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Serial Neuropsychological Assessment Toward a Reliable Concussion Protocol

Daniel J. Soden

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by

Daniel J. Soden

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Daniel J. Soden

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Signature of Examining Committee

Glena Andrews, PhD, MSCP, ABPP, Dissertation Chair

Kathleen Gathercoal, Ph.D.

Freeman Chakara, PsyD, ABPP

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Daniel J. Soden

Graduate School of Clinical Psychology

George Fox University

Newberg, Oregon

Abstract

With more than 10,000 Sports Related Concussions (SRCs) per year at the collegiate level, interdisciplinary teams are often tasked with determining when an athlete may return to activity (Zuckerman et al., 2015). Due to neurochemical changes following an SRC, athletes are vulnerable to further injury if they suffer another head injury before given appropriate time to heal (Giza & Hovda, 2014). Cognitive testing is routinely utilized to detect the presence of cognitive dysfunction and aid in individualized treatment planning. Because athletes often demonstrate practice effects when retested, it is difficult to distinguish if the athlete is demonstrating cognitive dysfunction. Reliable Change Indices (RCIs) provide a systematic framework for interpreting the change in an individual’s scores over time. The present study sought to develop RCIs with a brief battery of pencil paper tests within the cognitive domains most impacted by SRC. Results indicated significant increases in test scores across various tests due to practice effect. Additionally, reliability coefficients varied significantly across tests, ranging from low to excellent. Reliable Change Indices were calculated and recorded below.

Findings indicate the utility of many of the tests administered and provide context to more accurately interpret follow-up testing scores.

Keywords: sports related concussion, serial assessment, reliable change index

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Chapter 1

Introduction

Sport-related concussions (SRCs) have garnered widespread public attention in recent years, due in part to the frequency of this injury as well as the perceived risk for short-term and long-term consequences. The incidence of SRCs has increased in recent years, as have the laws and policies regarding concussion; this trend suggests professionals are more skilled in the diagnosis and treatment of SRC (Guerriero, Proctor, Mannix, & Meehan, 2012; Taylor, 2012; Trojian, Violano, Hall, & Duncan, 2015; Zuckerman et al., 2015). Zuckerman and colleagues (2015) discovered within the National Collegiate Athletic Association (NCAA) that SRCs constitute 6.2% of all injuries and NCAA athletes incur an estimated 10,558 concussions annually. The public perception of concussion sequalae has shifted dramatically as media sources have popularized Chronic Traumatic Encephalopathy (Kuhn, Yengo-Kahn, Kerr, & Zuckerman, 2017; Rice et al., 2018). Chronic Traumatic Encephalopathy is a controversial condition purported to entail psychiatric symptoms (e.g., depression and anger outbursts), deficits in cognition (e.g., attention, memory, and executive functioning), and eventual dementia (Asken et al., 2016; Merz, Van Patten, & Lace, 2017; Solomon, 2018). Given the paucity of peer-reviewed research linking SRCs and CTE (Asken et al., 2016; Ban, Madden, Bailes, Hunt Batjer, & Lonser, 2016; Solomon, 2018), a causal relationship has yet to be established. That said, there exists a spate of research that suggests proper management of SRCs is crucial to avoid short and long-term cognitive sequelae from repeated brain injuries in the absence of an appropriate recovery period (King, Brughelli, Hume, & Gissane, 2014).

Justification for Return to Play Guidelines

Neurological insult secondary to traumatic brain injury (TBI) results in a complex interaction of neurochemical changes, temporarily leaving a patient vulnerable to further damage from a second TBI (Giza & Hovda, 2001, 2014; MacFarlane & Glenn, 2015). Several animal studies have demonstrated axonal sheering, β-amyloid deposition, and cognitive impairment due to repeated head injury within a 3 to 5 day interval (Grant et al., 2018; Longhi et al., 2005; Prins, Hales, Reger, Giza, & Hovda, 2011). Researchers observed more significant negative consequences when the repeated head trauma occurred closer together (e.g., more significant consequences at 24 hours than 72 hours). Furthermore, human studies with collegiate athletes demonstrated a significantly elevated risk of recurrent TBI within the first seven to 10 days of returning to play (Guskiewicz et al., 2003; McCrea et al., 2009). Potentially, the most severe consequences of repetitive mild TBI can result in Second Impact Syndrome (SIS), a debated disorder manifested by severe neurological compromise, coma, and even death (Cantu, 2016; MacFarlane & Glenn, 2015; McLendon, Kralik, Grayson, & Golomb, 2016). This condition purportedly occurs when a second TBI is sustained before the initial neurochemical changes have fully resolved (Cantu, 2016; McLendon et al., 2016). The host of potential short and long-term sequelae of repetitive head injury substantiates the need for continued use of evidence-based return to play (RTP) guidelines.

Research on the pathophysiology of TBI has provided insight for RTP guidelines after experiencing an SRC. RTP guidelines were initially introduced in the mid 1900s but were revisited to reflect an evidenced based approach in the late 1990s (Carson et al., 2014; King et al., 2014). Numerous organizations (e.g., the Concussion in Sport Group, the American Medical Society for Sports Medicine) have produced RTP guidelines emphasizing a stepwise return to physical activity that follows the absence of cognitive and physiological symptoms (Harmon et al., 2019; McCrory et al., 2017). Current research suggests the physiological and cognitive sequelae of an SRC often dissipate in 7 to 14 days after the initial injury (Iverson et al., 2017; Ott, Bailey, & Broshek, 2018). However, athletes often experience significant variability in the resolution of concussion related symptoms due to variables such as history of SRC, concussion severity, age, sex, and level of sport performance to name a few (D'Lauro et al., 2018; McCrory et al., 2017). Thus, RTP guidelines are designed to be individually tailored while conforming to an objective standard (Harmon et al., 2019; King et al., 2014; McCrory et al., 2017).

Neuropsychological Assessment of Sports Related Concussion

Neuropsychological evaluations have been widely employed to assist in proper classification and treatment of sports-related concussions (King et al., 2014; McCrory et al., 2017). As part of an interdisciplinary team, neuropsychologists are uniquely trained to evaluate and interpret objective cognitive data in order to identify subtle neurobehavioral declines not readily evident in clinical examination alone (Harmon et al., 2019; Ott et al., 2018). In addition to investigation of acquired cognitive deficits, neuropsychological assessment provides insight into the interaction between psychological factors and recovery from SRC (Broshek, De Marco, & Freeman, 2015; Echemendia et al., 2012). Given these advantages, position statements across medical and psychological organizations (e.g. The American Medical Society for Sports Medicine, The National Academy of Neuropsychology, The American Psychological

Association) emphasize the importance of obtaining neurocognitive evaluations to aid in the treatment of SRC (Echemendia et al., 2012; Harmon et al., 2019; McCrory et al., 2017). The influence of these statements is most readily evident in national sport entities (e.g., National Hockey League, Major League Soccer, National Football League, etc.) who mandate players to obtain baseline, and in some instances serial, neuropsychological assessments due to their sensitivity and ability to monitor concussion symptoms (Ott et al., 2018).

Given this established role in the management of SRC, neuropsychologists are tasked with determining if short-term cognitive changes are present. The neurocognitive manifestation of SRC initially presents in cognitive domains of processing speed, working memory, verbal learning, verbal memory, and aspects of attention (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; King et al., 2014). These cognitive symptoms are often short-lived (i.e., 7 to 14 days), but may persist for some as a result of several interactive variables (e.g., age and gender). Neuropsychologists often conduct baseline evaluations, if possible, to establish premorbid functioning (Echemendia et al., 2013). In theory, this model improves diagnostic accuracy and limits misclassification due to premorbid weaknesses; however, careful consideration must be given to the psychometric properties of neuropsychological measures as well as sources of error for accurate interpretation.

As technology has advanced, neuropsychological testing has become available in computerized formats for the evaluation of SRC. Computerized administration is widely employed to evaluate cognitive abilities as 90-93% of collegiate athletic programs report using this method (Alsalaheen, Stockdale, Pechumer, & Broglio, 2016; Dessy et al., 2017). Within universities employing computerized assessment, 89% of athletic trainers report using the

Immediate Post Concussion Assessment and Cognitive Testing (ImPACT; Alsalaheen et al., 2016). Administration of neurocognitive tests to athletes in a computerized format (compared to pencil-paper testing) allows for rapid and standardized administration and reduces the economic burden of neuropsychological assessment (Alsalaheen et al., 2016; Resch, Driscoll, et al., 2013). However, ImPACT testing (a) is less comprehensive in the assessment of cognitive domains (Echemendia et al., 2013; King et al., 2014), (b) raises concern due to test-retest reliability and validity (Alsalaheen et al., 2016; Tsushima, Siu, Pearce, Zhang, & Oshiro, 2016), and (c) does not have equivalent alternate testing forms (Alsalaheen et al., 2016; Resch, Macciocchi, & Ferrara, 2013). Furthermore, this computerized assessment lacks a robust method of detecting individuals who intentionally score poorly during baseline evaluations (Manderino & Gunstad, 2018; Raab, Peak, & Knoderer, 2019). Raab and colleagues (2019) discovered the assessment validity indicators identified only 50% of students who intentionally underperformed. This finding was even more startling given the majority of intentionally underperforming students scored equal or less than the first percentile on a composite score. Given these concerns, traditional paper-pencil testing, albeit more economically demanding, provides more consistent reliability and clinical utility in determining cognitive deficits due to SRC.

Factors Impacting Repeated Neuropsychological Assessment

Repeated neuropsychological assessment provides invaluable information on the progression of a condition (e.g., Alzheimer’s Dementia, Multiple Sclerosis, and Brain tumor), the recovery from neurological insult (e.g., TBI, stroke, or chemotherapy), or evaluation of the efficacy of an intervention (e.g., use of medication or therapy). Although serial assessment provides numerous benefits, accurate interpretation of data is complex and requires thorough understanding of variables related to the test, individual, and the testing situation (Heilbronner et al., 2010). The consideration of these variables is necessary as the observed test score is considered to include the true ability of the patient and error (Duff, 2012; Strauss, Sherman, & Spreen, 2006). Thus, in repeated neuropsychological assessments, the variance in test scores represents the true change in ability and error (Duff, 2012; Strauss et al., 2006). Error in testing may be attributable to systematic bias or random variation (e.g., erroneous administration, poor effort, or a distracting environment). Given the potential for compounding effects of error, neuropsychologists must account for error in the tests used, the individual, and the testing situation.

Test variables. Reliability refers to the extent that test scores are systematic and devoid of error (Duff, 2012). Various types of reliability exist (e.g., test-retest, inter-rater, internal consistency, and parallel form); however, when conducting serial neuropsychological evaluations aimed toward assessing change, test-retest reliability is the most pertinent (Calamia, Markon, & Tranel, 2013). Test-retest reliability coefficients are impacted by the time between assessment administration (with longer intervals yielding smaller coefficients) and the number of individuals included in the sample (Calamia et al., 2013; Duff, 2012). Additionally, population characteristics (e.g., age) have been shown to influence reliability coefficients (Heilbronner et al., 2010; Salthouse, 2013). As assessments demonstrate higher reliability coefficients, less error contributes to the obtained scores, adding to their value in serial assessments.

Floor and ceiling effects refer to truncated distributions limiting the ability to demonstrate significant declines or improvements, respectively. When interpreting serial neuropsychological assessments, tests with skewed distributions should be considered carefully within the context of the patient's strengths and weaknesses. For example, if an individual demonstrates a free recall score of zero items on a memory assessment, it will not be possible to demonstrate further decline in memory ability (even if they suffer neurological insult). Thus, test variables significantly influence the evaluator's ability to distinguish individual change over time.

Individual variables. In conjunction with test characteristics, individual variables can drastically influence interpretation of serial neuropsychological assessment. Perhaps the most important factor when interpreting scores is the validity of data. Regarding SRC baseline evaluations, intentionally underperforming on assessments can lead to premature return to play and could lead to negative outcomes (Alsalaheen et al., 2016; Manderino & Gunstad, 2018). Previous research suggests purposeful underperformance is a particular concern in baseline evaluations for college athletes (Raab et al., 2019; Szabo, Alosco, Fedor, & Gunstad, 2013). Thus, it is imperative to evaluate performance validity in order to avoid misclassification and poor outcomes for athletes with SRC.

Prior exposure to testing materials (often referred to as practice effects) may artificially inflate scores leading to inaccurate clinical interpretations (Calamia, Markon, & Tranel, 2012). For example, Chelune, Naugle, Lüders, Sedlak, and Awad (1993) performed serial neuropsychological assessment on temporal lobectomy candidates; the authors cited practice effects as a variable with potential to obscure meaningful changes upon reevaluation. Thus, practice effects are widely studied in order to quantify the amount of change expected in repeated testing (Calamia et al., 2012; Estevis, Basso, & Combs, 2012). Despite their established presence, the exact impact of practice effect on test scores is not uniform; other individual variables (e.g., age or baseline ability) mediate the degree to which practice effects impact repeated evaluations (Calamia et al., 2012; Salthouse, 2013). In an attempt to eliminate practice effects, practitioners have suggested the use of alternate test forms (Beglinger et al., 2005). Ideally, an alternative test form would demonstrate identical psychometric properties as the original; however, many alternative forms do not demonstrate as robust test-retest reliability, limiting their utility (Beglinger et al., 2005; Calamia et al., 2013; Lezak, Howieson, Bigler, & Tranel, 2012). Practice effects are complex and vary in magnitude when interacting with additional individual variables.

In addition to prior exposure to testing materials, there are other individual factors influencing initial and repeated neuropsychological assessment. Neuropsychological literature has long recognized the importance of demographic variables (e.g., age, education, and gender) on test performance (Duff, 2012; Schoenberg & Scott, 2011). In addition to demographic variables, other individual characteristics (i.e., fatigue, diagnosis, intraindividual cognitive variability, and baseline performance) also impact the observed scores (Calamia et al., 2012; Duff et al., 2010; Rabinowitz & Arnett, 2013). Intelligibly, these factors not only impact initial scores, but influence subsequent changes in scores over time (Duff, 2012; Salthouse, 2013). A meta-analysis conducted by Calamia et al. (2012) examined the impact of numerous variables on practice effect. Results suggested as age increases, the magnitude of benefit due to practice effects dissipates (Calamia et al., 2012). The patient’s level of education has also demonstrated utility in predicting follow up scores in regression-based evaluation methods (Calamia et al., 2012; Duff et al., 2010). In addition to demographic variables, clinical diagnosis (e.g., Alzheimer’s Dementia, depression, HIV) also resulted in attenuated practice effects compared to healthy controls. While demographic and individual characteristics mediate practice effects, baseline performance is one of the individual variables most predictive of follow up scores (Duff et al., 2010; Rapport, Brines, Theisen, & Axelrod, 1997). The interaction of these individual variables presents complexity when attempting to interpret individual change over time.

Situational variables. The interval between the administrations of assessments in serial neuropsychological testing influences the reliability of the measure used and the amount of practice effects expected (Calamia et al., 2013; Duff, 2012). As mentioned above, the length of time between assessments impacts the test-retest reliability in a temporal gradient, with shorter periods yielding higher reliability coefficients. While testing manuals generally include test-retest coefficients, the interval between assessments is often too short (days to weeks) to be clinically useful (Estevis et al., 2012). Additionally, with shorter intervals between assessment, practice effects will be much more pronounced; conversely, longer intervals are associated with less variance attributable to practice effects (Calamia et al., 2012; Estevis et al., 2012). Thus, clinicians need to obtain appropriate test-retest data in order to accurately gauge the reliability for the tests and population in question as well as data for variance due to practice effects.

On repeated neurocognitive testing, scores have a tendency to move closer to the mean of the normative population, a phenomenon known as regression to the mean (RTTM; Duff, 2012; Hinton-Bayre, 2010). RTTM becomes more evident when an initial score is located at either extreme in a normal distribution. Patton and colleagues (2005) conducted repeat assessments at a one-year interval and a two-year interval. Results demonstrated that individuals initially scoring in the high average or low average range demonstrated a tendency to score closer to the mean on subsequent evaluations. These trends are vital to consider when conducting serial neuropsychological assessment in order to avoid misdiagnosis.

Statistical Models for Determining Individual Change

In attempting to ascertain changes in cognitive skills, statistical models have been developed in order to control for practice effects, test reliability, and numerous other variables known to impact the observed score (Hinton-Bayre, 2010; Schoenberg & Scott, 2011). While more simplistic models have been utilized in the past (e.g., simple discrepancy score and standard deviation index), these models are outdated as they do not control for important variables such as practice effects (Duff, 2012; Hinton-Bayre, 2010). As such, two models of change (i.e., reliable change index accounting for practice effects and standardized regression-based change scores) are primarily utilized in order to determine statistically significant change in an individual's neurocognitive functioning over time (Hinton-Bayre, 2016; Schoenberg & Scott, 2011). Both models are designed to yield a z-score; this score is then compared to a normal distribution in order to determine the significance of the observed change (Duff, 2012; Hinton-Bayre, 2010). Neuropsychological literature largely utilizes a cut off z-score of ± 1.645 as this represents a 90% confidence interval for determining significant change (Brooks, Holdnack, & Iverson, 2016; Hinton-Bayre, 2010). Literature indicates neither model produces universally superior results when evaluating change over time (Hinton-Bayre, 2011, 2016); instead, the selection of a reliable change model may differ by clinical scenario (Hinton-Bayre, 2011, 2016).

Originally, reliable change indices (RCI) were derived in order to determine statistically significant changes associated with psychological interventions (Jacobson & Truax, 1991). While this model is beneficial in assessing psychological constructs (e.g., depression and anxiety), the presence of practice effects leads to inaccurate conclusions when applied to performance-based measures (Duff, 2012; Hinton-Bayre, 2010). As a result, Chelune and colleagues (1993) developed a reliable change index model to account for practice effects (RCI_{PE}). Since the original inception of the RCI_{PE} model, various researchers have proposed changes to the RCI model (Chelune, 2003; Iverson, 2001). Iverson (2001) noted current formulas failed to control for the variability in scores (i.e., standard error of the difference) in the normative population when retested; thus, he provided changes to the RCI_{PE} formula to account for standard error of the difference (SED) in both the initial scores and when retested (Duff, 2012; Iverson, 2001). Conversely, Chelune (2003) provided changes in the RCI formula in order to account for RTTM effects. While changes to the RCI_{PE} formula have resulted in more precise methods of evaluating change over time, these formulas apply uniform practice effects to the entire population and do not correct for individual characteristics (Hinton-Bayre, 2016; Schoenberg & Scott, 2011).

In order to control for individual characteristics not accounted for in the RCI_{PE} model, McSweeny, Naugle, Chelune, and Lüders (1993) proposed the use of standardized regression-based (SRB) change formulas. In this model, regression formulas are used to predict the amount of change expected based on numerous variables (baseline performance, retest interval, age, education, etc.). This predicted score is then compared to the observed score and subsequently to a normative population to determine if the observed change is statistically significant (Duff, 2012; Schoenberg & Scott, 2011). Despite the ability to control for numerous variables, various limitations prevent their widespread use. Most notably, SRB formulas are complex to create and the normative data needed to create these formulas are not widely available (Duff, 2012).

Furthermore, regression formulas based on small normative populations may result in error and consequently overlook clinically significant changes (Schoenberg & Scott, 2011).

The Current Study

The current study sought to examine the variance associated with serial neuropsychological assessment, at approximately a three-month interval, across multiple cognitive domains with collegiate athletes. The independent variable is the fixed time interval between testing sessions and the dependent variables are the testing scores obtained. Hypotheses for the current study are as follows:

H1: The magnitude of improvement in testing scores upon follow up will be most evident on the Symbol Digit Modalities Test, Stroop (Word and Color trials), Ruff 2 and 7 (Speed scores), and Trail Making Test.

H2: With use of alternate test forms, follow up scores will demonstrate little practice effect for the learning and recall for the Hopkins Verbal Learning Test – Revised; however, improvements will be evident with learning and recall performance on the Brief Visuospatial Memory Test-Revised.

Chapter 2

Methods

Participants

Collegiate athletes (*n* = 12) were recruited from a private university in the Pacific Northwest. Athletes participated in track and field (*n* = 4), softball (*n* = 2), soccer (*n* = 1), lacrosse (*n* = 1), swimming (*n* = 1), tennis (*n* = 1), cross country (*n* = 1), or cheerleading (*n* = 1). Participant ages ranged from 18 to 21. Additional demographic variables collected include gender, ethnicity, and current academic standing. All participants reported English as their native and primary language. The participants had no history of head injury, learning disorder, attention-deficit/hyperactivity disorder, or psychiatric disorder and demonstrated adequate investment in the assessment procedures as indicated by a standalone performance validity measure. Participants were recruited from general psychology courses and received class credit as compensation as part of the course structure. Written informed consent was obtained prior to participation in the study.

Materials

Neuropsychological tests used in this study were selected due to their wide use in concussion assessment and research (Barr, 2003; Merritt et al., 2017). In addition, the assessments evaluate the cognitive domains typically implicated in sports related concussions (Echemendia et al., 2001; King et al., 2014). A brief description of each assessment is provided as well as a review of the pertinent psychometric properties.

Table 1

Demographic Information

Item	Category	Baseline Sample	Completed	Did Not Complete
Ethnicity	European American	5	5	--
	Asian American	3	2	1
	Latino/Latina	2	1	1
	Multiple Ethnicities	1	1	--
	Native American	1	1	--
Gender	Male	3	2	1
	Female	9	8	1
Age		18.90 (1.35)	18.95 (1.48)	18.65 (0.37)
Academic Standing	Freshman	10	8	2
	Sophomore	1	1	--
	Senior	1	1	--

Demographic and History Questionnaire. A survey was developed to gather demographic data (i.e., age, gender, ethnicity, sport played, and academic standing), history of learning disorders, history of Attention Deficit Hyperactive Disorder, medical history, social history, and substance use. See Appendix A.

Follow-Up Questionnaire. A follow-up questionnaire was designed in order to assess the presence of new medical symptoms, medications, injuries as well as changes in mood. See Appendix B.

Brief Visuospatial Memory Test-Revised. The Brief Visuospatial Memory Test-Revised (BVMT-R) is a test that requires encoding, consolidation, and retrieval of visual stimuli in the presence of time delays (Benedict, 1997). Patients are provided a display containing six varied geometric shapes for 10 sec; they are then tasked with replicating those shapes in the same location as the stimuli. Three learning trials are followed by a 25 min delay in which patients reproduce as many figures as possible from memory. Test-retest reliability coefficients range from 0.70 (i.e., trial 1) to .95 (i.e., trial 3) for an average 55.6 day interval. Interrater reliability was excellent with reliability coefficients ranging from .969-.979. Additionally, the BVMT-R demonstrated good convergent validity with other visual memory tests.

Controlled Oral Word Association Test. The Controlled Oral Word Association Test (COWAT) is an assessment measuring lexical and semantic fluency (Benton, 1969). In order to quantify lexical fluency, participants name as many words beginning with a specific letter of the alphabet provided by the examiner. Patients are restricted from using variations of the same word (e.g., help, helping, helped) and proper names (e.g., Heather, Hong-Kong, Honda). In order to measure semantic fluency, patients name as many different animals as possible. Patients are given 1 min in all trials to rapidly produce answers that conform to the criteria above. Extensive research has established the reliability and validity of the COWAT (Lezak et al., 2012; Strauss et al., 2006). Test-retest reliability coefficients range from .74 to .77 depending on testing interval and patient age; whereas interrater reliability coefficients ranged from .98 to .99 (Strauss et al., 2006).

Hopkins Verbal Learning Test-Revised. The Hopkins Verbal Learning Test-Revised (HVLT-R) is an assessment of rote verbal learning and memory (Brandt & Benedict, 2001). Across three trials, the patient listened to a list of 12 words and reproduces as many words as possible, in any order. The patient was also asked to recall as many words as possible after a 20-25 minute delay. The HVLT-R demonstrated test-retest coefficients of .74 for total recall and .66 for delayed recall (Brandt & Benedict, 2001). Convergent validity was established utilizing tests of visual and verbal memory. Tests of verbal memory demonstrated higher correlations (i.e., .65 to .77) than visual memory (i.e., .54 to .69 Strauss et al., 2006).

Ruff 2 and 7 Selective Attention Test. The Ruff 2 and 7 Selective Attention Test (RUFF) is a test of selective and sustained attention (Ruff & Allen, 1996). In this test, patients are administered 20 trials of a cancellation task in consecutive 15 sec intervals. Patients are instructed to rapidly mark all of the twos and sevens without marking any other stimuli. This assessment demonstrated excellent test-retest reliability for speed components (i.e., .89 to .93; (Ruff & Allen, 1996). Further validity was established using convergent and divergent correlations. Speed indices were highly correlated with alphanumeric coding tasks and demonstrated weak correlations with tests of auditory attention (Ruff & Allen, 1996).

Stroop Color and Word Test. The Stroop Color and Word Test (SCWT) consists of three trials and measures cognitive processing speed and inhibition (Golden & Freshwater, 2002). In the first trial, the participant rapidly reads a list of words as fast as possible without error. The second trial requires the rapid identification of various colors. In the final trial, the participant is presented with words (e.g., green, red, blue) printed in other colors. They must identify the color of the ink used and inhibit their natural response of reading the word. The SCWT demonstrated test-retest reliability coefficients of .86 for the word reading trial, .82 for color reading, and .73 for the interference task (Strauss et al., 2006). Validity was established through the use of correlations within the test and with other assessments. The correlations within the test are high suggesting that they measure similar, yet not identical cognitive abilities (Strauss et al., 2006). Additionally, the SCWT demonstrated high correlations with processing speed measures (i.e., Digit Symbol, trails A, and FAS; (Strauss et al., 2006).

Symbol-Digit Modalities Test. The Symbol Digit Modalities Test (SDMT) is an assessment primarily measuring cognitive processing speed, with contributions from learning/memory and attention (Smith, 1991). This test is a timed alphanumeric coding task where the participant must rapidly write the associated number under the provided symbols. The SDMT demonstrated test-retest correlations of .80 for the written form and .76 for the oral form. Convergent validity was demonstrated with Symbol Search and Coding subtests. Correlations ranged from .62 to .91 between assessments suggesting they measure the same constructs (Strauss et al., 2006).

Test of Memory Malingering. The Test of Memory Malingering (TOMM) is a Performance Validity Test used to detect suboptimal effort or purposeful exaggeration of cognitive deficits (Tombaugh, 2003). The TOMM is a memory test in which participants are presented 50 pictures for 3 sec each and are tasked with correctly identifying each picture when tested. Research suggests performance on the TOMM is not significantly impacted by individual factors such as age, education, psychiatric diagnoses, or cognitive impairment in non-demented individuals (Lezak et al., 2012; Strauss et al., 2006). The cutoffs provided correctly classified 95% for nondemented patients (Tombaugh, 2003). Additionally, this assessment demonstrated 100% specificity and 82% sensitivity when distinguishing a control group from a group simulating cognitive deficits (Tombaugh, 2003).

Trail-Making Test. The Trail-Making Test (TMT) is comprised of two conditions measuring psychomotor speed, visual scanning, sequencing, and set shifting abilities. In the first condition, the patient must rapidly locate and connect numbers in ascending order. The second condition requires participants to connect numbers and letters in order while switching between a number and then a letter (e.g., 1, A, 2, B, 3, C, etc.). Test-retest coefficients vary considerably across patient populations (e.g., .41 to .79 for Trails A and .44 to .89 for Trails B) due to diagnoses and age (Strauss et al., 2006). Convergent validity studies revealed significant correlations with tests of speed (e.g., Symbol Digit Modality Test and the Paced Auditory Serial Addition Test) and test of executive function (i.e., the Wisconsin Card Sorting Test; Strauss et al., 2006).

Wechsler Adult Intelligence Scale – Fourth Edition, Digit Span. Digit Span is a subtest of the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV) measuring attention, working memory, and mental manipulation (Wechsler, 2008). This subtest is divided into three distinct conditions: Forward, Backward, and Sequencing. In the forward condition, participants are asked to repeat a sequence of numbers in the same order as the examiner. In the backward task, the participant repeats numbers in reverse order. The final condition requires the participant to repeat the numbers in ascending order. Reliability, determined by internal consistency and test-retest methods, was excellent (r = .93) and good (r = .83) respectively (Wechsler, 2008). Digit Span demonstrated good convergent and divergent validity when compared to other subtests (e.g. vocabulary) and assessments (Wechsler, 2008).

Procedure

Following IRB approval, the principal researcher provided an oral presentation to general psychology classes regarding the purpose of the study and offered opportunity to participate. Interested students provided contact information in order to schedule appointments and receive further information (e.g., location of testing). Prior to commencing assessment procedures, participants signed informed consent and examiners emphasized the importance of good effort (See Appendix C). Baseline evaluations were administered by doctoral students under the supervision of a licensed psychologist. Assessment procedures were conducted individually in a quiet, distraction free environment. Instructions for each assessment measure adhered to the standardized administration detailed in each respective manual. Following testing procedures, participants immediately completed a demographic questionnaire and engaged in a brief intake with the principal investigator in order to explore history of ADHD/Learning Disorders as well as social and medical history.

After approximately a three-month interval, participants were contacted in order to schedule a follow-up evaluation. Participants engaged in repeat evaluation using the same measures administered at baseline, with exception to the HVLT-R and the BVMT-R (alternate forms 4 and 2 were used respectively). Finally, participants completed a follow-up questionnaire examining changes in medical and psychiatric symptoms. Baseline and follow up evaluations took approximately one hour each including the completion of questionnaires. Upon completion of all procedures, participants were provided with an informational handout about the current study and contact information for further inquiries. Course credit was awarded by the respective university professor.

Chapter 3

Results

Baseline Testing

Initial scores for the full sample are presented in Table 2. No additional analyses were completed between gender groups due to the limited sample size.

Table 2

Neuropsychological Test Scores at Baseline

	Total Sample, mean (S.D.) n = 12	*Men, mean (S.D.) n = 3*	*Women, mean (S.D.) n = 9*
Digit Span			
Forward	9.42 (2.07)	9.00 (2.65)	9.56 (2.01)
Backward	8.58 (1.56)	8.33 (1.53)	8.67 (1.66)
Sequencing	8.50 (1.62)	9.00 (1.00)	8.33 (1.80)
Total	26.50 (4.72)	26.33 (5.13)	26.56 (4.90)
Ruff 2 and 7			
Automatic Speed	140.08 (20.38)	131.67 (34.03)	142.89 (15.68)
Automatic Accuracy	95.69 (4.40)	98.25 (0.12)	94.84 (4.83)
Controlled Speed	131.42 (18.24)	117.00 (10.44)	136.22 (18.06)
Controlled Accuracy	95.59 (2.78)	95.66 (1.84)	95.56 (3.13)
Stroop			
Word Speed	94.08 (11.27)	101.33 (4.62)	91.67 (11.97)
Color Speed	73.17 (6.51)	68.33 (6.35)	74.78 (6.04)

Table 2 continued

	Total Sample, mean (S.D.) n = 12	*Men, mean (S.D.) n = 3*	*Women, mean (S.D.) n = 9*
Color-Word	46.08 (9.75)	45.67 (15.53)	46.22 (8.38)
Symbol Digit Modality Test	55.75 (8.62)	52.33 (2.89)	56.89 (9.71)
Trail Making Test			
Trail A	24.42 (7.68)	20.67 (5.51)	25.67 (8.15)
Trail B	64.92 (29.85)	88.00 (55.43)	57.22 (13.81)
COWAT			
Total Words	38.42 (13.19)	37.33 (11.55)	38.78 (14.32)
HVLT-R			
Trial 1	7.33 (1.92)	6.33 (3.21)	7.67 (1.41)
Total Learning	27.50 (4.03)	27.67 (5.69)	27.44 (3.78)
Delayed Recall	10.25 (1.36)	10.00 (1.00)	10.33 (1.5)
Discrimination	11.41 (0.90)	11.33 (0.58)	11.44 (1.01)
BVMT-R			
Trial 1	6.83 (2.37)	7.33 (3.06)	6.67 (2.29)
Total Learning	28.33 (5.43)	28.33 (8.14)	28.33 (4.90)
Delayed Recall	10.92 (1.08)	10.66 (1.53)	11.00 (1.00)

Test-Retest Effects

Pairwise *t*-tests were employed to determine if the participants demonstrated significant differences in testing performance following approximately a three-month delay. Neuropsychological data, represented in means and standard deviations, for Time 1 (T_1) and

Time 2 (T_2) are provided in Table 3. Results indicated significant mean differences for Stroop Word Speed, $t_{RM}(9) = 4.175$, $p = .002$; Stroop Color Speed $t_{RM}(9) = 3.611$, $p = .005$; Stroop Color-Word, $t_{RM}(9) = 2.779$, $p = .021$; SDMT $t_{RM}(9) = 6.511$, $p = <.001$; and BVMT-R Trial 1, $t_{RM}(9) = 2.623$, $p = .028$. Conversely, no significant differences were found across other tests. See Appendix D for statistical sentences.

Across different tests, the same net change in one's raw score could have vastly different implications on the magnitude of practice effect. Thus, the magnitude of a practice effect was calculated through comparing the mean difference ($T_2 – T_1$) to baseline performance, yielding a Standard Score (z-score). Across the tests administered, the greatest practice effects were evident in the Stroop Color Speed (z = 1.10), Stroop Word Speed (z = 0.82), Symbol Digit Modality Test (z = 0.69), Ruff 2 and 7 Automatic Speed (z = 0.69), and Digit Span Sequencing (z = 0.67).

Table 3

Test-Retest Characteristics

	T1, Mean (SD)	*T2, Mean (SD)*	*T2-T1, Mean (SD)*	r	*T1, T2*			
					$S.E.M_1$	$S.E.M_2$	S_{diff}	p
Digit Span								
Forward	9.50 (2.07)	10.00 (2.05)	+0.50 (1.78)	.627	1.26	1.25	1.78	.397
Backward	8.60 (1.58)	8.30 (1.64)	-0.30 (1.06)	.783	0.73	0.76	1.06	.394
Sequencing	8.50 (1.78)	9.70 (1.77)	+1.20 (1.93)	.406	1.37	1.36	1.93	.081
Total	26.6 (4.86)	28.00 (4.71)	+1.4 (2.84)	.825	2.03	1.97	2.83	.153
Ruff 2 and 7								
Automatic Speed	142.50 (18.73)	155.4 (26.87)	+12.90 (24.21)	.483	13.46	19.31	23.54	.126
Automatic Errors	7.40 (8.77)	3.20 (2.40)	-4.20 (7.93)	.465	6.42	1.82	6.67	.128

Table 3 continued

	T1, Mean (SD)	*T2, Mean (SD)*	*T2-T1, Mean (SD)*	*T1, T2* r	S.E.M$_1$	S.E.M$_2$	S$_{diff}$	p
Automatic Accuracy	95.40 (4.78)	98.11 (1.15)	+2.72 (4.65)	.232	4.19	1.01	4.31	.098
Controlled Speed	131.20 (15.43)	136.40 (14.47)	+5.20 (12.80)	.635	9.32	8.74	12.78	.231
Controlled Errors	6.40 (5.15)	9.10 (11.32)	+2.70 (7.66)	.824	2.16	4.76	5.23	.294
Controlled Accuracy	95.52 (3.06)	94.24 (6.21)	-1.28 (4.69)	.683	1.72	3.50	3.90	.411
Stroop								
Word Speed	91.90 (10.28)	100.30 (7.26)	+8.40 (6.36)	.790	4.71	3.33	5.77	.002
Color Speed	73.80 (5.57)	79.90 (7.45)	+6.10 (5.34)	.698	3.06	4.09	5.11	.006
Color-Word	47.10 (9.75)	51.30 (9.62)	+4.20 (4.78)	.878	3.40	3.36	4.78	.021
SDMT	55.70 (8.94)	61.90 (7.22)	+6.20 (3.01)	.953	1.94	1.57	2.50	<.001
Trail Making Test								
Trail A	23.40 (7.90)	18.7 (2.79)	-4.70 (8.10)	.107	7.47	2.64	7.92	.100
Trail B	57.60 (12.86)	50.50 (10.76)	-7.10 (12.27)	.472	9.34	7.82	12.18	.101
COWAT								
Total Words	40.1 (13.63)	44.9 (13.74)	+4.80 (7.24)	.860	5.10	5.14	7.24	.065
HVLT-R								
Trial 1	7.60 (1.78)	6.6 (1.58)	-1.00 (2.21)	.135	1.65	1.47	2.21	.186
Total Learning	27.5 (4.40)	26.5 (5.68)	-1.00 (5.12)	.509	3.09	3.98	5.04	.552
Delayed Recall	10.20 (1.48)	9.50 (1.51)	-0.70 (1.49)	.499	1.04	1.07	1.49	.173
Discrimination	11.40 (.967)	11.10 (1.29)	-0.30 (0.82)	.769	0.46	0.62	0.77	.279
BVMT-R								
Trial 1	6.90 (2.33)	8.20 (2.20)	+1.3 (1.57)	.762	1.14	1.07	1.56	.028
Total Learning	29.00 (5.01)	29.60 (3.84)	+0.60 (3.89)	.642	3.00	2.30	3.78	.638
Delayed Recall	11.10 (0.99)	10.80 (1.135)	-0.30 (1.57)	-.079	1.03	1.18	1.57	.560

Reliable Change Indices

The methodology posited by Chelune and colleagues (1993) and further refined by Iverson (2001) was utilized to calculate reliable change. All formulas used in this study are provided in Appendix E. When completed, the reliable change index formula below yields a change score. The change score is then compared to z-scores in a normal distribution to determine if it falls outside of the chosen confidence interval (e.g., ±1.64). While the most stringent confidence interval commonly used in clinical practice is 90% (±1.64), some have argued 80% (±1.30) and 70% (±1.05) confidence intervals may be more appropriate for concussion evaluations in order to avoid detrimental effects of misclassification (Barr & McCrea, 2001).

Table 4 provides raw score corrections for clinicians to use during serial evaluations.

Table 4

Reliable Change Index Values

	90% CI	80% CI	70% CI
Digit Span			
Forward	-2, +3 (0)	-2, +3 (0)	-1, +2 (10)
Backward	-2, +1 (0)	-2, +1 (0)	-1, +1 (10)
Sequencing	-2, +4 (0)	-1, +4 (10)	-1, +3 (10)
Total	-3, +6 (10)	-2, +5 (10)	-2, +4 (10)
Ruff 2 and 7			
Automatic Speed	-26, +52 (0)	-18, +44 (10)	-12, +37 (10)
Automatic Errors	-15, +7 (10)	-13, +4 (10)	-11, +3 (10)
Automatic Accuracy	-4, +10 (0)	-3, +8 (0)	-2, +7 (10)
Controlled Speed	-16, +26 (10)	-12, +21 (10)	-8, +19 (10)
Controlled Errors	-6, +11 (10)	-4, +9 (10)	-3, +8 (10)
Controlled Accuracy	-8, +5 (10)	-6, +4 (10)	-5, +3 (20)
Stroop			
Word Speed	-1, +18 (10)	+1, +16 (10)	+2, +14 (10)
Color Speed	-2, +14 (0)	-1, +13 (10)	+1, +11 (10)
Color-Word	-4, +12 (10)	-2, +10 (10)	-1, +9 (10)
Symbol Digit Modality Test	+2, +10 (0)	+3, +10 (20)	+4, +9 (20)
Trail Making Test			
Trail A (Seconds)	-18, +8 (10)	-15, +6 (10)	-13, +4 (10)
Trail B (Seconds)	-27, +13 (10)	-23, +9 (10)	-20, +6 (10)
COWAT			
Total Words	-7, +16 (0)	-5, +14 (0)	-3, +12 (10)
HVLT-R			
Trial 1	-5, +3 (0)	-4, +2 (0)	-3, +1 (10)

Table 4 continued

	90% CI	80% CI	70% CI
Total Learning	-9, +7 (10)	-8, +6 (10)	-6, +4 (10)
Delayed Recall	-3, +2 (0)	-3, +1 (0)	-2, +1 (10)
Discrimination	-2, +1 (0)	-1, +1 (0)	-1, +1 (0)
BVMT-R			
Trial 1	-1, +4 (0)	-1, +3 (0)	0, +3 (10)
Total Learning	-6, +7 (0)	-4, +6 (0)	-3, +5 (10)
Delayed Recall	-3, +2 (10)	-2, +2 (10)	-2, +1 (10)

Chapter 4

Discussion

To date, no study has provided Reliable Change Indices for an entire battery of assessments for use with collegiate athletes. This study discovered several reliable assessments across cognitive domains useful for the evaluation of collegiate athletes and documented the magnitude of practice effects in order to increase the sensitivity of follow up evaluations. The assessments selected examined aspects of attention (e.g., basic and selective/sustained), working memory, learning and memory (visual and verbal), processing speed, and executive functioning. Despite certain assessments demonstrating excellent reliability, the analysis of test-retest reliability in this sample revealed variability across measures, with some assessments demonstrating very poor test-retest reliability. Additionally, in regard to practice effects, tests demonstrating the greatest increase in scores included Stroop Color Speed, Stroop Word Speed, Symbol Digit Modality Test, Ruff 2 and 7 Automatic, and Digit Span Sequencing. RCI's were provided to enhance interpretation of follow-up testing scores in collegiate athletes who sustained a sports related concussion.

The first hypothesis for this study was partially supported, as the Stroop Color Speed, Stroop Word Speed, Symbol Digit Modality Test, Ruff 2 and 7 Automatic, and Digit Span Sequencing demonstrated the most improvement upon re-test. Practice effect is the most likely explanation for the changes in scores over time, as the participants were healthy adults with no history of psychiatric distress or learning disorder. Consistent with prior literature, tests vulnerable to practice effects feature time constraints, limited solutions, and novel problem solving (Duff, 2012). Not supporting the first hypothesis, scores on the Trail Making Test did not demonstrate significant improvement. The Trail Making Test may not have shown statistically significant improvement in test scores due to the ceiling effect that restricted improvement on test scores for young healthy participants.

Results partially supported the second hypothesis, demonstrating a differential impact between visual and verbal learning/memory when using alternate test forms. Practice effects across learning and memory scores were eliminated when utilizing an alternate form for verbal memory. Alternatively, on the BVMT-R participants demonstrated significant improvements on their single trial learning. Total learning and delayed recall scores did not differ significantly; however, this is likely due to ceiling effects, limiting the ability for young healthy participants to demonstrate improvement upon retesting.

Reliability

Test-retest reliability is a core component in the development of RCIs; as the reliability coefficients are stronger, a smaller variance in scores is more meaningful. Reliability coefficients across assessments were variable, spanning -0.079 to .953. Tests with the most rigorous test-retest reliability included the Symbol Digit Modalities Test, Stroop Color-Word trial, COWAT, Digit Span Total, and Ruff 2&7 Controlled Errors.

The Digit Span Total subtest stability index boasted less variability (r = .825) compared to prior values for this age group in the standardization sample ($r = .71$; Wechsler, 2008). However, stability coefficients were variable within the Backward and Sequencing conditions. Specifically, the current sample demonstrated more robust reliability compared to the standardization sample in the Backward condition (*r* = .783 and *r* = .51 respectively) but yielded larger variability in the Sequencing condition (*r* = .406 and *r* = .65 respectively; Wechsler, 2008). It is possible the differences may be entirely owed to the population assessed. That is, athletes participating in education at the collegiate level may demonstrate less variability in thinking skills related to complex attention/working memory and more variability when given simple organizational demands.

In addition to Digit Span, other tests also demonstrated good to excellent test re-test reliability. On the Symbol Digit Modalities Test, the current study boasted a superior stability coefficient (*r* = .953) compared to the standardization sample (*r* = .80; Smith, 1991), yet returned similar results to a previous study completed with athletes (r = .91; Hinton-Bayre, Geffen, Geffen, McFarland, & Frijs, 1999). The Controlled Oral Word Association Test yielded slightly better stability (*r* = .860) than prior studies completed with adolescents and young adults (*r* = .680 and *r* = .77; Barr, 2003; Echemendia, Lovell, Collins, & Prigatano, 1999). Additionally, the Stroop Color and Word Test demonstrated higher test re-test reliability for the interference task (*r* = .878) than the standardization sample (*r* = .73). These results suggest high utility of these assessments in the evaluation of cognitive functioning in college students.

Regarding the Trail Making Test, the current study revealed poor stability (Trails A: *r* = .107; Trails B: *r* = .472), corroborating past studies examining test-retest reliability in adolescents and adults (Barr, 2003; Matarazzo, Wiens, Matarazzo, & Goldstein, 1974). The low reliability coefficient on Trails A suggests practice effects were not uniform among participants. Instead the current sample demonstrated regression to the mean; the bottom 30% of scores on the baseline assessment improved by an average of 13 sec. Conversely, the participants scoring in the top 30% all performed worse during the follow-up condition, by an average of 3.67 sec. In addition to regression to the mean, the follow-up condition demonstrated a small variance in test scores, allowing for small changes to significantly influence reliability values. Regarding Trails B, suboptimal test-retest coefficients may be due to situational factors such as stress levels. Baseline testing was performed during a period of little academic stress; conversely, follow-up testing was scheduled toward the end of the semester when many students experience an increase of stress and less consistent sleep patterns. Neuropsychological literature implicates aspects of executive functioning (e.g., set shifting) when participants experience increased stress levels (Shields, Sazma, & Yonelinas, 2016). Conversely, other higher order thinking skills (e.g., inhibition) utilized in other assessments given (i.e., the SCWT) do not demonstrate significant differences when under stress (Shields et al., 2016). Because individuals vary in the amount of stress they experience, it is intelligible that the reliability coefficient for Trails B would be suboptimal.

Select reliability coefficients for the Ruff 2 & 7 Selective Attention Test sample were significantly lower than in previous research. Namely, scores related to speed have demonstrated excellent test re-test reliability across age groups. This discrepancy may be best understood when considering the sample size of the current study. Large variance in a few individual's scores drastically influenced the reliability coefficients. Although all participants demonstrated adequate effort as measured by the Test of Memory Malingering (Tombaugh, 2003), variable effort throughout this task may explain the individual variance found for this test.

Reliable Change Indices

Table 4 provides clinicians with a method to determine if meaningful change has occurred. For each confidence interval (e.g., 70%, 80%, or 90%), a change in the raw score exceeding the values provided is considered statistically significant. Additionally, the value following each interval represents the percentage of student athletes who fell below the lower limit on repeat testing. Within the context of assessing SRC, the lower limit is most salient in determining the presence of cognitive dysfunction. However, upper limits provide clinicians with the ability to monitor cognition over time and detect statistically significant improvements in more extensive brain insults.

For example, consider the following scenario using the Symbol Digit Modality Test to re-evaluate an athlete following a concussive injury. If the athlete scored 63 on the first testing session (pre-injury) and 64 on the second testing session (post-injury), one would have a difference score of +1. By comparing this to Table 4, one would discover the athlete performed below what would be expected for the 70%, 80%, and 90% confidence intervals. Although the athlete’s score improved from the first testing session, this is due to practice effects. From the normative sample, we would expect the athlete to improve much more than 1 point. Thus, the athlete is likely experiencing cognitive dysfunction due to the concussion and should continue to recover before returning to play. Conversely, if the athlete performs above the lower limits, they are likely not experiencing cognitive problems and would be ready to return to their sport if physiological symptoms have also subsided.

Limitations of the Present Study

The current study contains several potential limitations that need to be considered. The number of participants is small and may limit the generalizability of the results. Within such a sample, individual variability in cognitive skillsets can potentially influence results in significant ways. However, plans are in place for continued data collection in order to address this concern. In addition to a small sample size, the majority of participants were female athletes. This may limit the generalizability of the results to male athletes as past studies have demonstrated differences in cognitive abilities between genders (Barr, 2003). Although perhaps not generalizable to male athletes, the high percentage of female participants enhances the clinical utility of the results when evaluating a female athlete.

Suggestions for Future Research

Further research may benefit from replicating the current study with a wider demographic group and varied time intervals between initial and follow-up testing. This would allow for the use of regression-based change formulas to control for individual characteristics as well as the degree of expected change due to practice effect. In addition to varied time between assessments, it would be advantageous to utilize assessments that do not demonstrate ceiling effects with this population. However, while achieving this goal, it is important to consider administration time and test cost so research can be applied within universities at a relatively low financial burden.

Conclusion

The results of this study provide evidence for the use of specific testing instruments when evaluating a collegiate athlete, as well as guidelines for the interpretation of follow-up testing. While the majority of studies utilizing reliable change indices examine a specific testing instrument (or several instruments in a cognitive domain), the current study provides reliable change data for a battery of assessments spanning multiple domains. Utilization of this research will improve concussion evaluations and reduce the harm an athlete experiences by prematurely returning to their sport.

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Appendix A

Demographic and History Questionnaire

Neuropsychological Assessment Baseline Form

Name:________________________ **ID#:** ___________ **Date of Birth:** _______/_______/______

Age:_______________ **Gender:**____________________ **Date of Evaluation:**_____/______/_______

GFU Standing (circle one): Freshman Sophomore Junior Senior **Ethnicity:** ______________

ACADEMIC HISTORY

What grades did you usually get in elementary school?_____________

What grades did you usually get in middle school?______________

What grades did you usually get in high school?_____________

Have you ever been placed on an Individual Education Plan (IEP) or Modified Learning Plan (504 plan)?

_________ No _________ Yes, please explain ____

Did you receive a high school diploma or a GED?

_________ High school diploma _________GED; if so, what is the last grade you completed? ________________

Please answer the following questions about <u>YOURSELF AS A CHILD</u> (think elementary school age). How often did you:	Never	Rarely	Sometimes	Often	Very often	If Often or Very Often, where?	Sports	Friends	School	Home
Have difficulty making and keeping friends?										
Have others tell you that you talked out of turn?										
Have a disorganized workspace (e.g., desk, backpack, room)?										
Have excessive energy?										
Have others tell you that you do not listen?										
Daydream or feel like your attention was elsewhere?										
Have difficulty paying attention?										
Get in trouble with other people?										

Did you ever have significant difficulty with learning how to read or comprehending reading passages?

___________No ___________Yes

Did you ever have significant difficulty learning mental math (e.g., Answering 4 X 4 in your head)?

___________No ___________Yes

Did you ever have significant difficulty with expressing your thoughts in writing or organizing your writing?

___________No ___________Yes

Did you ever have an academic tutor or receive accommodations in school?

___________No ___________Yes If so, what classes____

Were you ever held back a grade?

___________No ___________Yes If so, what grade? ____

For the following questions, choose the answer that best describes how you have felt and conducted yourself over the past 6 MONTHS.	Never	Rarely	Sometimes	Often	Very often	If Often or Very Often, where?	Sports	Friends	School	Home
How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?										
How often do you have difficulty getting things in order when you have to do a task that requires organization?										
How often do you have problems remembering appointments or obligations?										
When you have a task that requires a lot of thought, how often do you avoid or delay getting started?										
How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?										
How often do you feel overly active and compelled to do things, like you were driven by a motor?										

MEDICAL HISTORY

Please check the box to indicate any problems for which you have been diagnosed and estimate the year of diagnosis.

Condition	**Yes**	**No**	**Date**
Stroke			
Seizure			
Head Injury (from a fall, car accident, or other situation)			
Cancer			
Heart problems			

Do you have any other medical conditions not listed above? ___________ No ___________Yes

If yes, specify:____

Medication	Dosage	How often do you take it?	Reason

Have you ever been hit in the head hard enough to lose consciousness?

___________No ___________Yes

Have you ever been hit in the head hard enough to cause confusion and feelings of disorientation?

___________No ___________Yes

Do you have any problems with FALLING asleep (it takes longer than 30 min)?

___________No ___________Yes If yes, how many days per week?___________________________________

Do you have any problems with STAYING asleep?

___________No ___________Yes If yes, how many days per week?___________________________________

On average, how many hours of sleep do you get per night? ___________________________________

Please indicate any family history of the following conditions:

Condition	Your relationship to person	Age they were diagnosed	How many times?
Stroke			
Seizure			
Cancer/Tumor			
Multiple Sclerosis			
ADHD			
Learning Disorder			
Depression			
Anxiety			
Suicide			
Psychosis			

How has your mood been in the last two weeks?

_____ Irritable _____Very negative _____ Sad _____Happy _____Neutral

Other:____

Have you ever had difficulty with:

_____Depression _____Anxiety _____Anger problems

_____Seeing things that others do not see _____Hearing things other people do not hear

_____Thoughts/desire to hurt yourself _____Thoughts/desire to hurt others

SOCIAL HISTORY

Where were you born? ____

Where were you raised? ____

Who were you raised by? ____

To the best of your knowledge, did your mother have any complications during your birth?

______No ______Yes If yes, explain: ____

Have you been married?

______No ______Yes

Do you have children?
______No ______Yes If yes, how many? ____________
Is it easy for you to make friends?
______No ______Yes

Is it easy for you to keep friends?
______No ______Yes

Have you used the following substances?

________ Tobacco ________Alcohol _________ Marijuana ________Cocaine

________ Heroin ________ Methamphetamines _________ Psychedelics

________ Opiates/Narcotics ________ Other non-prescribed medication ________ None of the Above

Appendix B

Follow-Up Questionnaire

Neuropsychological Questionnaire

Name:_____________________________ **ID#**: _______________________________

Age:_______________________________ **Gender**:_____________________________

Date of Evaluation:_____/_____/______ **Date of Birth**: _______/_____/______

During the last 3 months, were you diagnosed with any new medical conditions?

__________ No __________ Yes, please explain ____

During the last 3 months, did you start taking any new medications?

__________ No __________ Yes, please explain____

During the last 3 months, did you sustain any injuries?

__________ No __________ Yes, please explain ____

Please check any symptoms you have experienced in the last 3 months.

_____Headache _____Fatigue _____Poor balance _____Memory loss

_____Confusion _____Sleep problems _____Nausea _____Vomiting

_____Sensitivity to ____Sensitivity to Sound _____Irritability

_____None of the above

How would you describe your mood in the last two weeks?

How has your mood been in the last two weeks?

_____ Irritable _____Very negative _____ Sad _____Happy _____Neutral

Other:____

In the last 3 months, have you had difficulty with:

_____Depression _____Anxiety _____Anger problems

_____Seeing things that others do not see _____Hearing things other people do not hear

______Excessive energy/decreased need for sleep ______Thoughts/desire to hurt yourself

______Thoughts/desire to hurt others ______None of the above

Appendix C

Initial Script before Administration of Tests

Today we are going to do many different types of tasks. Some of them may be easy for you while others may be more difficult. The study is designed to gauge your effort during testing, and you will not receive research credit if scores reflect poor effort on the following tests. Therefore it is important that you do your best. Do you have any questions?

Appendix D

Statistical Sentences

Subtest	Statistical Sentence
Digit Span	
Digit Span Forward	t(9)= 0.889, p = .397
Digit Span Backwards	t(9)= 0.896, p = .394
Digit Span Sequencing	t(9)= 1.964, p = .081
Digit Span Total	t(9)= 1.561, p = .153
Ruff 2 and 7	
Automatic Speed	t(9)= 1.685, p = .126
Automatic Errors	t(9)= 1.675, p = .128
Automatic Accuracy	t(9)= 1.847, p = .098
Controlled Speed	t(9)= 1.284, p = .231
Controlled Errors	t(9)= 1.115, p = .294
Controlled Accuracy	t(9)= 0.862, p = .411
Stroop	
Word Speed	t(9)= 4.175, p = .002
Color Speed	t(9)= 3.611, p = .006
Color Word Speed	t(9)= 2.779, p = .021
Symbol Digit Modality Test	
Total Speed	t(9)= 6.511, p = <.001
Trail Making Test	
Trails A	t(9)= 1.836, p = .100
Trails B	t(9)= 1.830, p = .101
COWAT	
Total Words	t(9)= 2.097, p = .065
HVLT	
Trial 1	t(9)= 1.430, p = .186
Total Learning	t(9)= 0.618, p = .552
Delayed Recall	t(9)= 1.481, p = .173
Recognition	t(9)= 1.152, p = .279
BVMT-R	
Trial 1	t(9)= 2.623, p = .028
Total Learning	t(9)= 0.487, p = .638
Delayed Recall	t(9)= 0.605, p = .560

Appendix E

Formulas Used for Reliable Change Calculations

Standard Error of Measurement (SEM)

SEM = SD $\sqrt{1 - r}$

SD = standard deviation of the comparison sample

r = reliability coefficient of the comparison sample

Standard Error of Difference (S_{diff})

$S_{diff} = \sqrt{SEM_1^2 + SEM_2^2}$

SEM_1 = Standard Error of Measurement during the baseline evaluation

SEM_2 = Standard Error of Measurement during the follow-up evaluation

Reliable Change Index Formula Controlling for Practice Effects (RCI_{PE})

$RCI_{PE} = \frac{(T_2 - T_1) - (M_2 - M_1)}{S_{diff}}$

Appendix F

Curriculum Vitae

Daniel J Soden

601 West 1st Street Unit 3, Newberg, Oregon 97132
503.550.1669
Dsoden15@georgefox.edu

Education

PsyD **George Fox University,** Newberg, Oregon **Anticipated Graduation: May 2020**
Doctorate in Clinical Psychology

- APA Accredited Program.
- Dissertation: "Serial Neuropsychological Testing toward a Reliable Concussion Protocol" Committee: Glena Andrews, PhD, ABPP; Freeman Chakara, PsyD, ABPP; Kathleen Gathercoal, PhD
- Major Area of Study in Neuropsychology (Taxonomy for Education and Training in Clinical Neuropsychology, 2016).

MA **George Fox University,** Newberg, Oregon **2017**
Master of Arts in Clinical Psychology

BA **Lancaster Bible College,** Lancaster, Pennsylvania **2015**
Bachelor of Arts in Student Ministry

Supervised Clinical Experience

Assessment Clinic of the Behavioral Health Center, Newberg, Oregon **2018-Present**
Pre-Internship Practicum
Position: Co-Assistant Director of the Assessment Clinic
Supervisor: Glena Andrews, PhD, ABPP
Setting: Outpatient Community Mental Health Clinic
Population: Patients across the lifespan referred for concerns of ADHD/LD, TBI, dementia, autism, and other medical conditions
Duties:

- Managing administrative duties of the clinic, including billing, waitlist triage, and testing library maintenance.
- Providing peer supervision for neuropsychological cases that includes protocol development, test interpretation, case conceptualization, and report edits before vetting to the supervising psychologist.
- Leading group supervision exercises including fact finding exercises as well as participating in weekly didactics with topics ranging from ethical concerns in community mental health to TBI assessment.

- A community mental health setting provides an array of experiences working with low-income families from the surrounding rural communities. This often requires finding creative solutions (e.g., income-based fees, payment plans, and pro bono work as necessary), managing dual relationships, and finding cost-effective resources.

Rural Child and Adolescent Psychological Services, Newberg, Oregon **2018-Present**
Pre-Internship Practicum
Position: Advanced Assessment Service Coordinator
Supervisors: Elizabeth B. Hamilton, PhD, Andrew Kenagy, PsyD
Setting: Primary, intermediate, and high school rural school districts
Population: Pre-k to high school aged students presenting with a variety of psychosocial stressors, neurodevelopmental disorders, and sports-related TBI
Duties:

- Conducting file reviews, behavioral observations, and comprehensive psychoeducational assessment toward the development of individualized education plans.
- Working closely with the school-based autism specialist to provide comprehensive assessment of neurodevelopmental disorders.
- Reviewing referrals, constructing testing batteries, and assigning cases based on training needs.
- Serving as a peer supervisor for practicum students' psychoeducational assessments (e.g., SLD, ADHD, and behavioral concerns) as well as neuropsychological cases pertaining to prenatal drug exposure and TBI.
- Editing reports and meeting with students to provide feedback before vetting to the licensed psychologist.
- Leading eligibility meetings, providing feedback to the student, parents, and attending school officials.

Samaritan Neuropsychology, Albany, Oregon **2017-2018**
Practicum II
Supervisors: Robert Fallows, PsyD, ABPP; Audrina Mullane, PhD; Ashley Watts, PhD
Setting: Outpatient Neuropsychology Clinic
Population: Patients across the lifespan referred due to difficulties with cognition
Duties:

- Provided comprehensive outpatient neuropsychological evaluations.
- Interviewed patients, administered assessments, completed scoring, provided conceptualizations, and wrote reports on the same day.
- Participated in group supervision consisting of journal club, psychometric presentations, fact-finding, case presentations, and didactics.
- Completed a minor rotation with integrated health providing short term behavioral interventions and teaching coping skills.

Oregon State University, Corvallis, Oregon **2017-2018**
Supplemental Practicum
Supervisors: Robert Fallows, PsyD, ABPP; Audrina Mullane, PhD; Ashley Watts, PhD
Setting: University Testing Center
Population: Oregon State University Athletes
Duties:

- Observed structured interviews.
- Provided comprehensive neuropsychological testing for baseline concussion data as well as screening for ADHD/LD and psychiatric conditions.
- Scored protocols and entered data into a research repository.

Willamette Valley Medical Center, McMinnville, Oregon **2016-2017**
Practicum I
Supervisor: Luann Foster, PsyD
Setting: Senior Behavioral Health Unit (Inpatient Psychiatric Unit)
Population: Geriatric patients with psychiatric illness, suicidal ideation, homicidal ideation, and degenerative conditions
Duties:

- Served as the neuropsychological consult for attending physicians.
- Provided individual and group psychotherapy.
- Conducted interviews and neuropsychological evaluations toward differential diagnosis and treatment planning; findings were reported to the unit's psychiatrist.
- Provided feedback to patients and their families.
- Observed commitment hearings (i.e., hearings that determined involuntary commitment to the psychiatric unit).

Setting: McMinnville Surgical Associates (Outpatient Bariatric Consult)
Population: Candidates for bariatric surgery
Duties:

- Conducted psychological evaluations to determine candidacy for bariatric surgery.
- Provided individual therapy in order to assist patients in overcoming psychological barriers for weight loss and behavior change.
- Facilitated group therapy aimed toward attenuating harmful eating behaviors and provide support throughout the weight loss surgery.
- Collaborated with an interdisciplinary team in order to coordinate treatment plans.

Providence Behavioral Health, Lancaster, Pennsylvania **2016**
Supplemental Practicum
Supervisor: Freeman Chakara, PsyD, ABPP
Setting: Private Practice
Population: Individuals across the lifespan
Duties:

- Assisted with neuropsychological intake interviews and assessments.
- Completed integrated neuropsychological reports.
- Provided feedback and recommendations for patients.
- Assisted with independent medical evaluations.
- Researched and integrated contemporary literature as resources for clients and caregivers.

George Fox University, Newberg, Oregon **2016**
Pre-Practicum
Supervisors: Glena Andrews, PhD, ABPP and April Brewer, MA
Setting: University Counseling
Population: Undergraduate students
Duties:

- Provided outpatient individual psychotherapy services to volunteer young adult university students.
- Conducted intake interviews, prepared treatment plans, and wrote diagnoses.
- Created professional reports, presented case conceptualizations.
- Consulted with supervisors and members of clinical team.
- Taped all sessions, reviewed, and discussed them in individual and group supervision.

Research Experience

Oregon Health and Sciences University, Child Development and Rehabilitation Center **2017 - 2018**
Portland, Oregon
Supervisor: Trevor Hall, PsyD, ABPdN

- Assisted with research projects including "The Role of Post-traumatic Headache on Neurocognitive Outcomes in Pediatric Traumatic Brain Injury" and "Virtual Reality as a Method of Phenotyping Neurocognitive Function in Children and Youth."
- Collected data and collaborated toward publication and authorship.
- Gained in-clinic experience through shadowing neuropsychologists and assisting with scoring test data.

National Organization of Disorders of the Corpus Callosum, George Fox University **2016**
Chicago, Illinois
Supervisor: Glena Andrews, PhD, ABPP

- Administered the Bayley Scales of Infant and Toddler Development to children (1 month – 3.5 years of age) with partial or complete agenesis of the corpus callosum.
- Attended psycho-education workshops and presentations.
- Provided reports to parents regarding the developmental trajectory of their child.
- Compiled data to further inform early intervention in children with agenesis of the corpus callosum.

Cognitive Neuroscience Lab, George Fox University **2016**
Newberg, Oregon
Supervisor: Glena Andrews, PhD, ABPP

- Aided with EEG and ERP data collection and interpretation.
- Collaborated with other students for research projects.

Research Vertical Teams, George Fox University **2016 - Present**
Newberg, Oregon
Supervisor: Glena Andrews, PhD, ABPP

- Assisted team members with formulation of dissertation topics and collaborated at various stages.
- Collaborated with other students for research projects and posters.
- Prepared poster presentations of research projects.

Grants, Honors, and Awards

2017 Richter Scholars Program Grant ($1,600)
Funds applied to my dissertation: Serial Neuropsychological Testing toward a Reliable Concussion Protocol

2015 Recipient of the Annual Leadership Award
Lancaster Bible College

Publications

McConnell, B., Duffield, T., Hall, T., Piantino, J., Seitz, D., **Soden, D**., Williams Cyndi (Submitted). Headache after pediatric traumatic brain injury as a predictor for neurocognitive and morbidities outcomes: a retrospective cohort study. Pediatric Neurology.

Juried Presentations and Poster Presentations

Soden, D., Seitz, D., Meguro, L., Andrews, G., Hamilton, E. (2018, August 10). *Cognitive Differences between ADHD and Prenatal Polysubstance Exposure: Fluid Reasoning and Long-term Retrieval.* Poster presented at the American Psychological Association Annual Conference, San Francisco.

Seitz, D., **Soden, D**., Meguro, L., Hamilton, E., Andrews, G. (2018, August 10). *Differentiating Cognitive Deficits Between ADHD and In Utero Polysubstance Exposure: Processing Speed and Short-term Working Memory*. Poster presented at the American Psychological Association Annual Conference, San Francisco.

Otero, T., **Soden, D.**, Duffield, T., Mastel, S., Parsons, T., Piantino, J., & Hall, T. (February, 2018). *Virtual Reality as a Method of Phenotyping Neurocognitive Function in Children and Youth*. Poster presentation at the annual meeting of the International Neuropsychological Society, Washington DC.

Soden, D., Seitz, D., Summers, W., Mushlitz, A. (2018, January 14). *Psychological Foundations toward Short-Term Care.* Oral Presentation to Hillside-Inn staff members.

Soden, D. (2017, November 2). *The Neuropsychological Profile and Clinical Presentation of Dementia of the Alzheimer's Type and Vascular Dementia.* Oral presentation for the Neuropsychological Assessment doctoral course at George Fox University.

Soden, D., Seitz, D., Andrews, G. (2017, October 26). *Behavioral and Adaptive Functioning Differences in Children with Complete Agenesis of the Corpus Callosum.* Poster presented at the National Academy for Neuropsychology Annual Conference, Boston.

Seitz, D., **Soden, D.**, Andrews, G. (2017, October 26). *The Role of Dysgenesis of the Corpus Callosum on Neuropsychologist development: A Twin Case Study*. Poster presented at the National Academy for Neuropsychology Annual Conference, Boston.

Soden, D. (2017, October 20). *How to Conceptualize Neuropsychological Data.* Oral didactic for the Neuropsychology Student Interest Group at George Fox University.

Soden, D. (2017, September 29). *An Introduction to Neuropsychology: Understanding Brain Behavior Relationships.* Oral didactic for the Neuropsychology Student Interest Group at George Fox University.

Soden, D., Seitz, D., Andrews, G. (2016, October 19). *The Implications of Language and Dysgenesis of the Corpus Callosum on Emotional Regulation.* Poster presented at the National Academy for Neuropsychology Annual Conference. Seattle.

Seitz, D., **Soden, D.**, Andrews, G. (2016, October 19). *The Role of Dysgenesis of the Corpus Callosum and Language Development on Social Behaviors.* Poster presented at the National Academy for Neuropsychology Annual Conference Seattle.

Offices Held

Student Interest Group President: Neuropsychology, George Fox University **2016 – Present**
The Graduate Department of Clinical Psychology
Faculty Sponsor: Glena Andrews, PhD, ABPP

- Organizing meeting schedule, choosing monthly didactic topics, and inviting guest speakers.
- Meeting monthly to provide additional exposure to various neuropsychological conditions, testing profiles, and clinical manifestations.
- Presenting on the neuropsychological assessment and clinical manifestations of Alzheimer's Dementia.

Teaching Experience

Teaching Assistant for Neuropsychological Assessment, George Fox University **2016 - 2018**
The Graduate Department of Clinical Psychology
Supervisor: Glena Andrews, PhD, ABPP

- Demonstrated and instructed doctoral students in the administration, scoring, and interpretation of neuropsychological measures.
- Evaluated students in standardized administrative practices and scoring accuracy.
- Taught classes regarding report writing, Alzheimer's Dementia, and Vascular Dementia.
- Led group exercises including fact finding, battery construction, and case conceptualization.

Teaching Assistant for Child and Adolescent Assessment, George Fox University **2018**
The Graduate Department of Clinical Psychology
Supervisor: Elizabeth Hamilton, PhD

- Instructed doctoral students in the administration, scoring, and interpretation of cognitive, academic, behavioral, and projective assessments.
- Formulated batteries for assessment cases and fielded questions regarding individual assessment cases.

Professional Affiliations

Psi Chi, George Fox University **2017 - Present**
International Honor Society in Psychology

APA, American Psychological Association **2015 - Present**
American Psychological Association of Graduate Students (APAGS)

NAN, National Academy of Neuropsychology **2015 - Present**
Graduate Student Member

Professional Trainings and Workshops

"Old Pain in New Brains" **2018**
Speaker: Scott Pengelly, PhD
Site: George Fox University, Newberg, OR

Rural Behavioral Health Practice Conference **2018**
Presentations: "Adverse Childhood Experiences: Practice Issues in Rural Healthcare" and
"Ethics and Boundaries in Rural American – A Practical Approach
Speakers: Afton M. Koball, PhD, ABPP, LP; Denyse Olson-Dorff, PsyD; Judy Klevan, MD
Jennifer Andrashko, MSW, LICSW, Kimberly Sommers, PsyD, LP
Site: George Fox University, Newberg, OR

"Spiritual Formation and Life of a Psychologist: Looking at Soul-Care" **2018**
Speaker: Mark McMinn, PhD, Lisa McMinn, PhD
Site: George Fox University, Newberg, OR

"The History and Application of Interpersonal Psychotherapy" **2018**
Speaker: Carlos Taloyo, PsyD
Site: George Fox University, Newberg, OR

"The Cognitive Neuroscience of Memory" **2017**
Speaker: Larry Squire, PhD
Site: The Westin Boston, National Academy of Neuropsychology, Boston, MA

"Neuropsychology of Cognitive Aging and Dementia: Advanced in Clinical Diagnosis and Treatment" **2017**
Speaker: Kathleen A. Welsh-Bohmer, PhD
Site: The Westin Boston, National Academy of Neuropsychology, Boston, MA

"Cognitive Disorders of Aging: Unusual Cases and New Development in Diagnosis, Treatment, and Lifestyle Factors **2017**
Speaker: Andrew Budson, MD
Site: The Westin Boston, National Academy of Neuropsychology, Boston, MA

"Practical Recommendations and Newly Developed Norms for the Evaluation of Spanish-Speaking Children: What Every US Neuropsychologist Should Know" **2017**
Speaker: Juan Carlos Arango-Lasprilla, PhD
Site: The Westin Boston, National Academy of Neuropsychology, Boston, MA

"Clearing the Smoke: Assessing the Impact of Marijuana Use on Cognition and Related Variables" **2017**
Speaker: Staci Gruber, PhD
Site: The Westin Boston, National Academy of Neuropsychology, Boston, MA

"Sacredness, Naming and Healing: Lanterns Along the Way" **2016**
Speaker: Brooke Kuhnhausen, PhD
Site: George Fox University, Newberg, OR

"Children and Divorce" **2016**
Speaker: Wendy Bourg, PhD
Site: George Fox University, Newberg, OR

"Neuropsychological Assessment and Preclinical Alzheimer's Disease" **2016**
Speaker: Dorene Rentz, PsyD
Site: The Westin Seattle, National Academy of Neuropsychology, Seattle, WA

"Mood Matters: Late-Life Depression, Cognitive Impairment- and the Risk of Dementia" **2016**
Speaker: Meryl Butters, PhD
Site: The Westin Seattle, National Academy of Neuropsychology, Seattle, WA

"Neuropsychological Assessment and Preclinical Alzheimer's Disease" **2016**
Speaker: Dorene Rentz, PsyD
Site: The Westin Seattle, National Academy of Neuropsychology, Seattle, WA

"Preparation for Board Certification" **2016**
Speaker: Karen Wilhelm, PhD
Site: The Westin Seattle: National Academy of Neuropsychology, Seattle, WA

"Sacredness, Healing, and Naming" **2016**
Speaker: Brooke Kuhnhausen, PhD
Site: George Fox University, Newberg, OR

"Screening Brief Intervention and Referral to treatment (SBiRT): Alcohol and Substance Abuse Evaluation" **2016**
Speaker: Jim Winkle, MPH
Site: George Fox University, Newberg, OR

"Working with Multicultural Clients with Acute Mental Illness" **2016**
Speaker: Sandra Jenkins, PhD
Site: George Fox University, Newberg, OR

"The Collaborative Assessment and Management of Suicidality (CAMS)" **2016**
Speaker: Luann Foster, PsyD
Site: George Fox University, Newberg, OR

"Neuropsychology: What Do We Know 15 years after the Decade of the Brain?" **2016**
Speaker: Trevor Hall, PsyD
Site: George Fox University, Newberg, OR

"Brains, Drugs, and Addiction: The Neuroscience of Chemical Dependency" **2016**
Speaker: Kenneth Brown, PhD
Site: Kiggins Theater, Vancouver, WA

"The Neuroscience of Trauma: From Trigger Warnings to PTSD" **2015**
Speaker: Larry Sherman, PhD
Site: Kiggins Theater, Vancouver, WA

“Managing Emerging Sexuality in Therapy” **2015**
Speaker: Joy Mauldin, PsyD
Site: George Fox University, Newberg, OR

“Relational psychoanalysis and Christian faith: a Heuristic Dialogue” **2015**
Speaker: Marie Hoffman, PhD
Site: George Fox University, Newberg, OR