2021-05-01

The Immediate Post-Concussion Assessment And Cognitive Testing Battery And The Nih Toolbox® Cognition Battery: A Correlation Analysis On Working Memory

Genevieve R. Hernandez
University of Texas at El Paso

THE IMMEDIATE POST-CONCUSSION ASSESSMENT AND COGNITIVE TESTING BATTERY AND THE NIH TOOLBOX® COGNITION BATTERY: A CORRELATION ANALYSIS ON WORKING MEMORY

GENEVIEVE HERNANDEZ

Master's Program in Speech Language Pathology

APPROVED:

Anita Parada, Ph.D., Chair

Vanessa T. Mueller, Ph.D, CCC-SLP., Co-Chair

Benigno Valles, Ph.D, CCC-SLP.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

THE IMMEDIATE POST-CONCUSSION ASSESSMENT AND COGNITIVE TESTING BATTERY AND THE NIH TOOLBOX® COGNITION BATTERY: A CORRELATION ANALYSIS ON WORKING MEMORY

by

GENEVIEVE HERNANDEZ, B.S.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Speech Language Pathology

THE UNIVERSITY OF TEXAS AT EL PASO

May 2021

Acknowledgements

I would like to express my sincere gratitude to my supervisors, Dr. Anita Parada and Dr. Bess Sirmon-Taylor for their assistance at every step during this research project. Thank you for sharing your immense knowledge, expertise, and passion with me. Additionally, I am extremely grateful to my dear friend and colleague, Gladys Melendez, for her contribution to this study and support. I would also like to offer a special thanks to the El Paso Rhino's Hockey team for their contribution to this research project. Lastly, I am deeply grateful to my family and boyfriend for their unwavering support during this process. Without these incredible individuals and groups, I would not be where I am today.

Table of Contents

List of Tables

Introduction

Every year, estimates as high as 3.8 million sports-related concussions are reported (Langlois, Rutland-Brown, & Wald, 2006; Brown & Knollman-Porter, 2020). According to the Centers for Disease Control and Prevention (CDC), a concussion, the mild traumatic brain injury, is caused by a bump, blow, jolt, or rapid back and forth movement to the body and head. The Brain Injury Research Institute (BIRI) states that these abnormal movements to the head can lead to changes in brain function at the cellular level. These changes are known to cause various signs and symptoms that may affect daily living (BIRI, 2019). Health care professionals on a concussion management team, including a Speech-Language Pathologist (SLP), should properly treat athletes who sustain concussions so that they may reduce the chances of complications and further injury.

Chapter 1: Literature Review

CONCUSSION ASSESSMENT

Significant damage from concussive injuries can manifest at the cellular level only, and therefore, may not be seen through Magnetic Resonance Imaging (MRI) or a Computerized axial tomography (CAT) scan (Guskiewicz et al., 2004; McCrory et al., 2008; McCrory et al., 2012; Harmon et al., 2013; Broglio et al., 2014; Laker, 2015). The signs and symptoms, that should be evaluated to determine whether a concussion occurred, include, but are not limited to, emotional, physical, behavioral, cognitive, and/or sleep disturbances (Harmon et al., 2013; Broglio et al., 2014; Laker, 2015). Four common categories of assessments are agreed as important: balance assessments, neurocognitive assessments, genetic testing, and other experimental concussion assessment modalities (Guskiewicz et al., 2004; McCrory et al., 2008; McCrory et al., 2012; Harmon et al., 2013; Broglio et al., 2014; Laker, 2015).

One assessment tool mentioned previously that can aid in the diagnosis of a concussion, is a neurocognitive assessment (Guskiewicz et al., 2004; McCrory et al., 2008; McCrory et al., 2012; Harmon et al., 2013; Broglio et al., 2014; Laker, 2015). The SLP plays a significant role, along with other healthcare professionals, in performing neurocognitive evaluations, due to a strong background in language and cognition (Salvatore & Fjordbak, 2011; Hardin, 2019). SLPs are poised to administer the assessment and interpret the results along with other healthcare professionals (Salvatore & Fjordbak, 2011).

One specific role of the SLP includes conducting a baseline assessment (Salvatore & Fjordbak, 2011; Hardin, 2019). According to the Center for Disease Control (Centers for Disease Control, 2015), a baseline assessment is a series of evaluations and information gathering that provides valuable information regarding the athlete's cognitive performance and medical history prior to the athletic season. With the data from a baseline assessment, the SLP can then interpret subjective data that explains the athlete's current cognitive performance. This data leads to the determination of the next steps for the athlete and assists the concussion management team in making an informed decision about when to begin the return-to-play protocol. This protocol is a series of steps that ensure a safe return to academics, work, and athletics.

According to the U.S. Food and Drug Administration (FDA), the following measures have been approved as neurocognitive assessments that can help diagnosing and monitoring of changes over time after traumatic brain injuries: *Brain Trauma Assessment Kit, BrainScope Ahead 100*, *ImPACT*, *Infrascanner Model 1000*, and *EyeBOX*. One assessment measure that is used at the University of Texas at El Paso's Concussion Management Clinical Research Laboratory (CMCRL), is the *Immediate Post-Concussion Assessment and Cognitive Testing* (*ImPACT*).

The *ImPACT*, according to the technical manual and published studies, has been found to have primarily good reliability (Schatz, 2010; Schatz & Ferris, 2013) and good construct validity (Iverson, Lovell, & Collins, 2005; Schatz & Putz, 2006; Maerlender et al., 2010; Allen & Gfeller, 2011). Maerlender et al., (2010) measured construct validity using several standard neuropsychological tests, including the *Paced Auditory Serial Addition Test*, which was used to obtain validity on the construct of working memory. There has also been published data on the sensitivity and specificity of the *ImPACT* and its successfulness when differentiating those who were concussed from those who were not (Schatz & Pardini, 2006; Broglio et al., 2007; Schatz & Sandel, 2012).

The *ImPACT* test battery has been the standard assessment tool which has been used specifically to assist in managing and monitoring concussions (Allen & Gfeller, 2011). However, more recently, the National Institute of Health has promoted an assessment battery called the *NIH Toolbox®*. Particularly, the cognition battery portion of the *NIH Toolbox®* can be used to detect neurocognitive impairments in individuals with the traumatic brain injury (Nitsch et al., 2017; Holdnack et al., 2017). Furthermore, it can be noted that the *NIH Toolbox® Cognition Battery* measures similar cognitive functions as the *ImPACT* attention, memory, processing speed, and reaction time.

While there are similarities between the *ImPACT* and the *NIH Toolbox® Cognition Battery*, there is yet to be empirical data, at this time, comparing their results. With multiple assessment batteries available, choosing one to use may be a difficult choice for the concussion management team. Both assessment batteries may be given but if they yield similar results, however, it may not be an efficient use of the team's time. For this reason, it is beneficial to examine the similarities and or differences in results of these test batteries. One construct that both of these test batteries measure, is working memory.

.

Working Memory

Working memory (WM) is defined as a "declarative portion of memory" that actively stores and maintains "verbal and nonverbal information" during a short amount of time (Matthews, 2015; Wolk & Budson, 2010; Green et al., 2018). WM assists in completing goal-driven tasks and is an important component of executive functions as well as more complex cognitive processing (Baddeley, Kopelman, & Wilson, 2002; Tulsky et al., 2014). Additionally, WM is frequently impaired following a traumatic brain injury (Gosselin et al., 2012; Smith et al., 2015; Green et al., 2018; Sha-Basak et al., 2018; Arciniega et al., 2019).

Not only has WM been liked to linguistic deficits when a traumatic brain injury occurs but learning processes deficits as well (Ewing-Cobbs & Barnes, 2002; Tulsky et al., 2014). Given the immense amount of research indicating decreased performance in WM tasks following a brain injury and its effect on everyday living, it is important that this construct be used as a part of assessment in order to assist with determining and managing a concussion. Likewise, it is important to understand how WM is operationalized in different tasks and batteries and, as consequence, how results from different tasks/batteries compare. E.g., how WM is assessed in ImPACT and Cognitive Battery of NIH Toolbox and whether performance (i.e., results) in both of these assessment batteries are comparable.

PURPOSE OF THE STUDY

The purpose of this study is to investigate the stated above problem and answer the question: whether scores obtained in tasks evaluating WM from the *ImPACT* and the *NIH Toolbox® Cognition Battery* correlate. The *null hypothesis* is that there is no significant difference between the performance in WM evaluation tasks included in the *ImPACT* and WM task included in the *NIH Toolbox® Cognition Battery* (results correlate). The contrary hypothesis is that the performance in WM evaluation tasks included in two batteries differ significantly (results do not correlate).

Although there is not current evidence comparing WM in the *NIH Toolbox® Cognition Battery* and the *ImPACT*, there is some data on the validity of *ImPACT* scores when compared to other neurocognitive assessments. Specifically, Schatz and Putz (2006), found that when comparing results from the *ImPACT WM* subtests to results on WM subtests of the *CogSport, of the Headminder, the Trail Making Test,* and the *Digit Symbol Subtest* of the *Wechsler Scale* there was no correlation found between. This has been consistently found in studies that have examined performance on WM tests in athletes (Iverson et al., 2005). For this reason, the researcher hypothesizes that the *ImPACT* and the *NIH Toolbox® Cognition Battery's* working memory scores do not correlate.

To test our hypothesis, we conducted a study at the University of Texas at El Paso's Concussion Management Clinical Research Laboratory. We tested a group of athletes from the local hockey team before their season began and compared their performance on WM measures included in the ImPACT and the *NIH Toolbox® Cognition Battery* by completing a Pearson Product Moment Correlation (PPMC).

By demonstrating whether performance on WM evaluation included in two different neurocognitive batteries correlates, we improve understanding on how these tests may be utilized in a concussion management assessment. Furthermore, depending on either the null hypothesis is confirmed or not, results from this study may influence a clinical decision making in regard to administering one test as compared to the other.

Chapter 2: Methods

Participants

Participants were 23 ice hockey players between 17-20 years old (M =18.8; SD = 0.9), all males. We recruited them from a local ice hockey team (El Paso Rhinos) during a baseline, pre-season, evaluation testing. All included in this study participants were native English speakers and English was their preferred language. It is important to note that some participants had a history of a previous concussion. Detailed demographics for individual participants are presented in Table 2.1.

Materials

Two neurocognitive assessment tools were implemented in this study to evaluate WM:

- The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)
- The NIH Toolbox® Cognition Battery

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

The *Immediate Post-Concussion Assessment and Cognitive Testing* (*ImPACT*) is a computerized assessment that was developed in order to assess and manage concussions, according to the administration and interpretation manual (ImPACT Applications, Inc., 2016). The ImPACT evaluates cognition across several domains including: sequencing, attention, word memory, visual memory, working memory, and reaction time and consists of six modules: Word memory, Design memory, X's and O's, Symbol Match, Color Match, and Three letters (ImPACT Applications, Inc., 2016). This test battery takes around 20 to 25 minutes to complete (ImPACT Applications, Inc., 2016).

Based on the performance in tasks included in these six modules several raw and composite scores are calculated indicating participants' efficiency (accuracy and timing) in particular tasks as well as different cognitive domains. Specifically, module scores are derived for Word memory, Design memory, X's and O's, Symbol Match, Color Match, and Three Letters. Composite Indices are used to exhibit scores for each specific cognitive domain measured. These scores are compared to the normative data and are expressed as percentile scores. The composite scores are Visual Memory Composite Score, Verbal Memory Composite Score, Visual-Motor Speed Composite Score, Reaction Time Composite Score, and Impulse Control Composite Score.

In this study, we evaluated a performance of participants in the modules included in the calculation of two composite scores which are considered as indicators of the WM, i.e., the Verbal Memory Composite Score (an indicator of the WM in a verbal domain) and the Visual Memory Composite Score (an indicator of the WM in a non-verbal domain; ImPACT Applications, Inc., 2016). These scores also indicate a level of attentional and learning processes in verbal and non-verbal domains respectively. The total percent of correct responses from the Design Memory module and the total number of correct responses in the X's and O's module are included in calculation of the Visual Memory Score. In the Design Memory module, the participant has to recall 12 designs which are randomly displayed on the screen after performing a distractor task (20 minutes' worth of other test modules). In the X's and O's module the participant has to memorize the location of objects X and O which are randomly displayed on the screen and recall the memorized location of a target after performing a distracter task (a choice reaction task, responding with a hand which is congruent with a specific object presented on a screen).

The total percent of correct responses from the Word Memory module, the total number of correct responses from the Symbol Match module, and percent of total correct responses from the Three Letters module are included in the calculation of the Verbal Memory Composite Score. In the Word Memory module, the participant has to recall 12 words which are randomly displayed on the screen after performing a distractor task (20 minutes' worth of other test modules). In the Symbol Match module, participant has to memorize symbols with corresponding numbers and then match a particular symbol with a number. In the Three Letters module, the participant has to memorize three consonants and their position. The participant is given a distracter task where they must click numbers on a grid backwards from 25. After this task, the participant is asked to recall the three letters. The sum of the Visual Memory Composite Score and the Verbal Memory Composite Score calculated for each participant separately is the total Memory Composite Score (ImPACT Applications, Inc., 2016).

The NIH Toolbox® Cognition Battery

The *NIH Toolbox® Cognition Battery* is a computerized neurobehavioral assessment that was developed to assess cognition in various populations including clinical (Slotkin, et al., 2012). More recently, this test battery has been proved as valid to detect neurocognitive impairments in individuals with a traumatic brain injury (Nitsch et al., 2017; Holdnack et al., 2017). The NIH Toolbox® Cognition Battery is administered through an iPad app. It includes several tests: The Flanker Inhibitory Control and Attention Test Age 12+< Picture Sequence Memory Test Age 8+, List Sorting Working Memory Test Age 7+, Picture Vocabulary Test Age 3+, Oral Reading Recognition Test Age 3+, Dimensional Change Card Sort Test Age 12+, Pattern Comparison Processing Speed Test Age 7+, Auditory Verbal Learning Test 8 +, and the Oral Symbol Digit Test which allow evaluating of attention, executive functioning, episodic memory, working memory, language, processing speed, and learning (Slotkin, et al., 2012).

The level of functioning in cognitive domains is reflected as raw scores, as well as standard scores in the tests mentioned above. Specifically, this test battery provides age-adjusted scale scores, age-adjusted national percentiles, fully adjusted scaled scores, and unadjusted scale scores. Moreover, a Fluid Cognitive Composite score is derived from the average of the Flanker, Dimensional Change Card Sort, Picture Sequence Memory, List Sorting and Pattern Comparison (Slotkin, et al., 2012). A Crystalized Cognition Composite Score is derived from the Picture Vocabulary and Reading Tests (Slotkin, et al., 2012). A general Cognitive Function Composite Score is obtained from all the previously mentioned composites. Once the participant has finished the battery, the program scores the responses.

This test battery takes around 40 to 45 min to complete (Slotkin, et al., 2012).

In the current study, scores obtained in the List Sorting Working Memory Test Age 7+ were evaluated as indicators of WM. In this test, a participant is presented with a series of different pictures simultaneously with sounds representing their names (i.e., a banana, strawberry, and watermelon) and, once a blank screen is displayed, a participant is asked to recall the pictures in a particular order (from smallest to biggest, i.e., strawberry, banana, and watermelon). Furthermore, a difficulty of task increases over time with longer picture lists and mixing of the pictures' categories, so that a participant must list one category first and then the other in size order (i.e., food first and then animals).

RESEARCH DESIGN

This study utilized a correlation analysis design (Hedge & Salvatore, 2021). According to Hedge and Salvatore (2021), a correlation analysis is used when researchers look to explore the relationship between variables. Moreover, it is important to note that because the WM scores on the *ImPACT* and the *NIH Toolbox® Cognition Battery* are not being manipulated there is not a control group.

In this study, two explored variables were: the WM indicators from the *ImPACT* and the WM indicators from the *NIH Toolbox® Cognition Battery*. First, a sum of the Visual and Verbal Memory Composite Scores (obtained based on a performance in the *ImPACT)* was calculated separately for each participant to obtain the Total Memory Composite Score as the WM indicator of ImPACT. Then, the Visual Memory Composite Scores, the Verbal Memory Composite Scores, the Total Memory Composite Scores from the *ImPACT* and the raw scores obtained in the *List Sorting Working Memory Test Age 7+* from the *NIH Toolbox® Cognition* Battery (the WM indicators of the *NIH Toolbox® Cognition Battery)* were entered to a series of correlation analysis.

PROCEDURES

First, each participant was given a demographics form to complete. This form included the following demographic information:

1. Name
2. Date of Birth
3. Email
4. Address
5. Age
6. Ethnicity
7. Organization
8. Position Played
9. Number of Years with the Organization
10. Number of Previous Concussions
11. Number of Languages Spoken
12. Preferred Language

The participants who met the inclusion criteria were given the *ImPACT* and the *NIH Toolbox® Cognition Battery*. The *ImPACT* was administered for a group of participants simultaneously in a computer laboratory room by a research assistant who provided instructions to the participants and then monitored the participants as the test was being completed. The *NIH Toolbox® Cognition Battery* was administered individually to each participant in the separate research laboratory room by the research assistant who provided instructions and collected responses. The order of administration of the *NIH Toolbox® Cognition Battery* and the *ImPACT* was counterbalanced between the participants.

The study protocol was approved by the Institutional Review Board at the University of Texas at El Paso. Prior to participation each athlete signed an informed consent form after obtaining information about the study, reading the consent form, having opportunity to ask questions, and getting answers.

ADMINISTRATION FIDELITY

Two graduate level research assistants were trained by a licensed Speech Language Pathologist and Neuropsychologist in the administration of both the *ImPACT* and the *NIH Toolbox® Cognition Battery*. For the training of the *ImPACT* administration, the Speech Language Pathologist had the research assistants learn about the different modules. Then, the research assistants practiced and watched administrations of the test with the guidance from the Speech Language Pathologist.

For the training of the *NIH Toolbox® Cognition Battery*, the research assistants watched training videos provided on the test battery website (Northwestern University, 2021). After completing the online videos, the Neuropsychologist showed the research assistants how to administer the battery and had them practice on each other. The Speech Language Pathologist and Neuropsychologist were present during the test administrations in order to supervise the two research assistants. When administering both tools, protocols and scripts provided by the test batteries were followed to ensure consistent administration.

STATISTICAL ANALYSIS

The WM indicators from the ImPACT and the NIH Toolbox Cognitive Battery were statistically analyzed with the *Statistical Package for the Social Sciences (*SPSS) software using the Pearson Product Moment Correlation (PPMC). The correlational coefficient was utilized to test the linear relationship between the WM indicators from the *ImPACT* and the *NIH Toolbox® Cognition Battery* (Hedge & Salvatore, 2021). This analysis allowed to determine whether these two assessment measures of WM are highly correlated (1.00) or weakly correlated (0) (Hedge & Salvatore, 2021). For the current analyses, we used following indicators of WM: 1) NIH Toolbox®

Cognitive Battery - Raw Scores obtained in the List Sorting Working Memory Test, 2) ImPACT® - Verbal Memory Composite Score, Visual Memory Composite Score, and Total Memory Composite Score calculated as a sum of Verbal and Visual Memory Composite Scores for each participant separately. The WM indicators from NIH Toolbox® and ImPACT Test® were entered into Pearson's correlation included in the IBM® SPSS® 25. In addition, Raw Scores obtained in the tasks included in the ImPACT modules which are specifically linked to the WM functioning (memorizing location of a target object in the X's and O's module and counting backward numbers on randomly positioned in a matrix in the Three Letters module; ImPACT Applications, Inc., 2016) were entered into a series of correlation analysis with Raw Scores from List Sorting Working Memory Test). We used the parametric correlation coefficients, because the distributions of the all scores included in the correlation analyses did not differ significantly from the normal (Kolmogorov-Smirnov Test).

List of Tables Chapter 2

Table 2.1: Participant Demographics. Education level reflects a level of education completed (14 – 11th grade; 16 – High School Graduate; 17 - GED; 18 – some college credit but less than 1 year; M – male; N/A – no data).

Participant	Age	Education Level	Gender
1	18	16	M
2	18	16	M
3	18	18	M
4	18	14	M
5	19	16	M
6	18	16	M
7	19	16	M
8	19	16	M
9	18	16	M
10	19	16	M
11	18	16	M
12	17	14	M
13	19	16	M
14	20	16	M
15	19	16	M
16	N/A	N/A	M
17	18	16	M
18	20	16	M
19	20	16	M
20	20	16	M
21	20	17	M
22	19	16	M
23	20	16	M

Chapter 3: Results

The mean and standard deviation results calculated for each WM indicator (Raw Scores from List Sorting Working Memory Test from the NIH Toolbox Cognition Battery and Composite Scores from the ImPACT test) are presented in Table 3.1.

The average results obtained in the List Sorting Working Memory Test (NIH Toolbox) reflected as a standard uncorrected score (norms: M = 100, SD = 15; sample: M = 106.91, SD = 10.15) showed that our sample's results did not differ from the results of the nationally representative normative sample (National Institutes of Health & Northwestern University, 2016). The average results from the ImPACT® (Verbal, Visual, and Total Memory Composite Scores: M = 85.39, SD = 12.41; M = 79.26, SD = 13.24; M = 161.65, SD = 22.14, respectively) were also similar to previously published results, including a sample of young ice hockey players (Sasaki et al, 2014).

All Pearson's coefficients calculated between Raw Scores from the List Sorting Working Memory Test (NIH Toolbox®) and Verbal, Visual, and Total Memory Composite Scores from ImPACT® were non-significant ($r = -.178$, $p > .05$; $r = -.054$, $p > .05$; $r = -.132$, $p > .05$, respectively) (Table 3.2). The additionally calculated correlation coefficients between Raw Scores from the List Sorting Working Memory Test (NIH Toolbox) and Raw Scores from individual modules/tasks from ImPACT that are specifically link to WM functioning (listed above in the Statistical Analysis section) (ImPACT Applications, Inc., 2016), were also non-significant (Table 3.3).

List of Tables Chapter 3

Table 3.1: Mean and standard deviation values calculated for the WM indicators based on participants' results obtained in the ImPACT Test (Ver Mem Comp - Verbal Memory Composite Score, Vis Mem Comp - Visual Memory Composite Score, and Tot Mem Comp -Total Memory Composite Score) and in the List Sorting Working Memory Test included in the NIH Toolbox Cognitive Battery (NIH Raw – Raw Score, Uncorrected Stand – Uncorrected Standard Score).

Ver Mem Comp M=85.39 SD=12.41	Vis Mem Comp M= 79.26 SD=13.24	Tot Mem Comp M= 161.65 SD=22.14
NIH Raw M=18.48 SD=2.64	Uncorrected Stand M=106.91 Sd=10.15	

Table 3.2: Pearson's Coefficients between Raw Scores from the List Sorting Working Memory Test (NIH Toolbox®) and Verbal, Visual, and Total Memory Composite Scores from ImPACT®

		Verbal Memory Composite Score	Visual Memory Composite Score	Total Memory Composite Score	NIH WM Raw Score	NIH WM Uncorrected Standard Score
Verbal Memory Composite Score	Pearson Correlation	1	.491*	.854**	-.178	-.182
	Sig. (2-tailed)		.017	.000	.417	.405
	N	23	23	23	23	23
Visual Memory Composite Score	Pearson Correlation	.491*	1	.873**	-.054	-.053
	Sig. (2-tailed)	.017		.000	.805	.809
	N	23	23	23	23	23
Total Memory Composite Score	Pearson Correlation	.854**	.873**	1	-.132	-.134
	Sig. (2-tailed)	.000	.000		.548	.542
	N	23	23	23	23	23
NIH WM Raw Score	Pearson Correlation	-.178	-.054	-.132	1	1.000**
	Sig. (2-tailed)	.417	.805	.584		.000
	N	23	23	23	23	23
NIH WM Uncorrected Standard Score	Pearson Correlation	-.182	-.053	-.134	1.000**	1
	Sig. (2-tailed)	.405	.809	.542	.000	
	N	23	23	23	23	23

Table 3.3: Correlation coefficients between Raw Scores from the List Sorting Working Memory Test (NIH Toolbox) and Raw Scores from individual modules/tasks from the ImPACT that are linked specifically to the WM.

		NIH WM Raw Score	NIH WM Uncorr. SS	XO Mem Total Correct	XO Interference Total Correct	3 Letters Avg. Counted	3 Letters Avg. Counted Correctly
NIH WM Raw Score	Pearson Correlation	1	1.000**	-.415	-.164	.244	.243
	Sig. (2-tailed)		.000	.049	.453	.262	.264
	N	23	23	23	23	23	23
NIH WM Uncorrected Standard Score	Pearson Correlation	.1.000**	1	.-.414	-.166	.237	.236
	Sig. (2-tailed)	.000		.049	.448	.277	.279
	N	23	23	23	23	23	23
XO Mem Total Correct	Pearson Correlation	-.415*	-.414*	1	.231	.055	.068
	Sig. (2-tailed)	.049	.049		.288	.802	.757
	N	23	23	23	23	23	23
XO Interference Total Correct	Pearson Correlation	-.164	-.166	.231	1	.466*	.483*
	Sig. (2-tailed)	.453	.448	.288		.025	.020
	N	23	23	23	23	23	23
3 Letters Avg. Counted	Pearson Correlation	.244	.237	.055	.466*	1	.998**
	Sig. (2-tailed)	.262	.277	.802	.025		.000
	N	23	23	23	23	23	23
3 Letters Avg. Counted Correctly	Pearson Correlation	.243	.236	.068	.483*	.998**	1
	Sig. (2-tailed)	.264	.279	.757	.020	.000	
	N	23	23	23	23	23	23

Chapter 4: Discussion

Our findings demonstrated that WM evaluated in the NIH Toolbox® and ImPACT® appeared not to be linked. Moreover, the additionally calculated correlation coefficients between Raw Scores from the List Sorting Working Memory Test (NIH Toolbox) and Raw Scores from individual modules/tasks from ImPACT that specifically are linked to the WM, were also non-significant. Similar results have been found in previous studies comparing results obtained for various cognitive domains evaluated in the ImPACT Test to results obtained for the same cognitive domains using other computerized neurocognitive assessments and paper-pencil neuropsychological measures (Iverson et al., 2005; Schatz and Putz 2006; Maerlender et al., 2013). However, Allen & Gfeller (2011) conducted a study comparing the ImPACT Test to paper-pencil neuropsychological measures and found moderately significant relationships between the constructs of memory on the assessments measured.

The discrepancy in the correlation of memory measures found in the previous studies, as explained in Allen & Gfeller (2011), may be due to the demographics of the participants. In the present study and other studies, athletes who have played many seasons and may or may have not had previous concussion were utilized as participants. In Allen & Gfller (2011), "neurocognitively" intact participants were utilized. It is explained that individuals who have suffered concussions previously may have different cognitive processing then the norms leading to different outcomes in cognitive constructs (i.e., working memory). This may justify the non-correlation found in the present study, as semi-professional athletes who have had years of playing behind them were included.

Further, the present study has raised questions regarding the utilization of one specific tool when measuring certain constructs and informing return to play decisions. The results obtained in this study show that different neurocognitive measures derived scores that were not correlated. If we were to rely on one measure, as opposed to the other, we would not be using our best clinical judgment as we have only part of the picture of the athlete's cognitive performance. By utilizing multiple measures, a whole picture is developed and safer return to play decisions will be made. Moreover, this study is not the first to realize the importance of using multiple assessment to determine cognitive function.

Mayers & Reick (2012), explains the issue of the lack of a "gold standard" in concussion management. Specifically, they describe the lack of psychometric properties needed in computerized neurocognitive tests to single-handedly make decisions regarding return to play (Mayers and Reick, 2012 & Maerlender et al., 2013). While we do agree with the importance of neurocognitive testing to assess brain functioning, we also realize the danger in only utilizing one assessment measure for return to play decisions. This is apparent in the results of the current study.

LIMITATIONS

With our present study, as with many studies, limitations did arise during the course of our research. First, we acknowledge the reduced sample size utilized. Although we did assess around 50 hockey players, utilizing the *ImPACT*, this total was condensed due to the limited languages available for use in the iPad version of the *NIH Toolbox® Cognition* Battery. Further, as mentioned previously, our selection process was not as standardized as we would prefer due to time constraints and limited iPad availability. Lastly, we recognize the assessment of only one construct within both test batteries. The analysis of the correlation of all constructs, in both batteries, is essential as it will assist in decision making regarding overall use of both tests. An additional limitation may be the use of participants with a mixed history of previous concussions or no history of concussion at all.

CONCLUSIONS

When investigating the construct of working memory (WM) scores on the *ImPACT* and the *NIH Toolbox® Cognition Battery* and how they correlated, the obtained results showed that the constructs were not related as well as appeared to measure different cognitive functions. We theorize, with review of current literature, that this may be due to the difference in cognitive structure processing of concussed athletes, as the participants utilized varied in their history of previous concussions. Further, we acknowledge that there is not a current gold standard to concussion assessment and believe that, as shown in this study, different neurocognitive assessments make measure constructs differently and a return to play decision should not be made based on the use of one battery alone.

SLPs and the concussion management team are encouraged to utilize differential diagnosis when assessing this population. Further, as explained by the literature (Guskiewicz et al., 2004; McCrory et al., 2008; McCrory et al., 2012; Harmon et al., 2013; Broglio et al., 2014; Laker, 2015), other categories of assessment should be utilized in conjunction with neurocognitive assessments. Lastly, we are left with additional questions including the heterogeneity of WM abilities in concussed athlete and measuring WM in general. Additional research in this parameter is needed to provide the best return-to-play decisions by the SLP and the concussion management team.

References

Allen, B. J., & Gfeller, J. D. (2011). The immediate post-concussion assessment and cognitive testing battery and traditional neuropsychological measures: A construct and concurrent validity study. Brain Injury, 25(2), 179-191. doi:10.3109/02699052.2010.541897

American Speech-Language Hearing Association. (1970, January 01). Scope of Practice in Speech-Language Pathology. Retrieved from https://www.asha.org/policy/sp2016-00343/

Arciniega, H., Kilgore-Gomez, A., Harris, A., Peterson, D. J., McBride, J., Fox, E., & Berryhill, M. E. (2019). Visual working memory deficits in undergraduates with a history of mild traumatic brain injury. Attention, Perception & Psychophysics, doi:10.3758/s13414-019-01774-9 [doi]

Baddeley, A. D., Kopelman, M. D., & Wilson, B. A. (2002). *The handbook of memory disorders*. (Ed.). Chichester, SXW: John Wiley & Sons, Ltd.

Brain Injury Research Institute. (2019). *What is a Concussion?* Retrieved from http://www.protectthebrain.org/Brain-Injury-Research/What-is-a-Concussion-.aspx

Broglio, S. P., Cantu, R. C., Gioia, G. A., Guskiewicz, K. M., Kutcher, J., Palm, M., & McLeod, T. C. V. (2014). National athletic trainers' association position statement: Management of sport concussion. *Journal of Athletic Training, 49*(2), 245-265.

Broglio, S. P., Macciocchi, S. N., & Ferrara, M. S. (2007). Sensitivity of the concussion assessment battery. *Neurosurgery*, 60(6), 1050–1058. dos: 10.1227/01.neu.0000255479.90999.c0

Brown, J., & Knollman-Porter, K. (2020). Continuum of Care Following Sports-Related Concussion. *American Journal of Speech-Language Pathology*, 29(3), 1389-1403. doi:10.1044/2020_ajslp-19-00131

Centers for Disease Control. (2015, February 16). *FAQs about baseline testing*. Retrieved from https://www.cdc.gov/headsup/basics/baseline_testing.html

Centers for Disease Control and Prevention. (n.d.). What Is a Concussion? *Heads up CDC injury center*. Retrieved from https://www.cdc.gov/headsup/basics/concussion_whatis.html

Duff, M. C. (2009). Management of sports-related concussion in children and adolescents. *ASHA Leader, 14*(9), 10-13. doi:10.1044/leader.FTR1.14092009.10

Ewing-Cobbs, L., & Barnes, M. (2002). Linguistic outcomes following traumatic brain injury in children. *Seminars in Pediatric Neurology*, 9(3), 209–217. doi: 10.1053/spen.2002.35502

Gosselin, N., Bottari, C., Chen, J. K., Huntgeburth, S. C., De Beaumont, L., Petrides, M., . . . Ptito, A. (2012). Evaluating the cognitive consequences of mild traumatic brain injury and concussion by using electrophysiology. Neurosurgical Focus, 33(6), E7: -7. doi:10.3171/2012.10.FOCUS12253 [doi]

Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., . . . McLeod, T. C. V. (2004). National athletic trainers' association position statement: Management of sport-related concussion. *Journal of Athletic Training, 39*(3), 280.

Hardin, K. Y., & Kelly, J. P. (2019). The role of speech-language pathology in an interdisciplinary care model for persistent symptomatology of mild traumatic brain injury. *Seminars in Speech and Language, 40*(1), 65-78. doi:10.1055/s-0038-1676452 [doi]

Harmon, K. G., Drezner, J. A., Gammons, M., Guskiewicz, K. M., Halstead, M., Herring, S. A., . . . Roberts, W. O. (2013). American medical society for sports medicine position statement: Concussion in sport. *Br J Sports Med, 47*(1), 15-26.

Hegde, M. N., & Salvatore, A. P. (2021). *Clinical research in communication disorders: principles and strategies*. San Diego, CA: Plural Publishing, Inc.

Holdnack, J. A., Iverson, G. L., Silverberg, N. D., Tulsky, D. S., & Heinemann, A. W. (2017). NIH toolbox cognition tests following traumatic brain injury: Frequency of low scores. Rehabilitation Psychology, 62(4), 474-484. doi:10.1037/rep0000145

ImPACT Applications, Inc. (2016). *ImPACT administration and interpretation manual* . Pittsburg , PA: ImPACT Applications, Inc.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2005). Validity of ImPACT for measuring processing speed following sports-related concussion. *Journal of Clinical and Experimental Neuropsychology*, 27(6), 683–689. dos 10.1081/13803390490918435

Laker, S. R. (2015). Sports-related concussion. *Current Pain and Headache Reports, 19*(8), 3. doi:10.1007/s11916-015-0510-3 [doi]

Lester B. Mayers & Thomas S. Redick (2012) Clinical utility of ImPACT assessment for postconcussion return-to-play counseling: *Psychometric issues, Journal of Clinical and Experimental Neuropsychology*, 34:3, 235-242, DOI: 10.1080/13803395.2011.630655

Maerlender, A., Flashman, L., Kessler, A., Kumbhani, S., Greenwald, R., Tosteson, T., & Mcallister, T. (2010). Examination of the construct validity of Impact™ computerized test, traditional, and experimental neuropsychological measures. *The Clinical Neuropsychologist*, 24(8), 1309–1325. dos: 10.1080/13854046.2010.516072

Maerlender , L. Flashman , A. Kessler , S. Kumbhani , R. Greenwald , T. Tosteson & T. McAllister (2013) Discriminant Construct Validity of ImPACT™ : A Companion Study, *The Clinical Neuropsychologist*, 27:2, 290-299, DOI: 10.1080/13854046.2012.744098

McCrory, P., Meeuwisse, W. H., Aubry, M., Cantu, R. C., Dvorak, J., Echemendia, R. J., . . . Raftery, M. (2013). Consensus statement on concussion in sport—the 4th international conference on concussion in sport held in zurich, November 2012. *Pm&r, 5*(4), 255-279.

McCrory, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., & Cantu, R. (2009). Consensus statement on concussion in sport–the 3rd international conference on concussion in sport held in zurich, November 2008. *South African Journal of Sports Medicine, 21*(2)

Nitsch, K. P., Casaletto, K. B., Carlozzi, N. E., Tulsky, D. S., Heinemann, A. W., & Heaton, R. K. (2017). Uncorrected versus demographically-corrected scores on the NIH toolbox cognition battery in persons with traumatic brain injury and stroke. Rehabilitation Psychology, 62(4), 485-495. doi:10.1037/rep0000122

Northwestern University. (2021). *Demonstration Videos*. Retrieved from https://www.healthmeasures.net/explore-measurement-systems/nih-toolbox/obtain-and-administer-measures/demonstration-videos

Salvatore, A. P., & Fjordbak, B. S. (2011). Concussion management: The speech-language pathologist's role. *Journal of Medical Speech-Language Pathology, 19*(1), 1-13.

Sasaki, T., Pasternak, O., Mayinger, M., Muehlmann, M., Savadjiev, P., Bouix, S., Kubicki, M., Fredman, E., Dahlben, B., Helmer, K. G., Johnson, A. M., Holmes, J. D., Forwell, L. A., Skopelja, E. N., Shenton, M. E., Echlin, P. S., & Koerte, I. K. (2014). Hockey concussion Education Project, Part 3. White matter microstructure in ice hockey players with a history of concussion: a diffusion tensor imaging study. *Journal of neurosurgery*, *120*(4), 882–890. https://doi.org/10.3171/2013.12.JNS132092

Schatz, P. (2010). Long-term test-retest reliability of baseline cognitive assessments using ImPACT. *The American Journal of Sports Medicine*, 38(1), 47–53. dos 10.1177/0363546509343805

Schatz, P., & Ferris, C. S. (2013). One-month test-retest reliability of the ImPACT test battery. *Archives of Clinical Neuropsychology*, 28(5), 499–504. dos: 10.1093/arclin/act034

Schatz, P., Pardini, J., Lovell, M., Collins, M., & Podell, K. (2006). Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. *Archives of Clinical* Neuropsychology, 21(1), 91–99. dos: 10.1016/j.acn.2005.08.001

Schatz, P., & Putz, B. O. (2006). Cross-validation of measures used for computer-based assessment of concussion. *Applied Neuropsychology*, 13(3), 151–159. doi: 10.1207/s15324826an1303_2

Schatz, P., & Sandel, N. (2012). Sensitivity and specificity of the online version of ImPACT in high school and collegiate athletes. *The American Journal of Sports Medicine*, 41(2), 321–326. dos: 10.1177/0363546512466038

Slotkin, J., Nowinski, C., Hays, R., Beaumont, J., Griffith, J., Magasi, S., … Gershon, R. (2012). *NIH toolbox scoring and interpretation guide*. National Institutes of Health and Northwestern University.

Tulsky, D. S., Carlozzi, N., Chiaravalloti, N. D., Beaumont, J. L., Kisala, P. A., Mungas, D., … Gershon, R. (2014). NIH Toolbox Cognition Battery (NIHTB-CB): List sorting test to measure working memory. *Journal of the International Neuropsychological Society*, 20(6), 599–610. doi: 10.1017/s135561771400040x

Vita

Genevieve Hernandez is a 2nd year graduate student in the University of Texas at El Paso's Master's Speech Language Pathology Program. In May 2021, she will graduate with her Master's of Science in Speech Language Pathology. Genevieve has been apart of National Student Speech-Language Hearing Association- UTEP chapter for the last 5 years and is now the current president. She is passionate about serving individuals with traumatic brain injuries or neurodegenerative diseases and has received the UTEP Concussion Management Certificate. Upon graduation, Genevieve hopes to work with the geriatric population in the medical setting.

Contact Information: genevievehernan@hotmail.com