Abbas et al. [7] used resting state functional magnetic resonance imaging (rs-fMRI) to detect subtle changes taking place in the brain of high school football players. Default Mode Network (DMN) was the network that was used in this study because previous studies completed by Shehzad et al. and Geicius et al. found it to be consistent and clinically useful, respectively. Ten high school athletes were used for this study, primarily because of the number of imaging sessions, 9, throughout the study. Five out of the ten participants had reported one prior concussion in their life. DMN decreased during month 1 and increased during month 2; this could be described by the brain becoming accustomed to the activity and loads being placed on it. After imaging session in month 2, all postseason imaging sessions except for December displayed decreased connections. These results show that high school football players are experiencing symptoms and an altered functional connectivity after the season has been completed due to the sub-concussive impacts throughout the season.

Rabadi et al. [8] aimed to observe the effects of chronic traumatic brain injury (CTBI) across the realm of multiple sports. The complications with head trauma had been discussed in the sport of boxing primarily before, but researchers wanted to understand how the brain was effected more in boxing, soccer, football, ice hockey, and martial arts. There is also a section about prevention and what healthcare professionals can do in order to keep athletes safe. Boxers have been found to suffer from motor, cognitive, and/or behavioral differences after their brain was exposed to so many sub-concussive and acute concussive blows to the head. Soccer was a sport discussed in the research because of the constant sub-concussive blows being absorbed by the athletes when they head the ball. In hockey, data has found that the incidence of concussion increases with the level of play. Martial arts is a sporting area with very limited research on the impacts of head trauma, but should be looked into because of the high rate of impacts to the brain.

Prevention tactics listed in this review include wearing protective equipment and continuously monitoring exposure of athletes in high-risk sports. The most important concept for minimizing CTBI and the effects of sub-concussive blows is to limit the exposure to head impacts and evaluate cognitive and motor function sporadically throughout competition time.

The research on the presence of sub-concussive blows has shown negative effects on the brain. These results are not solely in heavy collision sports, like football, but also being observed in soccer players from heading the ball. More clinical detection of sub-concussive blows needs to be performed to identify athletes who could be at risk for sustaining a concussion; they may also be performing with neurocognitive deficiencies without presenting with symptoms.

Concussion Effect

Concussions can present within an athlete with a variety of symptoms. There are no clear-cut signs that present in diagnosed concussions, but typically they will cause anything from headaches to nausea, but other neurocognitive or motor problems may also occur. Sometimes they will produce rapid-onset symptoms, but an athlete can feel no signs of concussion until hours after the impact were absorbed. Concussions typically heal much slower in a younger population when compared to an older population.

The youth population has been discovered to take longer to recover from concussion and the brain trauma associated [9-14]. A study by McCrea et al. [15] used a sample of 1631 football players from the National Collegiate Athletic Association college teams of Division I, II, and III level to observe the length of time it takes for college athletes to recover from concussion. Throughout the 1999-2001 seasons, 94 players sustained a concussion. Data collection for this study consisted of a Graded Symptom Checklist (GSC), Standard Assessment of Concussion (SAC), and Balance Error Scoring System (BESS). The concussed athlete performed these assessments within 2-3 hours of injury and on post injury days 1, 2, 3, 5, 7, and 90. Seventy-nine of the athletes completed the entire protocol through day 90. All of the results showed that the symptoms gradually returned to normal after the brain began to rest. No significant differences were found between the initial day of collection and day 90. More research is necessary to determine a more accurate timeline as to when the majority of concussed college-aged athletes begin to heal after injury.

A study done completed at the United States Military Academy (USMA) by Bleiburg et al. [16] aimed to identify the length of time that a participant would experience cognitive impairment after sustaining a concussion. A baseline neurocognitive test was taken to use as a comparison to future data collected. Seven hundred and twenty nine cadets signed up as participants for this study. Out of those participants, 68 were concussed while participating in the physical education boxing program, which is required of all new cadets at USMA. Follow-up sessions were conducted within 24 hours of injury, 1 to 2 days, 3 to 7 days, and 8 to 14 days post injury. Cognitive function was assessed using the Automated Neuropsychological Assessment Metrics (ANAM), a computerized battery consisting of 6 sub-tests. Data showed cognitive impairment during days 1 to 2 post injury, but saw a recovery of cognitive performance during days 3 to 7. This recovery time was consistent with the Academy's protocol for return to play at that time.

Thomas et al. [13] conducted a prospective cohort study of patients who went to the emergency department within 12 hours of a head injury. They were evaluated using the ImPACT assessment, the Acute Concussion Evaluation (ACE), and the Galveston Orientation and Amnesia Test (GOAT). The purpose of this study was twofold: 1) to determine if ImPACT performed on adolescents within 12 hours of injury would correlate with ImPACT performed 3 to 10 days after injury and 2) if emergency department ImPACT would display differences in neurocognitive deficits that traditional clinical grading scales could not. Despite improved scores in all 4 sections of the ImPACT during follow-up testing, participants continued to display significant dysfunction and lower scores than average. This study suggests that it is important to assess for neurocognitive deficits in the emergency department using ImPACT. It can greatly improve clinicians' abilities to individualize management and care for the patient.

Sports-related concussions display a variety of symptoms and can last for any time from a couple of days to a few weeks. It has been proven that athletes with previous history of concussion are at a greater risk of sustaining another concussion. This has a great impact on how clinicians go about treatment and prevention for concussion to decrease the likelihood of re-injury and possible brain damage later in life. The purpose of this study by Iverson et al. [12] was to examine whether athletes with a history of three or more concussions perform more poorly on neuropsychological testing, or report more subjective symptoms, during a baseline, preseason evaluation. 786 participants were included in the database that underwent preseason testing on the ImPACT system. Twenty-six athletes between the ages of 17 and 22 self-reported a history of three or more concussions. All athletes were matched based off of their demographic information and concussion history if present. The ImPACT concussion assessment program was used to determine neurocognitive function at the beginning of the season. The athletes with previous concussions and the control subjects were compared on the four neurophysiological composite scores from ImPACT using multivariate analysis of variance (MANOVA) followed by univariate ANOVAs. MANOVA revealed no significant results and there was only significant effects found for the verbal memory composite. Athletes with more than three concussions did score lower on the verbal memory composite than athletes with no concussion history. This can lead researchers to believe that there is a link between multiple concussions and head trauma to decreased memory or brain damage.

A retrospective cohort study by Corwin et al. [11] in 2015 was looking at the presence of vestibular issues following a concussion in the youth population. The 4 purposes of this study were: 1) describe the prevalence of the vestibular deficits in youth concussion, 2) identify any association of vestibular deficits with prolonged recovery from youth concussion, 3) correlate vestibular deficits in youth concussion with results of computerized neurocognitive testing, and 4) determine whether previous history of concussion influenced the prevalence and severity of vestibular and neurocognitive deficits. All patients were identified as having vestibular deficits if she showed any abnormalities on Vestibular Ocular Reflex (VOR) or tandem gait stance. Neurocognitive testing was done using the ImPACT assessment protocol, with verbal memory, visual memory, processing speed, and reaction time as the outcome measures. ImPACT was measured at initial patient visit and each subsequent follow-up visit. A total of 247 participants were used for the study, with 81% of them showing either abnormal VOR scores or tandem gait on initial physical examination.

The prevalence of sports-related concussion, specifically in youth athletes, has been increasing in recent years. Schatz et al. [17] aimed to identify possible precursors to post-concussion syndrome by documenting emotional and behavioral symptoms in high school athletes that had sustained multiple concussions before adulthood. Because the youth population is still growing, when they sustain a concussion, their brain takes longer to heal and can permanently cause damage to the processing function of the brain. This study used 2557 high school students who participated in athletics between 1997 and 2008; participants were split into 3 groups based off of concussion history: none, 1 previous, 2 or more previous. Participants performed the ImPACT assessment as well as a post-concussion symptom scale (PCSS). Two MANOVAs were conducted using the dependent variable of 22 baseline concussion-related symptoms and baseline concussion symptoms grouped into physical, emotional, cognitive, and sleep symptom clusters. Participants with any previous concussions were more likely to present with symptoms than those who had not sustained a concussion before. Specifically, the group with 2 or more experienced more feelings of fatigue and nausea than the others. The subtle symptoms experienced at a young age could be indicative of future concussion-related health issues.

History of concussion can have a large effect on neurological and motor processes even after an athlete has presented with no symptoms for an extended amount of time. In general, mental abilities were lacking after sustaining a concussion, but different aspects of cognition (i.e. balance) would return to baseline on their own time with the help of rest. Because of the high risk of concussion in sports, specifically in the youth population, new, more efficient methods for assessment and management of concussion are necessary.

Concussion Management and Assessment

Identifying signs and symptoms of concussion can be simple if clinicians have the most valid and reliable tool with them for the assessment. This, however, is not always the case when an athletic trainer is on the sideline of a football game. Because laboratory equipment cannot be used everywhere, many clinical assessments have been created to adapt to the new understandings of concussion-related symptoms. Leading healthcare professionals are also looking for new techniques for managing symptoms after they present.

Johnson et al. [18] were interested in compiling all of the research completed to date on football-related concussion and sub-concussive brain trauma and review it. By using the search terms “football”, “sports”, “concussion”, “Chronic Traumatic Encephalopathy”, “athlete” “youth”, and “pediatric”, any relevant article to youth concussion recovery, management, and knowledge was taken into account. The presence of second impact syndrome increases the importance of a gradual RTP protocol. Several states have passed RTP laws to avoid the slightest chance that an athlete gets placed back into participation when they are not ready. Johnson stated that more research is necessary to ensure that current RTP protocols are conservative enough, or maybe increasing the physical and cognitive rest time to after the athlete is symptom free. This review believes that RTP protocols cannot solve the football-related concussion problem and that other modifications must be made. Some recommendations include a ban on tackling in athletes less than 16 years of age and to elaborate on that, progressive education on how to properly tackle was suggested for athletes 15 and up. Overall, Johnson knows that as understanding of concussions increases, changes will come to football, it is just a matter of finding out how to make it safer without a complete transformation to the sport.

Research on concussions has been so improved recently and athletic trainers and other healthcare professionals, who are responsible for quick recognition and management must adapt to cover all of the new findings. In the National Athletic Trainers' Association (NATA) initial position statement on Management of Sport-Related Concussion in 2004, Guskiewicz et al. [19] stated the importance of bridging the gap between research and clinical practice; affirming that it could be the key difference in decreasing the total number injury incidence in the athletic population. This statement presents a number of changes that can help athletic trainers manage concussion scenarios much more direction. It is encouraged to work with the physician on the sideline to determine return to play on the sideline during competition. Baseline testing is highly encouraged as well as using a number of tests when assessing concussion symptoms after acute brain trauma has occurred. Also included in the position statement is the description of the role that athletic trainers must play in helmet fitting to help decrease the likelihood of injury. Helmets will not completely prevent all head injuries, but athletic trainers are in the frontline of the equipment fitting and can make sure that the athlete is playing in the safest conditions possible.

There are a variety of assessments that have been created with the intentions of detecting symptoms of a concussion and Broglio et al. [20] wanted to determine which one was the most sensitive. College athletes that were determined to be at high risk of sustaining a concussion were used as the sample over the course of their season between 1998 and 2005. The athlete would be diagnosed by the team physician and then begin the other assessments, same as baseline tests, within 24 hours. To evaluate sensitivity, headache, nausea, balance problems, fatigue, trouble falling asleep, drowsiness, feeling "slowed down", feeling "in a fog", and difficulty concentrating were all self-reported by the athlete on a Likert scale from "not severe at all" to "always". The postural control assessment was completed using the NeuroCom SOT, using a force plate to track center of pressure in 6 different conditions. Five neurocognitive assessment methods were used during this study: Hopkins Verbal Learning Test, Trail Making Test, Symbol Digit Modalities Test, Digit Span, and Controlled Oral Word Association test. The 2 computerized assessments were the HeadMinder CRI and the ImPACT. Seventy-five Division-1 athletes (62 men, 13 women) sustained a concussion and were diagnosed by team doctors during the study. The computer-based assessments were found to be the most sensitive out of all of the tests at 79.2% and 78.6% for ImPACT and HeadMinder CRI, respectively. No single test was sensitive enough to solely use that assessment method when detecting concussions, but this data does suggest that using a variety of test batteries would strengthen the findings and better display the presence of concussion.

This position statement published the NATA is a modification to the initial position statement released in 2004. Broglio et al. [21] presented these findings to new research to stay up with what literature most recently stated concussion management for practicing athletic trainers; specifically education and prevention, documentation and legal aspects, evaluation and return to play, and other considerations. Athletic trainers are recommended to educate coaches, parents, and athletes about the proper terms for a concussion and how to properly manage it. If others in the situation understand the injury and the implications it has on the rest of the athlete's life, they will have to take it as seriously as it is. The athletic trainer is expected to be mindful of policies in place by any schools or leagues in which they are providing care for and to document the concussed athlete's knowledge of the signs and symptoms that they are presenting. A more in-depth return to play and evaluation section discuss the necessity of a comprehensive baseline examination. This can help indicate anyone at risk and can be used as a valid comparison when determining return to play. Athletic trainers are required to understand the equipment being used in the sports that they are covering; it is necessary to be able to remove any in the case of an emergency. Often athletic trainers have more training in equipment removal than many other medical professionals, which gives great responsibility to be knowledgeable in this area.

The ImPACT program is one of the most widely used computerized neurocognitive function assessment tool. By looking at a variety of neurocognitive abilities, it is able to give clinicians a composite score on four subtests. These subtests include: verbal memory, visual memory, reaction time, and processing speed. The neurocognitive abilities that are being evaluated are word recognition, design memory, visual processing and memory, symbol matching, color matching, and working memory/visual response speed. The purpose of this study by Nakayama et al. [22] is to re-examine the test-retest reliability of the ImPACT neurocognitive test battery between baseline, 45 days, and 50 days after baseline on physically active college students. There were five hypotheses recorded in the paper and the first four stated that there would be acceptable test-retest reliability in each of the four composite scores. The fifth hypothesis stated that there would be no difference in test takers' effort level. This study used 120 college-aged individuals that scored similarly on the health questionnaire that was distributed. The ImPACT program was the only instrument necessary for the data to be collected. Subjects would arrive to take their test for the baseline test and then 45 and 50 days after that. Descriptive statistics were performed for all tests to determine means and standard deviations. SPSS Version 16.0 was used to obtain ICC for each composite score. Specifically, a 2-way random effects analysis of variance ICC for absolute agreement was calculated in order to estimate the test-retest reliability of ImPACT for baseline to day 45 assessments and for day 45 to day 50 assessments. All intraclass correlation coefficients between baseline to Day 45, Day 45 to Day 50, baseline to Day 50, and overall intraclass correlation coefficient exceeded the threshold value of .60 for acceptable test-retest reliability. The pre and post-testing survey with 0 to 10 Likert scales revealed the participants were moderately stressed (average 4.64) and mildly fatigued (average 3.45), with low level of distraction (average 1.73) while completing the ImPACT test. The results from this study would present that the ImPACT test is a reliable neurocognitive test battery. This assessment tool can be used throughout the athletic population and yield significant results and provide clinicians with the information that they need about their athletes.

Postural stability can tell clinicians a lot of information about the state of a person's neurocognitive function. It is a factor that has been difficult for athletic trainers to observe because there are not a lot of clinically valid assessments that are feasible due to high cost or availability of a force plate. Riemann et al. [23] looked to observe the efficiency of the Balance Error Scoring System (BESS) as a clinical tool to detect postural instability after head injury has occurred. Sixteen athletes who sustained a head injury, as well as 16 matched controls completed the assessments on days 1, 3, 5, and 10 post-injury. At every session, participants were tested with both a clinical test and the Sensory Organization Test (SOT) on the NeuroCom Smart Balance system. The data was analyzed using a repeated-measures ANOVA. The most significant finding in the study was that a clinical balance testing battery was sensitive to acute postural stability. The data from this study will help clinicians when dealing with any return to play decisions. This research has helped identify a clinical test that will present symptoms of postural instability following a head injury, with a battery of stances on a foam surface in combination with BESS being the suggestion.

As the management for concussion has become more understood and research has presented itself as to the most effective tool for observing neurocognitive deficits, the ImPACT assessment has been determined to be the current gold standard for computerized assessments. Covassin et al. [24] aimed to examine exactly how sports medical professionals are using this product in their practice. This was an online survey of 399 certified athletic trainers from institutions across the United States. The athletic trainers who responded to the study averaged over 13 years of experience and had been using the ImPACT assessment system for 3.27 2.25 years. About 95% of the users of this tool responded that they have used it for baseline testing in addition to post-injury testing. Most of the athletic trainers also said that they would not return an athlete to competition if they exhibited any symptoms. The use of baseline testing has been determined to be necessary for proper use of this concussion assessment tool. If, however, athletes are not trying their hardest on this baseline test, these scores must be thrown out and the test redone. Using poor baseline scores or general scores reported may put the athlete at risk for future injury due to not being completely healed. Both baseline and post-injury test scores must be taken into account, but most athletic trainers used ImPACT as a reference tool and determined return to play based on the presence of symptoms.

Guskiewicz et al. [25] gathered all of the previous literature on postural stability and balance in order to determine if there are any characteristic deficits in individuals who have experienced head-injury. Until this point, most research has not looked into the acute phase of recovery time in athletes; this has proven to be one of the key times for return to play decisions to be made. The most current forms of assessment for postural stability include the use of a force plate or a clinical test such as the Balance Error Scoring System (BESS). Because of the variety of presenting symptoms and deficits caused by concussion, postural stability may or may not display decreased ability on assessments after head trauma is received. The main finding in this review is that postural stability is a small piece of a large puzzle, that is proper assessment and management of concussion, and that using a battery of tests can help identify any neurologic impairment in athletes.

Technology revolutionized the neurocognitive assessment field by giving clinicians the ability to test different parts of patients' neurocognitive abilities and get an immediate score compared to a baseline. Computerized programs are now the gold standard in the assessment of concussions. A gradual return to play protocol has also been suggested as the standard of care. It is important to use the computerized data in collaboration with the standards of practice to provide an athlete with the best care possible.

Dual-Task in Geriatric

The use of DT assessment has been used much more frequently in recent years for the geriatric population. Having a participant use multiple parts of their brain's ability can tell clinicians what is deficient. By combining a motor and a neurocognitive task, the area that needs more attention will become apparent and can lead to more findings of a person's health.

The Timed Up and Go Test (TUG) has been used as a test to observe for the ability for older individuals to move around independently and complete tasks of everyday living on their own. Shumway-Cook et al. [14] looked into this assessment to see the validity that it presents when indicating individuals who were at risk for a fall. Thirty individuals above the age of 65 were used for this study, 15 with no history of falls, and 15 adults with a history of 2 or more falls in the previous 6 months. An activities-specific balance confidence scale was used as a self-report measure to rate their confidence in their ability to balance. Fourteen balance exercises were used during a balance assessment at the beginning; a Berg Balance Scale was used to score these tests. Individuals were then asked to complete 3 trials of the TUG under 3 conditions: TUG alone, TUG with a cognitive task, and TUG with an upper-extremity motor task. After a MANOVA was completed on the data, participants with a history of falling were slower than those who had no history of falls in all 3 trials. The addition of cognitive or motor tasks increased the time to completion in both groups. Data from this study suggest that the TUG is a sensitive and specific indicator of falls occurring in older adults.

The use of the Timed Up and Go Test (TUG) presented clinicians a valid and reliable assessment for identifying older individuals at risk for falling. There were issues found in that test, one being that it was one continuous task, which made it difficult to identify specific tasks within the greater assessment. The Expanded Timed Get Up and Go Test (ETGUG) was derived from the TUG to enhance the assessment and make it easier to collect the data from specific actions. The purpose of the study by Botolfsen et al. [26] was to test the intrarater, interrater, test-retest reliability of the ETGUG protocol, internal consistency from ETGUG from video recordings, and the concurrent validity with the TUG. Thirty-three home-dwelling individuals over the age of 75, with impaired mobility were recruited for this study. The participants were tested and retested with ETGUG and TUG on the same day of collection. During the ETGUG, clinicians observed specific sub-sections of the test to score it: sit-to-stand, 3-m walk at preferred speed, 180 degree turn, 3-m walk at fast speed, turn and sit down, and total time. Small differences were found in intrarater and interrater reliability throughout the trials of the ETGUG. The test-retest reliability was lower than the intra and interrater reliability. The internal consistency was considered to be acceptable. The ETGUG was scored best on video, but in general it tests more than the TUG, so it could be considered when assessing individuals in the future.

The Expanded Timed Get Up and Go (ETGUG) assessment has been shown to have good interrater, intrarater, and test-retest reliability. Botolfson et al. [27] aimed their study in 2006 to test the reliability and concurrent validity of the ETGUG assessment. Twenty-eight participants, over the age of 75, with a variety of physical limitations were used for this study. The TUG and ETGUG were both performed within 1 hour of each other. The TUG was recorded on a standard stopwatch, while the ETGUG was videotaped on a camera. The researcher's reasoning for using the ETGUG is because by timing individual tasks, it gives the clinician the understanding of which task is most difficult for the individual, which is good information that could be used if the test is considered reliable for assessing concussion symptoms. ETGUG scored from a video displayed good reliability within testers. Concurrent validity shows a moderate correlation between ETGUG and TUG, meaning that they do not overlap in what they found.

Whitney et al. [28] measured the sensitivity and specificity of the Timed Up and Go (TUG) and the dynamic gait index (DGI) for self-reported falls in people with vestibular disorders. Whitney claims that many gait and balance tools have been proven to predict fall risk in older adults, but it is not quite known whether these same tools could be used to indicate increased fall risk in adults with vestibular and balance disorders. One hundred three participants were used and recruited from a balance and vestibular clinic. All participants were evaluated by three physical therapists. They would ask each participant about their fall history and also to complete the TUG and DGI. Mean TUG and DGI scores were calculated for age group, diagnostic group, and symptom duration. An ANOVA was used to compare TUG and DGI between participants. Analysis of the statistics proved that the TUG and DGI are both effective in identifying fall risk in people with vestibular dysfunction. Clinicians can observe these risks in individuals based on their scores on the assessments; slower scores on the TUG and lower scores on the DGI correlated with reports of falls.

Dual-task assessment has been proven valid and reliable for the identification of vestibulocochlear disorders and older individuals who may be at risk for a fall. This can greatly indicate the ability of a person to live individually or if they will need assistance with daily living. With the strong data in this population, DT assessment should be evaluated in other populations to identify its use in assessing concussion.

Dual-Task in Young

The younger population exhibits greater symptoms and a longer recovery time after sustaining a concussion. Depending on the sport played, young athletes are exposed to head trauma every day at practice and during games. Dual-task assessment may be useful in identifying lingering symptoms of a concussion in a younger, athletic population based off of the previous research done in other populations.

A gap in the research on DT testing was found in the area of assessing performance on a dynamic motor task. Fait et al. [29] also observed little research performed on concussed individuals. In this study, an 18 year old hockey player was concussed during a game and was entered into this study to help researchers determine what effect concussion had on navigational behavior by comparing trials of locomotion and circumvention of a fixed obstacle with or without a visual stimulus. The clinical neuropsychological measures of attention and executive function were taken before and 14 days after the concussion to have a single post-injury measure for comparison. The lab portion of data collection utilized technology that tracked 3-dimensional kinematic data. This study used a Stroop test as the visual stimulus on the screen during the navigation of the participant. The data showed that even when the participant displayed no symptoms during testing, his locomotor navigational abilities were still affected up to 30 days following the concussion. In addition, the participant made errors on his dominant side, suggesting that even when using the dominant side of the body, the brain still has trouble correcting mistakes and navigating the body around obstacles. This study shows evidence that the brain’s functional ability is diminished up to 30 days after injury and stresses the importance of cognitive rest after sustaining a head injury.

Dual-Task assessment has primarily been performed in healthy populations when aimed at indicating signs and symptoms of concussion, but Dorman et al. [10] investigated the diagnostic utility of DT cognitive testing with balance testing in a young concussed population. Eighteen participants who were diagnosed with a concussion by a certified sports medicine physician were recruited for the study. Twenty-six injury free individuals were used as healthy controls. During the patients’ visits to the clinic, physicians asked them a series of questions to rate their symptoms of concussion at that point. Two data collection sessions were used for this study, in which participants stood on a force platform under 4 conditions: eyes open, eyes open with a cognitive task, eyes closed, and eyes closed with the same cognitive task. Positional changes and center of pressure were observed throughout the trials. Every time the participants visited the clinic, their symptom scores got increasingly better. Postural stability increased in accordance with the symptom scores, continuing to get better after time. The evidence presented in this study suggests that these tests would be helpful in evaluating any impairment in young concussed individuals when determining return to play.

Simultaneous activities, such as almost any action while competing in athletics, require different mental and functional processes to work together to complete the task. This study, by Broglio et al. [30] was aimed to investigate a DT testing methodology to establish if it could be used in concussed population. Twenty participants, 10 male, 10 female, were recruited for this study. There were 2 testing sessions required for data collection. Session 1 consisted of time for the participants to orient themselves to practice the balance and cognitive tasks. Session 2 involved of 2 phases; in the first phase, participants would complete the cognitive and balance tests separately. The second phase of session 2 consisted of the participants performing the tasks together in a DT assessment. Analysis of the DT assessment consisted of the response times for all participants being measured and calculated via a 4 x 4 within-subject, repeated measures ANOVA. During the DT assessment, response times were found to be slower only in trials when the participants had to differentiate between letter and number. Healthy participants actually showed an improved performance during DT rather than single-task. The methodology of this DT protocol showed increases in postural control and cognitive function, but more research must be done in order to appropriately use this clinically.

Condron et al.[31] investigated DT assessments on a force plate, with age, balance impairment, and cognitive testing as the variable of interest. Sixty volunteers were recruited for this study, 20 healthy adults were between the ages of 20 and 40, and the other groups consisted of older adults, 20 healthy and 20 with a mild increase in fall risk (MIFR). Using a force platform, center of pressure was measured under a variety of conditions. The single task balance exams consisted of 6-25 second tests with the platform tiled or with other conditions affected. The DT incorporates a cognitive test in which participants were required to count backwards by 3 from a randomized, predetermined number provided by the clinician. Healthy older people demonstrated greater sway on the dynamic platform than the healthy younger people. The MIFR group had significantly higher mediolateral center of pressure differences than the healthy older persons group on the stable and dynamic platform when tilted in the front and back directions. When adding in the cognitive task, this dynamic assessment can be used to differentiate between healthy older individuals and those who are at a greater risk of experiencing a fall.

Research has proven that certain DT assessment methods present significant data that suggests that it can identify symptoms of concussion in the younger population. Using force plates and a variety of testing procedures, deficits in motor or neurocognitive ability can be observed when the brain cannot perform tasks at the same capacity when compared to baseline.

Dual-Task in Healthy

When investigating DT assessment’s ability to identify the symptoms of concussion, the majority of early research was performed on a healthy population. Clinicians sought to understand if the tests were able to detect what was desired. If healthy populations were able to provide significant data, then there would be a valid baseline that could be clinically used in a concussed population.

As the brain attempts to heal after a concussion is sustained, the vestibular system requires more conscious control to perform everyday coordinated actions. Dual-task testing has been proved to indicate deficiencies in neurocognitive and/or motor function in the geriatric population and new research is being done in healthy populations to gather information to identify concussion symptoms in injured individuals. Bigsby et al. [9] performed a study with the purpose of establishing normative data on visual motor testing with and without a simultaneous balance assessment. This study used 105 athletes from a Division I college football team. The instrument being used to determine visual motor ability was the Dynavision D2 Visumotor Training Device. Using this device, participants performed 2 tests, the A-star (A*) test and the reaction test (RT). The A* requires the athlete to depress lighted buttons as quickly as possible, while the RT requires the athlete to depress a lighted button and hold it down until the next one is lit up, when they would hold that one, and so on. Both tests were done on the flat surface of the floor as well as using a BOSU ball as an uneven surface. When comparing the single-task to DT assessment, both tests displayed significant results showing that performance was decreased on the DT. More research is necessary to strengthen the claim in this article that it could be used as normative data to determine symptoms and lingering effects of concussion for return to play.

Resch et al. [32] wanted to investigate DT testing as a valid tool for sport-related concussion assessment. Twenty healthy, college-aged students were recruited for this research. The DT test consisted of a balance assessment and a cognitive assessment. The balance assessment consisted of a modified Smart Balance Master SOT, in which the participant undergoes 6 conditions to challenge the function of the brain: fixed surface with fixed vision (fixed-fixed), fixed surface and absent vision (fixed-absent), fixed surface and sway-referenced vision (fixed-sway), sway-referenced surface and fixed vision (sway-fixed), sway-referenced surface and absent vision (sway-absent), and sway-referenced surface and sway-referenced vision (sway-sway). The cognitive test was an auditory switch task that presented participants with 40 computer generated letters or numbers. During trials, participants were asked to identify vowels versus consonants as well as odd or even numbers. The DT assessment on data collection days consisted of the participants standing on a platform and completing the cognitive test under the 6 conditions of the balance assessment. Scores were higher on the balance assessment during the DT fixed-fixed and fixed-sway conditions. Response times were longer during DT when compared to single-task during the switch trials of the cognitive assessment. This data indicates that postural control took priority over cognitive ability, suggesting that a clinician could use DT assessment for observing a decreased level of certain mental processes.

An unpublished study from the University of Hawaii sought out to determine the best combination of previously validated, clinical, single-task cognitive and motor tests. When a motor task, like the expanded timed get up and go (ETGUG) test, is paired with a cognitive task, serial sevens, the brain focuses on one task more than the other. Most previous DT assessment research has been done suing laboratory equipment and could not be used clinically, so this study was aimed to observe which clinical assessments would produce significant reliability. Both single and DT assessments were collected during 2 data collection sessions. A randomized repeated measures design was used. The independent variables were the 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. All participants were assessed in a baseline for all of the tasks and then the ETGUG was paired with the individual tasks: Series Sevens (SS), Auditory Pure Switch Task (APST), and Backward Digit Recall (BDR). Expanded timed get up and go scores were decreased during all trials under the DT conditions. The DT with APST combination was the only pairing that did not have an indication of a learning or practice effect.

This data presented in the research suggests that the ETGUG with APST, using ETGUG time to completion as the main outcome measure is the strongest and clinically practical DT assessment method. [33]

In order to gain knowledge on the effect of DT use in the military, May et al. [34] conducted this study in 2009 on the use of backpack load on the balance and decisional processes of cadets. Specifically, the purposes of this study include 1) impact of substantial load on participants' posture and on their cognitive performance, 2) the magnitude of effects of the backpack load on balance and cognitive performance over time, 3) the impact-specific types of balance perturbation on posture and cognitive function. Twenty participants were recruited for this study from the Air Force and Army ROTC programs. The data collection consisted of 3 sessions, separated by 24-48 hours. A modified SOT was used as the balance assessment under the 6 balance perturbation conditions. The cognitive task was an auditory switch task in which computer-generated letters or numbers were presented to the participant, whose job was to differentiate between odd and even numbers and vowels and consonants. A 2x7 ANOVA was used to calculate the statistics; with and without carry-load as the 2 groups. Concurrent balance control and auditory choice-reaction task performance were assessed. Within-subject data showed that the larger carry load did negatively influence cognitive processes, but only during the tasks requiring executive, higher-level, mental processing. The ROTC cadets showed that balance control and situational awareness were both affected by the load placed in the backpack.

Research on DT assessments performed in healthy populations with the intended use for identification of concussion is becoming more common in the sports medicine world. A study by Ross et al. [35] were interested in the previous evidence found stating that after a concussion is sustained, an athlete experiences a deficiency in the ability to divide attention. The purpose of this study was to examine the effects of single vs. a DT on cognition and balance in healthy subjects. Another purpose of this study was to examine reliability of 2 DT paradigms while examining the overall feasibility of the tasks. The outcome measures were the procedural reaction time (PRT) and a modified adapted procedural auditory task (PAT) used to assess cognition. An SOT and BESS were used to assess balance performance in participants. Participants were tested twice, with sessions coming 14 days apart. Orientation trials (single task) were used prior to the DT assessment in order to familiarize the participants with the task. On the SOT and PRT, scores improved significantly from the single to DT. The BESS test proved to be more reliable than the SOT; it also displays a greater use as a clinically functional tool.

Concussion assessment is moving towards a DT system, as opposed to testing neurocognitive and motor function separately. In an attempt to examine the sensitivity and reliability of DT method when assessing the effects of concussion, Okumura et al. [36] Recruited 59 healthy young participants for this study in 2012. Three testing session were completed at baseline, 1 week late, and approximately 7 months later, consisting of an auditory switch task of different lengths (cognitive test), while simultaneously performing a modified Harvard step test (motor test). Global switch tasks scores and percent accuracy were recorded for each task. For both the global switch cost scores and percentage error scores, an initial 3 (30, 40, 60) × 2 (sitting, stepping) ANOVA was conducted to assess the between-group group performance. Significant results were found for effect of condition. This suggests that DT testing can be used to help indicate someone who is presenting with the effects of concussion in athletes. Return to play protocols can use this testing method to help make decisions for athletes based off of the results yielded.

Certain DT assessment methods have been proven to be valid and reliable in a healthy population. Research previously completed strengthened the claim that DT could be used in a concussed population for clinical use. The decreased performance on specific areas of the test display any deficits present and can help healthcare professionals make educated clinical return to play decisions.

Recent findings from research on concussions have significantly enhanced the standard of care for a variety of populations. More information has been presented on the effects of sub-concussive blows and the concurrent lingering effects. The geriatric population can be cared for in a more individualized manner by understanding if they are capable of living on their own or whether assistance is needed. Dual-task assessment has been applied to multiple populations and has been proven to be valid and reliable in the majority of studies. This new method of assessment can greatly increase the ability to indicate the presence of concussion and will continue to be helpful in the clinical setting.

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APPENDIX A: Informed Consent

INFORMED CONSENT FORM

Department of Kinesiology and Rehabilitation 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:** Sam Fox, ATC, Kaori Tamura, PhD, ATC; Morgan Kocher, MS, ATC

Title of Study: ASSESSMENT OF CONCUSSION AND SUB-CONCUSSIVE BLOWS USING IMPACT AND DUAL-TASK TESTS DURING A HIGH SCHOOL FOOTBALL SEASON

Purpose of Research: My name is Sam Fox and I am a graduate student at the University of Hawaii at Manoa in the Post-Professional Athletic Training and Education Program. This study is being conducted as part of the graduation requirements set forth by the Department of Kinesiology and Rehabilitation Science for a Master's Degree in Athletic Training. Concussion may be caused by a blow to the head or by acceleration forces without a direct impact, which can cause a variety of physical (headache, nausea, dizziness etc.), cognitive (memory problem, difficulty thinking clearly, difficulty concentrating etc.), and emotional (sadness, irritability, nervousness etc.) symptoms. Current sport-related concussion assessment involves the use of separate physical and cognitive tests that the patient must complete. This is a reliable method for concussion management, however, it is limited to evaluating one aspect at a time. These tests can be performed simultaneously, called Dual-Task testing, which has a potential to be a better concussion assessment test. The purpose of this study is twofold: (1) to examine how the scores of the computerized cognitive test and a Dual-Task test change after a concussion compared to the pre-season scores, and (2) to examine how the scores of the computerized cognitive test and a Dual-Task test change after the season compared to the pre-season scores.

II. **Expected Duration for Participants**: The baseline ImPACT testing is as part of the schools' standard safety protocol that all participating athletes are required to complete. An addition of Dual-Task test will take approximately 5 extra minutes, therefore, a completion of ImPACT and Dual-Task testing will take approximately 45 minute. In addition to baseline and post-concussion tests (if concussed), all athletes were asked to complete post-season test. Only those who are diagnosed with a concussion during the season will take the post-concussion tests.

III. **Description of Procedures**: All athletes will have completed a baseline ImPACT assessment within two years of the study as part of the protocol designed by the Hawaii Concussion Awareness and Management Program (HCAMP). A baseline Dual-task assessment will also be conducted. This will consist of 3 trials of the Expanded Timed Get-Up-and-Go (ETGUG) with Auditory Pure Switch Task (APST) protocol. The ETGUG involves standing up from a seated position, walking 10 meter and coming back to the chair at a self-selected pace, and sitting down on the chair. The APST involves distinguishing out loud between even and odd numbers as they are stated out loud by the researcher. Participants will then perform 3 trials of Dual-Task test, performing

INFORMED CONSENT FORM

ETGUG and APST simultaneously. These baselines will be taken during the summer camp of football and during preseason workouts for basketball.

If an athlete is diagnosed with a concussion during the season, a post-concussion assessment will be conducted under the same protocol as the baseline testing within 72 hours of injury. The athlete will continue to take both assessments, once every 72 hours until they are considered cleared for symptoms based on their ImPACT score. Athletes will begin the gradual return to play protocol as stated by HCAMP, when the post injury ImPACT has returned to normal baseline level as determined by a neuropsychologist. The gradual return to play protocol will be supervised by Board of Certification certified athletic trainers at the high school. During this time, the athlete will continue to perform dual-task assessment once every 72 hours until they are cleared for practice without restrictions. This procedure will not interfere with the participant's normal return to play protocol.

When the season is completed, all participants will take a post-season ImPACT and dual-task assessment. These tests will be conducted within 1 week of the completion of the season. If an athlete participates in both football and basketball, the baseline test from football will also serve as the preseason test for basketball

V. **Benefits**: There are no direct benefits for participating in this research study. However, this research study may help developing more sensitive, time efficient, and practical concussion assessment protocol.

VI. **Risks**: For the concussed participants, the Dual-Task test may cause a temporary increase in symptoms. If athletes become uncomfortable or the symptoms become too severe, they can stop the testing session or withdraw from the study all together. You should understand that if your child is injured in the course of this research process that you alone will be responsible for the costs of treating your injures.

VII. **Voluntary Participation:** Your child's participation in this study is completely voluntary. Your decision is voluntary about permitting or not permitting participation. You can withdraw your consent without any loss of benefits or rights. I realize that I may be both the researcher, and at the same time, the athletic trainer of your child. I want to assure you that the choice to participate or not participate in this study will have no impact on your child's medical care or return to play process after a concussion has been sustained.

VIII. **Confidentiality**: All personal information and data 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. When I report the results of my research, I will not use any names or other personal identifying information. All personal information will be destroyed upon completion of the research project.

IX. **INFORMED CONSENT FORM**

X. **Contact Information**: If you have any questions or concerns regarding your participation in this study, you may contact any of the key personnel: Sam Fox at 510.499.1625, 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	Parent/Legal Guardian
________________________________	____________________
Signature	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.

APPENDIX B: Informed Assent

Assent to Participate in Research

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

Title of Study: ASSESSMENT OF CONCUSSION AND SUB-CONCUSSIVE BLOWS USING IMPACT AND DUAL-TASK TESTS DURING A HIGH SCHOOL FOOTBALL SEASON

A concussion is a brain injury. Because brain is inside the head (skull bone), we can't see if brain is injured or not. Because of this, we have to use thinking test and movement test to find out if you have a concussion or not. There is a new type of concussion test called Dual-Task test, and we want to find out if this new type of concussion test is better than the thinking and movement tests that we have been using. We would like you to be in this study, because you are playing football and/or basketball and age between 12 and 18. Before you decide if you would like to be a part of this study, it is important for you to know:

- It is your choice to be part of this study or not;
- If you join the study, you can stop at any time; and
- Your parent or guardian must also agree for you to be in this study.

<u>What will you be asked to do if you join this study?</u>

You will be asked to take a baseline Dual-Task test together with the ImPACT test that you usually take before the season. Dual-Task test is a walking test and thinking test combined together, and takes about 5 minutes. If you get a concussion during your sport you will be asked to come back within 3 days to take the these tests. After the season, you will be asked to take these tests again within 1 week of the end of your season.

<u>Will anything happen to make you feel uncomfortable or unsafe?</u>

If you are taking these tests after getting a concussion, these tests may make you to feel worse, for example head to hurt, for a short time. If you feel worse during the test and would like to stop, please let the researcher know and you may end the testing session.

<u>Are there any benefits to your participation in this study?</u>

You may not benefit directly by being a part of this study, but you may be able to help future athletes return to their sport safely in the future.

Assent to Participate in Research

Who will have the information about me?

The researchers of this study will have your personal information, such as your name, age, and when you get a concussion. But we will use a code number instead of your name. All information will be stored in locked file cabinets. After the project has ended, all code numbers will be deleted.

Do you have to be in this study?

You do not have to be in this study if you don't want to. Even if you start, you can stop later if you want to. If you do not want to take part in this study, there will be no impact on you.

Who can answer your questions?

If you have any questions about this study, you may call: Sam Fox at 510.499.1625, or Morgan Kocher at 971.237.6903.

Agreement

By signing your name at the bottom of this form means that you agree to be in this study. You and your parents or guardian will be given a copy of this form after you have signed it.

Participant name: ____________________

Participant signature: ______________________________ Date: ______________

APPENDIX C: ImPACT

The sub-sections included in the test are, 1) Demographic Profile and Health History Questionnaire, 2) Current Concussion Symptoms and Conditions, 3) Baseline and Post-Injury Neurocognitive Tests, 4) Graphic Display of ImPACT Test Scores. Demographic Profile and Health History Questionnaire is a series of questions about the athlete and their health history. These questions include simple information such as height and weight, and the rest ask about prior concussion history or other learning disabilities. The second section of the test is the Current Concussion Symptoms and Conditions. This section asks the athlete to give information on their most recent concussion that they are being tested for. The subject then responds to a questionnaire on twenty-two concussion symptoms via a 7-point Likert Scale. Section 3: Baseline and Post-Injury Neurocognitive Tests is the section of the test in which the athlete will perform a series of tests, six modules, which evaluate the different parts of the brain.

Module 1: Word Discrimination: This sub-section evaluates the athlete's attentional processes and verbal recognition memory by using a word discrimination paradigm.

Module 2: Design Memory: Design Memory is used to analyze the subject's attentional processes and visual recognition memory.

Module 3: X's and O's: Measures visual working memory as well as visual processing speed and consists of a visual memory paradigm with a distractor task that measures response speed.

Module 4: Symbol Matching: Analyzes visual processing speed, learning, and memory.

Module 5: Color Match: Represents a choice reaction time task and also measures impulse control and response inhibition.

Module 6: Three Letter Memory: Measures working memory and visual motor response speed.

Section 4 of the ImPACT test is the Graphic Display of ImPACT Test Scores. A total of five scores are produced by the test and each one displays itself graphically. The scores displayed by the neuropsychological tests are Composite 1: Verbal Memory Composite, Composite 2: Visual Memory Composite, Composite 3: Processing Speed Composite, Composite 4: Reaction Time Composite, Composite 5: Impulse Control Composite.

APPENDIX D: Data Collection Form

Data Collection Form

Subject Name: ______________________

Subject Number: ___________

Collection Session: _________________

Sport:______ Level:__________ Position:___________

Age:______ Height:______ Weight:________

Assent Signed (circle one): Yes No
Consent Signed (circle one): Yes No
History of concussion (circle one): Yes No If so, how many: ______

SINGLE TASK					
ETGUG			**APST**		
Trial Number	Time (sec)		Trial Number	Total CORRECT Responses	Total Responses ATTEMPTED
1			1		
2			2		
3			3		
4 (if necessary)			4 (if necessary)		

DUAL TASK			
Trial Number	Total CORRECT Responses	Total Responses ATTEMPTED	Time to Completion
1			
2			
3			
4 (if necessary)			

APPENDIX E: Recruitment Information Form

A sample of verbal recruitment procedures at the summer and winter sports informational meetings:

Aloha Parents,

My name is Sam Fox. I am a certified athletic trainer and graduate student at the University of Hawai'i at Manoa, in the Department of Kinesiology and Rehabilitation Science and clinically work here at Damien Memorial School. One requirement for earning my Master's degree is to complete a research project. The purpose of my research project is to compare the effects of concussion and sub-concussive blows on multiple tests. This will help us determine the best way to assess concussions in younger age groups and identify any effects from sub-concussive blows on brain function. I am asking you to consent for your child to participate because you have a child who plays football and/or basketball and is between 12 and 18 years old.

If you as the parent/guardian choose to participate in this project, you will be asked to:

- Complete an informed consent form

If your child chooses to participate in this project, they will be asked to:

- Complete an assent form
- Complete several tests that examine their thinking and coordination

There will be no direct benefit to you or your child for participating in this research project. All of your and your child's information will be kept private and locked behind two doors at the university. Your participation in this project is completely voluntary and you may stop participating at any time. There will be no change to the current return to play protocol set in place at DMS. This data is being collected for concussion research that could help better manage concussions in the future.

If you have any questions about this study, please feel free to contact me.