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## Neurocognitive Correlates of the Comprehensive Trail Making Test (CTMT) in Brain Injured Children

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NEUROCOGNITIVE CORRELATES OF THE COMPREHENSIVE TRAIL MAKING  
TEST (CTMT) IN BRAIN INJURED CHILDREN

By

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Bachelor of Science in Psychology  
Texas State University - San Marcos  
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A thesis submitted in partial fulfillment  
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Abstract  
Neurocognitive Correlates Of The Comprehensive Trail Making Test (CTMT) In Brain  
Injured Children

by

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The Comprehensive Trail-Making Test (CTMT) is a commonly used assessment tool shown to be sensitive to brain dysfunction. Research has found cognitive abilities such as processing speed, working memory, motor speed, sustained attention, and cognitive flexibility influence performance on the CTMT in non-clinical populations. However, little research has been done to examine the neurocognitive abilities that influence performance on the CTMT in clinical populations. Research has demonstrated that the factor structure of the CTMT differs between clinical and non-clinical groups, which supports the need for further validation of the CTMT in clinical populations. This study examines the neurocognitive correlates that are thought to underlie performance on factor scores of the CTMT in children that with brain dysfunction. The sample for the current study consisted of 98 children, with various sustained and developmental and neurological disorders and a subgroup of children with a TBI ( $n = 71$ ) selected from the overall sample. These children completed a neuropsychological battery, which included the CTMT and measures of processing speed, working memory, motor speed, and sustained attention. The relationship between the neurocognitive correlates and the CTMT factor scores were examined using a regression analysis. It was hypothesized that the simple sequencing factor would be predicted by tests that assess Processing Speed,

Sustained Attention and Motor Function, while the complex sequencing factor would be predicted by Processing speed and Working Memory. Results indicate that Processing Speed and Motor Function were significant predictors for both the Simple and Complex Sequencing factors. In addition to Processing Speed and Motor Function, Working Memory was a significant predictor for Complex Sequencing for the overall sample. In contrast, Sustained Attention, along with Processing Speed and Motor Function, significantly predicted Complex Sequencing for the TBI subgroup. These findings provide evidence for the use of the CTMT in clinical population, and clarify the underlying mechanisms measured by the CTMT.

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## Chapter 1

### Introduction

The Trail Making Test (TMT) is one of the most frequently administered neuropsychological assessment measures (Rabin, Barr, & Burton, 2005). The TMT is useful for detecting brain dysfunction in children and adults that results from a number of acquired and neurodevelopmental disorders, including traumatic brain injury (Allen, Haderlie, Kazakov, & Mayfield, 2009; Armstrong, Allen, Donohue, & Mayfield, 2008; Williams, Rickert, Hogan, & Zolten, 1995), learning disabilities, and epilepsy, (Barth et al., 1983; Boll, Berent, & Richards, 1977; Davids, Goldenberg, & Laufer, 1957; Jaffe et al., 1993; Mittelmeier, Rossi, & Berman, 1989; O’Leary, 1983; Periañez et al, 2007; Reitan, 1955, 1958, 1971; Rourke & Finlayson, 1975; Reitan & Wolfson, 1992a, 1992b; Sroufe et al., 2010), and a number of other neurological disorders. The TMT gained popularity because it is easy and brief to administer, is highly sensitive to brain dysfunction and there is now substantial support for its validity. Because of its common use, much information regarding the validity of the TMT has been collected and a number of newer versions of the test have been developed that purport to improve upon the original version, although there is little information available that would substantiate these claims. One newer version of the TMT, the Comprehensive Trail Making Test (CTMT), has a number of innovative features and initial reliability and validity data suggest it has clinical utility. However, limited information is available regarding its application in clinical populations, which is problematic because its primary application is with these groups. The current study addresses this shortcoming by examining the psychometric properties of the CTMT factor structure in a group on children with various

neurodevelopmental and neurological disorders, in order to establish the construct validity of the CTMT factor scores. It is anticipated that the results of this investigation will assist in establishing the validity of the test and aid in its clinical utility when used to assess children with brain disorders.

In order to provide a background for the current study, the following sections of the literature review will include historical information on the CTMT and the use of the CTMT with clinical population.

## Chapter 2

### Literature Review

The TMT was originally developed as the Test of Distributed Attention to serve as an alternative method to assess intellectual function (Partington, 1949). It was subsequently incorporated into the Halstead-Reitan Neuropsychological Battery (Reitan and Wolfson, 1992a) because of its sensitivity to brain injury. The TMT is administered in two parts, A and B. For Part A, test subjects are instructed to connect a series of 25 numbered circles in sequence. As in Part A, for Part B test subjects are also instructed to connect series of circles, but this time alternate between a numerical and alphabetical sequences (i.e., start at “1”, and then draw a line to “A”, then “2”, then “B”, and so on). The primary score for the test is the time it takes to complete each part of the test (measured in seconds), although errors are also recorded.

Successful completion of the TMT requires a number of different abilities including motor speed, attention, working memory, visuospatial ability, visual search/scanning, and what has been referred to as cognitive flexibility, the latter which is particularly important for Part B of the TMT. Studies have examined the cognitive abilities required to perform the TMT in a number of clinical populations, by correlating TMT scores with tests of other neurocognitive abilities. Thaler et al. (2012) demonstrated a number of neurocognitive abilities are required to efficiently complete the TMT for children (TMT-C) including psychomotor speed, complex attention, visual scanning, and mental flexibility. The TMT-C is a shortened version of the original TMT, which consists of 15 targets instead of 25. Specifically, this study investigated the neurocognitive correlates involved in performance on the TMT-C in a clinical population. In this study

61 children between the ages of 9 and 14 years with moderate to severe TBI completed, as part of a neuropsychological battery, the TMT-C. Researchers performed a regression analysis to examine neurocognitive correlates involved in performance on both Trail A and B of the TMT-C. Results indicated that performance on Trail A was best predicted by processing speed, while performance on Trail B was best predicted by backward span tasks. These findings are consistent with studies of adult populations, which have found that while Part A is associated with visuoperceptual processing speed, motor speed, and perceptual abilities, Part B requires working memory, inhibition, and executive functions (Langenecker, Zubieta, Young, Akil, & Nielson, 2007; Ríos, Periañez, & Muñoz-Céspedes, 2004; Sánchez-Cubillo et al., 2009). These and other studies suggest that while the Part A and Part B of the TMT require a number of the same cognitive abilities, Part B is the more complex of the two and places greater demands on working memory.

Since development of the original version of the TMT, a number of different trail making tests have been developed (DKEFS; Delis, Kaplan, & Kramer, 2001; CTMT; Reynolds, 2002; Color Trails Test; D'Elia, Satz, Uchiyama, & White, 1996). These versions have been developed in an attempt to improve on the original version by increasing difficulty level, including different types of trail tasks that assess a broader range of cognitive abilities, and allowing for repeated assessment. Although gaining more widespread use in clinical and research settings, much less reliability and validity information is available for these newer versions of the TMT and so it remains unclear whether they do actually represent an improvement over the original version. Among the more recent versions, one of the most commonly administered is the Comprehensive Trail Making Test (CTMT; Reynolds, 2002). The CTMT differs from the TMT in a

number of important ways. It consists of five trails rather than two in order to provide a more comprehensive assessment of executive function such as set shifting abilities and inhibition. The CTMT has extensive normative data based on 1,664 individuals selected to represent the United States population in terms of sex, gender, education, race/ethnicity, family income, geographical region, educational attainment of parents or adults, and disability status. The CTMT was designed and normed for individuals between 8 and 89-years of age.

Although the CTMT has a number of appealing features that may make it a more useful assessment procedure than its predecessor, validity evidence supporting its scores are lacking, particularly for individuals with brain disorders, although some evidence for the validity of the CTMT has developed over the years. Reynolds and Horton found that in the standardization sample, CTMT performance peaked for individuals in their early to mid-20's (Reynolds & Horton, 2008), which is consistent with the time course for frontal lobe development and maturation. Reynolds (2002) also reported that there was an expected pattern of correlations between CTMT scores and visuo-perceptual constructional abilities and motor speed in nonclinical populations, which are expected given that the CTMT ostensibly assesses these abilities. Similar findings were reported by Smith et al. (2008) in a sample of 55 college students. Significant correlations were present among some CTMT trails and tests of visual perception, visuoconstructional abilities, and attention. Practice effects are also apparent following repeated administrations (Reynolds, 2002; Buck, Atkinson, & Ryan, 2008).

To address issues of clinical applicability, the creators included in the test manual, data from 30 individuals with learning disability and 28 with cerebrovascular accidents.

Both of these groups performed below the standardization sample, with those that suffered cerebrovascular accidents performing roughly two standard deviations below the mean (Reynolds, 2002). Additional support for the criterion validity of the CTMT was provided by Smith et al. (2008) whose work found the CTMT to be sensitive to neuropsychological deficits in college students ( $n=19$ ) with a variety of learning disabilities and ADHD.

Similarly, Armstrong et al. (2008) found that children with TBI ( $n=30$ ) score significantly lower than matched controls ( $n=30$ ) on all five trails as well as the composite index. Trails 4 and 5 and the Composite Index scores provided the best discrimination between the between clinical and non-clinical groups. Allen et al. (2009) provided additional support for the criterion and construct validity of the CTMT by comparing 50 children with TBI and 50 healthy controls. In this study, scores on all CTMT trials as well as the Composite score were significantly lower for the TBI group than for the control group. Allen, Thaler, Barney, and Mayfield (2012) matched 121 healthy controls with 121 children with TBI on age and sex in order to examine the overall sensitivity of the CTMT to TBI. Receiver operating characteristic (ROC) analysis indicated that of the CTMT scores, the Composite Index was the best measure for classifying children as having brain dysfunction. The CTMT had a sensitivity of .74 and a specificity of .82, which are comparable to similar estimates reported in the literature for the original TMT. The CTMT Composite index correctly classifies 79% of cases, suggesting that the classification accuracy of the CTMT is similar to that of its predecessors (Allen et al., 2012).

Construct validity of the CTMT scores have been examined using convergent and discriminant validity. Regarding the discriminant validity of the CTMT, Smith et al. (2008) found that like the TMT (Gass & Daniel, 1990), it did not significantly correlate with conceptually unrelated measures in a sample of 55 undergraduate students. CTMT scores did not correlate significantly with tests of psychopathology as well as verbal measures of the WASI and WAIS-III, which supported the discriminant validity of the CTMT. Regarding the convergent validity of the CTMT, Smith et al. (2008) found that the CTMT was significantly correlated with tests of visual perception and visuoconstructional abilities in 55 college students.

In addition to the examination of convergent and discriminant validity, the construct validity of the CTMT has also been evaluated using factor analysis. Studies of clinical and nonclinical populations have typically identified two underlying factors, although the CTMT trails that load on each of the factors appear to vary across normal and clinical samples. For the standardization sample, the first factor was composed of Trails 1, 2, and 3, and referred to as simple sequencing because each trail contains only one concept the examinee must use to connect the circles. The second factor was composed of trails 4 and 5, and referred to as complex sequencing because each trail contains two kinds of stimuli that the examinee must shift between. Since then, additional support for a two-factor model has been provided in normal samples (Atkinson & Ryan, 2008).

For clinical samples, initial studies found there were differences in the magnitude and pattern of correlations among the CTMT individual trail, factor and Composite scores for brain-injured and normal comparison samples. These initial findings suggested

that the CTMT had a different factor structure for controls and TBI groups, although the samples were relatively small, limiting more detailed analyses of the data (Allen et al., 2009; Armstrong et al., 2008). Bauman-Johnson, Maricle, Miller, Allen, and Mayfield (2010) examined the factor structure of the CTMT in children with TBI ( $n=80$ ) and found that all five trails of the CTMT loaded onto one factor. While the findings did support the contention that the CTMT factor structure differed for clinical samples, the sample size was small for factor analytic work. In a subsequent confirmatory factor analysis (CFA) of 191 children with brain dysfunction and 191 age and sex matched normal comparison children, Allen et al. (2012) identified two CTMT factors for each group reflecting Simple Sequencing and Complex Sequencing/Shifting abilities. However, differences in the pattern of loadings were apparent. Similar to the standardization sample, for the normal comparison group Trails 1, 2, and 3 loaded on the simple sequencing factor, while Trails 4 and 5 loaded on the complex sequencing factor. In contrast, for the clinical group, Trails 1 and 2 loaded on the simple sequencing factor, while Trails 3, 4, and 5 loaded on the complex sequencing factor. These results suggest that the presence of brain dysfunction may alter the factor structure of the CTMT in children and adolescents. While the reason for the difference is unclear, Allen et al. (2012) suggested that since Trail 3 contains stimuli intended to distract the examinee, Trail 3 requires more response inhibition than Trails 1 or 2. For the clinical group, brain dysfunction may have impaired their ability to inhibit response to distractor stimuli, while the non-clinical groups performance may not be affected by inhibition (Allen et al., 2012). In comparison to Bauman et al., limited sample size may have precluded detection of two factors in that study, while the larger sample size in the Allen et al. (2012) study allowed for detection

of the second factor.

To date, while the differences discussed have been well established, it is still unclear why these differences exist. However some explanations can be excluded, Bauman-Johnson et al. (2010) matched TBI and control groups on age and therefore differences between the standardization sample and the clinical samples cannot be explained by differences in age. Age was also considered and excluded as a possible explanation when Riccio et al. (2011) conducted a confirmatory factor analysis of children and adolescents on data from the CTMT standardization sample and found that age had small to no effect on the factor structure of the CTMT.

Another possible explanation for the difference in factor structure is sample size. Studies examining the factor structure of the CTMT in clinical populations have been somewhat small. Use of a small sample could potentially create problems in the stability of factor solutions, which may lead to factors not being recognized in spite of being strongly correlated. The problem of small sample size is a common occurrence in studies involving neuropsychological tests. These studies also utilized both confirmatory and exploratory factor analysis and either orthogonal or oblique rotations, these variations in methodology could also account for differences in findings.

The difference in the factor structure of the CTMT between groups could be due to inherent differences between clinical and non-clinical groups. Research has shown this to be the case with many other neuropsychological and intellectual tests (Allen et al., 1998; Delis, Jacobson, Bondi, Hamilton, & Salmon, 2003). Correlations of scores may differ in clinical populations from the normal population as a result of the nature of the impairments associated with the neurological condition. As a result of the differences in

correlations, there may also be differences in factor loadings. This can result in the identification of unique factors based on the neural systems affected by the neuropsychological abilities that the specific test measures. For example, Allen et al. (1998) found that coding tasks have different factor loadings in schizophrenia, which may be due to the motor requirements of these tasks. Another example is the separate memory factors (immediate, delayed and recognition memory) that have been identified in Alzheimer's, than those factors found in normal populations (Delis et al., 2003). This pattern of findings support the idea that research is needed to examine how the factor structure of assessment tools differs in clinical population from the standardization sample. While some efforts have been made to examine the CTMT in clinical populations, more work is needed to determine whether the CTMT scores should be interpreted as a measure of general sequencing abilities (single factor), or simple sequencing and complex sequencing/shifting (two-factors).

As discussed, studies examining the convergent and discriminant validity have found that, like the TMT, the CTMT simple and complex sequencing factors correlate significantly with perceptual organizational ability, processing speed, and motor function (Allen et al, 2009; Reynolds, 2002; Smith et al., 2008). When these same correlations are considered in children with TBI, these abilities are more highly correlated with the complex sequencing factor (Allen et al., 2009). These findings demonstrate that the primary cognitive abilities assessed by the CTMT are perceptual organizational ability, processing speed, and motor function. Findings also suggest trails 4 and 5 also command the most working memory, inhibition, and executive functions.

Likewise, when the factorial validity of the CTMT is examined, findings have suggested that Trail 1 and Trail 5 assess different abilities. Specifically, Trail 1 has been shown to assess “sequencing” or “simple sequencing”, while Trail 5 assesses “shifting” or “complex sequencing” (Atkinson & Ryan, 2008; Reynolds, 2002; Riccio et al., 2011).

As the research reviewed supports, CTMT scores are sensitive to brain dysfunction. The CTMT has also been shown to correlate with other neuropsychological tests, however the pattern of performance of children with brain dysfunction suggests a different factor structure of the CTMT for clinical groups than the factor structure found in the standardization sample. As discussed, research has explored the neurocognitive abilities required to efficiently complete the TMT-C for clinical populations (Thaler et al., 2012). However, given that the factor structure differs for clinical and non-clinical groups, research is needed to determine the neurocognitive abilities required to perform well on the CTMT in clinical groups.

The purpose of the current study is to further investigate the factor scores of the CTMT to determine similarities and differences between the factors scores in the abilities they assess. This information is important because it will aid in the clinical interpretation of the test and provide insight into the cognitive abilities and associated brain regions that are impaired following injury. For this study we will use a mixed sample of children with various forms of brain dysfunction and also examine performance in a select subgroup of children who have sustained TBI. TBI is selected for separate analysis because a significant number (over one million) of children suffer traumatic brain injury each year in the United States (World Health Organization, 2005). Of those children that suffer a TBI, roughly 125,000 will become permanently disabled, which can create a

significant financial burden, such that the life-time cost for each individual is estimated at over four million (Faul et al., 2010). Some deficits that result from TBI can lead to an individual being classified as disabled include, motor, sensory and neurocognitive deficits. Of the neurocognitive deficits that often follow TBI, slowed information processing, attention and concentration deficits are observed regularly (Felmingham, Baguley, & Green, 2004).

The deficits that often follow TBI make rehabilitation and educational placement more challenging (Kraemer & Blancher, 1997; Lowther & Mayfield, 2004). For this reason, clinicians must be able to assess the deficits and cognitive abilities in children and adolescents with TBI using reliable instrument. While test creators often provide ample support regarding the reliability and validity of the assessment instruments they create, the reliability of those measures are often not tested in clinical populations.

Based on review of the current literature, the current study will examine cognitive abilities that predict CTMT performance using regression analyses. CTMT factor scores will be examined in the current study given literature supporting their usefulness. It is hypothesized that:

1. The simple sequencing Factor will be predicted by tests that assess working sustained attention (CPT), motor function (Grooved Peg Board), and processing speed (Digit Symbol/Coding and Symbol Search).
2. The complex sequencing factor will be predicted by working memory (digit span- digits forward and backward) and processing speed (Digit Symbol/Coding and Symbol Search).

### Participants

Participants included 98 children who had neurodevelopmental or acquired brain dysfunction. They were on average 14.7 years old ( $sd = 2.2$ ), 65.3% were male, and Full Scale IQ was 87.5 ( $sd = 14.4$ ). Causes of brain dysfunction among the sample include traumatic brain injury ( $n = 71$ ), anoxia ( $n = 3$ ), ADHD-C ( $n = 1$ ), AVM/Stroke ( $n = 10$ ), learning disorder ( $n = 6$ ), and other diagnoses ( $n = 6$ ). Other demographic data is included in Table 1. Because a subgroup of children with TBI was examined separately from the entire group in the analyses, demographic data is also reported for the 71 children with TBI. As can be seen from the table, compared to the overall group, the TBI group was on average 15.1 years old ( $sd = 2.1$ ), 67.6% were male, and Full Scale IQ was 89.9 ( $sd = 15.7$ ).

Participants were selected from a database that contained approximately 850 children and adolescents between the ages of 5 and 19 who were referred for neuropsychological evaluation at a pediatric specialty hospital due to brain dysfunction. All assessments were administered according to standardized procedures by a pediatric neuropsychologist or clinical psychology doctoral candidate under supervision of the neuropsychologist. Children were individually assessed in one session in a quiet room within a rehabilitation hospital setting. Approximately 60% of the children are male, and 67% are Caucasian, 22% Hispanic/Latino, 9% African American and 2% other ethnicities. Children were selected for inclusion in the current study if they were administered the CTMT as part of the neuropsychological evaluation, were also

administered other tests used in the study (CPT, Digit Span, Grooved Pegboard, Coding), and had brain dysfunction confirmed by appropriate laboratory, neuroimaging, and examinational findings.

Most of the children selected had traumatic brain injury (72.4%). For those with traumatic brain injury, the most common cause of injury was being a passenger in a motor vehicle accident (49.3%), fall (15.5%), struck by a motor vehicle (12.7%), 4-wheeler accident (11.3%), gunshot (2.8%), skiing accident (1.4%), and other (7.0%). Median Glasgow Coma Scale (GCS) scores collected on children with TBI were 6 (mean = 6.4), suggesting that these children sustained moderate to severe brain injuries. The GCS was typically collected by first responders to the accident site or completed on admission to the hospital emergency room. The proposed study was conducted in accordance with local institutional review board policies.

## **Measures**

The Comprehensive Trail Making Test, Digit Symbol/Coding and Symbol Search subtests from the Wechsler Intelligence Scales, Digit Forward and Digit Backwards Subtests from the Test of Memory and Learning, Conners' Continuous Performance Test-II, and the Grooved Pegboard Test were used to assess executive function, motor speed, processing speed, sustained attention and working memory. These tests were selected because they each assess cognitive abilities identified in the literature that contribute to performance on trail making tests such as the CTMT.

**Comprehensive Trail Making Test.** The Comprehensive Trail Making Test (CTMT; Reynolds, 2002) is an expanded version of the TMT. The CTMT includes 5 trails that allow for the evaluation of specific cognitive abilities including, sustained

attention, sequencing, visual-spatial scanning, and cognitive flexibility (CTMT; Reynolds, 2002). The CTMT trails typically increase in complexity and difficulty level in order to isolate different cognitive abilities that contribute to performance. Trail 1 contains 25 plain black circles numbered 1 through 25. Examinees are asked to connect these circles in numerical order beginning at number 1 and ending at number 25. Trail 2 also includes the 25 numbered circles and 29 blank distractor circles. Examinees must connect just the numbered circles while avoiding the distractors. Trail 3 includes 25 target circles as well as a total of 32 distractor circles (13 empty circles and 19 circles containing line drawings). As in trail 2, the examinee must connect the target circles, while avoiding the distractors. Trail 4 includes 20 circles with numbers written as Arabic numerals (e.g. 1, 2, 3) as well as numbers spelled out as words (e.g. five) and the examinees must connect the 20 circles in numerical order. Lastly, Trail 5 contains 25 circles, 1 through 11 and A through L. The examinee must connect the circles by starting at number 1 and alternate between numbers and letters in both numerical and alphabetical order (e.g. 1-A-2-B). The raw score for each trail is the time in seconds it takes for the examinee to complete the trail.

The CTMT was designed and normed for individuals between 8 and 89 years of age. The CTMT was standardized on a sample of 1,664 individuals ages 11-74 with demographic characteristics matched to the 2000 U.S. Census data. Subsequently, norms were extended to allow evaluation of children as young as 8 years old and adults up to 89-years old. Normative data is used to convert raw scores to standardized scores (t-scores) for each trail and a composite score may also be calculated which reflects performance across all 5 trails. The reliability of individual trail scores and the

composite score are high, with the composite score having a reliability coefficient of .90 or higher depending on the specific age group. Information presented in the test manual and subsequent research studies of brain-injured populations suggest the CTMT individual trail and composite scores are sensitive to brain dysfunction (Allen, Thaler, Barchard, et al., 2012; Allen, Thaler, Ringdahl et al., 2012).

**Wechsler Intelligence Scales.** Participants completed either the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV; Wechsler 2003) or the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV; Wechsler, 2008) to measure of overall intellectual ability. Full-scale IQ (FSIQ) scores are calculated from performance on the ten core subtests. Scores from Digit Symbol—Coding and Symbol Search were used for the purposes of this study. Scaled scores for Digit Symbol—Coding and Symbol Search were averaged and used as a composite score for processing speed (Allen et al., 2010; Donders and Janke, 2008). The Wechsler Intelligence Scales are the most commonly used measures to assess intelligence in children and adults. They are normed on large, nationally representative samples. Digit Symbol-Coding and Symbol Search subtests on the WISC-IV and WAIS-IV were developed to assess processing speed and have reliabilities of .85 and .79 respectively (Wechsler 2003, 2008). Extensive research documents the validity of Digit Symbol-Coding and Symbol Search subtest scores in clinical populations, suggesting that these subtests are the most sensitive of the Wechsler scale subtests to the effect of brain dysfunction on cognition. For the current study, some children were administered the WISC-IV while other the WAIS-IV, depending on their age when evaluated. Digit Symbol-Coding and Symbol Search scores from the WISC-IV and WAIS-IV were combined for analytic purposes, given that these

subtests on the adult and child versions of the Wechsler scales were designed to assess the same cognitive abilities in adults and children, the test stimuli and administration instructions are very similar, and research suggests that the subtests have similar psychometric properties, including sensitivity to brain damage.

**Test of Memory and Learning.** The Test of Memory and Learning (TOMAL; Reynolds & Bigler, 1994) assesses verbal and non-verbal short term and long-term memory and learning. The TOMAL can also be used to assess attention span using the Digits Forward (DF) and Letters Forward (LF) subtests. The DF and LF subtests require examinees to repeat number or letter series that are presented orally by the examiner. Working memory was assessed with Digits Backward (DB) and Letters Backward (LB) subtests of the TOMAL. The DB and LB subtests require that the examinee repeat in reverse order number or letter strings presented orally by the examiner. The distinction between forward and backward was selected due to backward span tasks generally being thought of as requiring greater working memory load relative to forward span tasks (Reynolds, 1997). For the analyses, two composites were developed by taking the average of the DF and LF subtests to reflect attention span, and the average of the DB and LB subtests to reflect working memory.

**Conners' Continuous Performance Test-II.** The Continuous Performance Test-II (CPT-II; Conners, 2000) is a computerized measure of attention that examinees are asked to press a button in response to a target stimuli. The CPT-II has been primarily thought of as measuring sustained attention, however recent studies of the factor structure and validity have shown that it assesses other sub-processes of attention, such as focused and sustained attention, vigilance, and hyperactivity/impulsivity (Egeland & Kovalik-

Gran, 2010a, 2010b). The current study uses Hyperactivity/Impulsivity and Sustained Attention sub-processes. Based on the factors identified by Egeland and Kovalik-Gran (2010a), a Hyperactivity/Impulsivity composite was calculated by averaging the t-scores of CPT Commission Errors, a measure of responses to distractors, and Hit Reaction Time, a measure of the average pace of correct response. The Sustained Attention composite score was calculated by averaging the t-scores for Hit Reaction Time by Block Change, a measure of changes in reaction times and Standard Error by Block, a measure of response consistency.

**Grooved Pegboard Test.** Motor speed and manual dexterity were assessed using the Grooved Pegboard Test (Lafayette Grooved Pegboard; Lafayette Instrument Company 2002). The pegboard contains 25 holes that are positioned randomly, and 25 pegs that must be rotated in order to be inserted. Participants must fill the holes with the pegs in order, as fast as they can, until the entire board is complete. Raw scores were based on the amount of time required for the examinee to place all the pegs in the board with the dominant and non-dominant hands. Raw scores were then converted to t-scores using normative data contained in the test manual.

## **Statistical Analyses**

### **Data Entry and Screening**

Prior to evaluating the main hypothesis, preliminary analyses were conducted. First, neuropsychological test data was inspected to ensure the assumptions of multiple regression were met, including normality, linearity, multicollinearity and homoscedasticity. Next, frequency distributions and scatterplots were used to examine skewness and kurtosis. If variables were not normally distributed, then transformations

were conducted to improve normality based on recommendations of Tabachnik and Fidell (2012). If scores were more than 2 SD from the mean, they were considered outliers. Outliers were adjusted using standard procedures (Tabachnik & Fidell, 2012) to minimize the influence these scores had on measures of central tendency.

Additionally, principal components analysis with varimax rotation was used to examine the factor structure of the predictor variables. In these analyses, four factors were extracted based on prior studies of these measures indicating four underlying factors.

### **Data Analyses to Test of Main Hypotheses**

Multiple regression analyses were the primary analytic approach in order to examine the study hypotheses. In these analyses, CTMT factor scores were predicted using the scores from the other neuropsychological tests. Two sets of regressions were accomplished. The first set included the entire sample of 98 children and consisted of four regression analyses. The first and second regression analyses used the CTMT factors scores identified in the standardization sample as the dependent variables. For these factor scores, CTMT trials 1, 2 and 3 made up the Simple Sequencing factor, and trials 4 and 5 made up the Complex Sequencing factor. The third and fourth regression analyses used the CTMT factor scores identified in TBI samples (e.g., Allen et al., 2012) as the dependent variables. For these factor scores, CTMT trials 1 and 2 made up the Simple Sequencing factor, and trials 3, 4 and 5 made up the Complex Sequencing factor. The second set of regression analyses was identical to the first set but included only the 71 children who sustained TBI. The 71 participants with TBI were analyzed separately from the entire sample in order to determine whether or not the results of the regression

analyses generalized from a sample with a specific diagnosis (TBI) to a more heterogeneous sample. The clinical and normative sample CTMT factors structures were also examined separately in order to determine what effect, if any, differences noted in factor structure for clinical populations influenced abilities assessed by the factors.

For hypothesis 1, it is expected that the results of the regression will indicate that sustained attention, motor function, and processing speed are significant predictors of the Simple Sequencing factor. With regard to hypothesis 2, it is expected that the results of the regression will indicate that working memory and processing speed are significant predictors of the Complex Sequencing factor. It is anticipated that these results will be consistent when the TBI sample and the entire sample are examined. Also, the hypotheses are specific to those analyses that involve the factors scores derived based on the CTMT factors structure identified in clinical populations (Simple Sequencing = Trials 1, 2, and 3; Complex Sequencing = Trials 4 and 5). No specific hypotheses were made regarding results of analyses examining factor scores derived based on the standardization sample factor analysis reported in the CTMT test manual although one might expect comparable results to those for the clinical groups.

## Chapter 4

### Results

Skewness and kurtosis of the data were examined and Grooved Pegboard scores were skewed, so to normalize the distribution, a log transformation was performed. All other data were within acceptable limits of  $< 1$  (skewness) and  $< 1.5$  (kurtosis) and therefore considered normally distributed.

#### **Principal Components Analyses**

Results of the PCA examining the factor structure of the predictor variable is presented in Table 3. When four factors were specified, predictor variables loaded on the factors as expected based on prior factor analytic studies of these measures (e.g., Park, Allen, Barney, Ringdahl & Mayfield, 2009). These four factors accounted for 76.5 percent of the variance. As can be seen from Table 3, the CPT scores loaded together on a factor representing Sustained Attention, the grooved pegboard variables loaded on a factor assessing motor speed, the digit span scores loaded on a factor reflecting working memory, and the Symbol Search and Coding subtests loaded on a factor assessing processing speed. Given the results of the PCA, composite scores were developed for the Sustained Attention, Working Memory, and Processing Speed factors by averaging performance of the measure loading on each factor (e.g. the Processing Speed composite score was the average of the Symbol Search and Coding subtest scores). Because 10 individuals did not complete the Grooved Pegboard with the nondominant hand, the dominant hand performance was used as the index of motor function. These scores were used in the regression analyses.

## **Correlational Analysis**

Correlations were performed between the composite predictor scores and the CTMT simple and complex sequencing factor scores to examine significant relationships. Correlations were performed first using the CTMT factor structure found in the standardization sample and then again using the CTMT factor structure found in the clinical sample. These correlations were calculated for the overall group of participants with brain dysfunction as well as the TBI subgroup. For the overall group, the Simple Sequencing factor was significantly correlated with Processing Speed, Motor (grooved pegboard), Hyperactivity/impulsivity, and Working Memory for both factor structures. Likewise, the Complex Sequencing factor was significantly correlated with Processing Speed, Motor (grooved pegboard), Hyperactivity/impulsivity, and Working Memory for both factor structures. Similar results were obtained when the participants with TBI were examined separately with the exception that the simple sequencing factors were not significantly correlated with the Working Memory composite, which may have resulted from the reduced sample size in the TBI group ( $n=71$ ) compared to the overall group ( $n=98$ ). Results are presented in Table 4.

## **Regression Analysis**

Comparable regression analyses were completed for the entire sample and for the TBI subgroup. These analyses included examination of predictors for the simple sequencing and complex sequencing factors based on the factor solution for the normative sample and the factor solution obtained for individuals with TBI. A summary of the results of these analyses is included in Table 5.

### Analyses for entire sample

Two multiple regressions were performed to predict CTMT Simple Sequencing and Complex Sequencing factor scores based on the factor analytic results for the standardization sample. The predictor variables in these regression analyses were the composite scores previously described. For the Simple Sequencing factor, the model was significant ( $R^2 = .52$ , adjusted  $R^2 = .51$ ,  $p < .001$ ). The Processing Speed composite ( $t = 6.89$ ,  $p < .001$ ) and Motor Function score ( $t = 3.71$ ,  $p < .001$ ) were retained in the model. Higher scores on the Processing and Motor Function were associated with better performance on the Simple Sequencing factor. For the Complex Sequencing factor, the model was significant ( $R^2 = .52$ , adjusted  $R^2 = .50$ ,  $p < .01$ ). Predictors retained in the model included the Processing Speed composite ( $t = 5.45$ ,  $p < .001$ ), Motor Function score ( $t = 3.54$ ,  $p < .001$ ), and the Working Memory composite ( $t = 3.15$ ,  $p < .01$ ). Higher scores on these predictors were associated with better performance on the Complex Sequencing factor.

Two multiple regressions were also performed to predict CTMT Simple Sequencing and Complex Sequencing factor scores based on the factor analytic results identified in children with brain dysfunction. The predictor variables in these regression analyses were the same as those used in the prior regression analyses. For the Simple Sequencing factor, the model was significant ( $R^2 = .48$ , adjusted  $R^2 = .47$ ,  $p < .001$ ). Predictors retained in the model included the Processing Speed composite ( $t = 6.18$ ,  $p < .001$ ) and Motor Function score ( $t = 3.67$ ,  $p < .001$ ). For the Complex Sequencing factor, the model was significant ( $R^2 = .54$ , adjusted  $R^2 = .52$ ,  $p < .001$ ). Predictors retained in the model included the Processing Speed composite ( $t = 6.06$ ,  $p < .001$ ),

Motor Function score ( $t = 3.41, p < .001$ ), and the Working Memory composite ( $t = 2.90, p < .01$ ). For both regression analyses, higher scores on the predictors were associated with better performance on the Complex Sequencing factor.

### **Analyses for TBI subgroup**

A sub-group of participants with TBI were then examined using the same statistical approach. Two multiple regressions were performed to predict CTMT Simple Sequencing and Complex Sequencing factor scores for based on the factor analytic results for the standardization sample. The predictor variables in these regression analyses were the composite scores used in the previous analyses. For the Simple Sequencing factor, the model was significant ( $R^2 = .47$ , adjusted  $R^2 = .46, p < .001$ ). The Processing Speed composite ( $t = 4.98, p < .001$ ) and Motor Function score ( $t = 3.68, p < .001$ ) were retained in the model. Higher scores on the Processing Speed and Motor Function were associated with better performance on the Simple Sequencing factor. For the Complex Sequencing factor, the model was significant ( $R^2 = .53$ , adjusted  $R^2 = .51, p < .05$ ). Predictors retained in the model included the Processing Speed composite ( $t = 4.47, p < .001$ ), Motor Function score ( $t = 3.76, p < .001$ ), and the Sustained Attention composite ( $t = -2.04, p < .05$ ). Higher scores on Processing Speed and Motor Function were associated with better performance on the complex sequencing factor, while lower scores on the Sustained Attention composite was associated with better performance on the complex sequencing factor, which was anticipated given that lower scores on Sustained Attention are associated with better performance.

Two multiple regressions were also performed to predict CTMT Simple Sequencing and Complex Sequencing factor scores, for the TBI group, based on the

factor analytic results identified in children with brain injuries. The predictor variables in these regression analyses were the composite scores discussed previously. For the Simple Sequencing factor, the model was significant ( $R^2 = .46$ , adjusted  $R^2 = .44$ ,  $p < .001$ ). The Processing Speed composite ( $t = 4.57$ ,  $p < .001$ ) and Motor Function score ( $t = 3.92$ ,  $p < .001$ ) were retained in the model. Higher scores on the Processing Speed and Motor Function were associated with better performance on the Simple Sequencing factor. For the Complex Sequencing factor, the model was significant ( $R^2 = .48$ , adjusted  $R^2 = .46$ ,  $p < .001$ ). Predictors retained in the model included the Processing Speed composite ( $t = 5.33$ ,  $p < .001$ ), and Motor Function score ( $t = 3.45$ ,  $p < .001$ ). For both regression analyses, higher scores on the predictors were associated with better performance on the complex sequencing factor.

## Chapter 5

### Discussion

These findings shed light on the neurocognitive correlates that underlie performance on the CTMT in children with brain dysfunction. Limited information is available regarding the application of the CTMT in clinical populations, and the results of the current study aid in establishing the validity of the CTMT in clinical populations and more specifically in children that have sustained a TBI. Furthermore, as a complex task, multiple cognitive abilities are required for its completion and impairment of any one will negatively impact performance. While there is abundant evidence supporting the sensitivity of trail making tests to various forms of brain damage, much less information is available that would explain how the unique patterns of cognitive deficits associated with various forms of neurological injury predicts performance on the trail making test. The current investigation examined these matters and based on prior research it was hypothesized that for the CTMT, Simple Sequencing and Complex Sequencing factors would be predicted by overlapping and unique cognitive abilities. These predictions were examined for two different factors solutions for the CTMT, one derived from normal controls and the other from children with TBI, as well as for a mixed clinical group with various neurological disorders and a homogeneous group composed of individuals with TBI.

Results indicated that Simple Sequencing factor scores were predicted by Processing Speed and Motor Function. This was true when the Simple Sequencing factor score was based on the factor structure found in clinical population or on the factor structure found in standardization sample. Furthermore, Processing Speed and Motor

Function contributed significantly to predicting performance on the Simple Sequencing for the overall sample as well as the TBI sub-group. It was initially hypothesized that in addition to Processing Speed and Motor function, the Simple Sequencing factor would be predicted by the Sustained Attention although the results of the current study did not support the role of sustained Attention as a significant predictor in the regressions analysis. However, these results should not be taken to mean that sustained attention is not required for adequate performance on the CTMT simple sequencing as initially predicted, for the following reasons. As Table 4 indicates, correlational analysis indicates that Sustained Attention was significantly correlated with the simple sequencing factor ( $r = -.27$  total sample;  $r = -.36$  TBI sample). It was also significantly correlated with the Processing Speed composite ( $r = -.41$  total sample;  $r = -.38$  TBI sample) (see Table 6). These analysis suggest that while sustained attention is associated with simple sequencing ability, its variance in the regression model is accounted for by the Processing Speed composite score and so it is not included as a final predictor in any of the models. This interpretation would also explain why prior studies have found that processing speed, but not sustained attention, is a significant predictor of simple sequencing (e.g., Thaler et al., 2012). Based on these results the CTMT simple sequencing score best reflect an individual's ability to perform tasks quickly (Processing Speed) and efficiently and perform fine motor task speedily (Motor Function), and these predictors appear consistent across factors structures and clinical group.

For the Complex Sequencing factor the Working Memory Composite was a significant predictor along with the Motor and Processing Speed composites. The findings support the second hypothesis that Working Memory and Processing Speed

predict performance on complex sequencing when using both the factor structure found in clinical population and when using the factor structure found in standardization sample for the overall group. Notably, there were differences between the abilities that predicted performance for the overall group and the TBI sub-group on the Complex Sequencing factor. Specifically, for the overall sample, in addition to the hypothesized predictors, Motor Function was also found to significantly predict performance on Complex Sequencing both when using the factor structure found in clinical population and when using the factor structure found in standardization sample.

In contrast, the significant predictors for Complex Sequencing for the TBI sub-group included the hypothesized Working Memory and Processing Speed composites, as well as the Sustained Attention composite when the factor structure found in standardization sample was used. However, when the factor structure found in clinical population was used, the Sustained Attention composite was no longer a significant predictor of performance on the Complex Sequencing factor. Difference between the regression models for the TBI subgroup and overall group could not be directly investigated but involved decreased predictive power of working memory in the TBI subgroup and possibly an increased contribution of sustained attention. Examination of the correlations between the composite scores and the CTMT factors do show a pattern of higher working memory vs. sustained attention correlations with complex sequencing in the overall group, and the opposite pattern when the TBI subgroup is examined separately (See Table 4). In contrast, correlations among the predictor scores appeared relatively consistent across the overall group and TBI subgroup (Table 6). It may be then that complex sequencing relies less on working memory and more on sustained attention in

TBI than in more general clinical populations, although differences in sample size and group characteristics (age, sex, etc.) could also be contributing to the variability in models produced by the regression analyses for the groups.

Considering the simple and complex sequencing finding together, Processing Speed was found to be a significant predictor for both Simple and Complex Sequencing factors. Processing speed deficits are frequently observed in individuals with a brain dysfunction, and more specifically in patients with a TBI (Donders & Minnema, 2004). Furthermore, research has shown there to be a dose-response relationship between an individuals processing speed and the severity of their injuries (Catroppa & Anderson, 2003; Sigurdardottir et al., 2015). The results of the current study support that performance on both the Simple and Complex Sequencing factors of the CTMT is mediated by Processing Speed as well as the use of the CTMT in estimating overall severity of impairment over the recovery process.

Motor function was also found to be a significant predictor for both Simple and Complex Sequencing factors. This was expected given the motor component of the task. While impairments in motor function are not always seen in individuals that have brain dysfunction, impairments in motor function would be expected if an individuals has a neurological condition that is associated with motor function or has sustained a TBI that affects motor regions of the brain. In terms of clinical utility, the results suggest that if an individual does demonstrated impairments in motor function, it is expected they will perform worse on both Simple and Complex Sequencing factors.

Working Memory's role in predicting complex but not simple sequencing ability was also anticipated given the higher cognitive demands and more complex nature of the

CTMT complex sequencing task, particularly when the overall group was examined. However Working Memory did not predict performance for either factor in the TBI group. This was of some surprise, given that Working Memory has been shown to be impaired in individuals that have sustained a TBI (Vallat-Azouvi, Weber, Legrand, & Azouvi, 2007). While Working Memory was not a significant predictor for Complex Sequencing in the TBI subgroup, Sustained Attention was, although only when the factor structure found in standardization sample was used. When the factor structure found in clinical populations was used, Sustained Attention no longer significantly predicted performance on the Complex Sequencing factor. It is not clear whether variability in working memory ability in predicting complex sequencing is the result of inherent differences between the overall group and the TBI subgroup, or if the reduced sample size affected the model.

While the findings of the current study are useful in understanding the neurocognitive correlates that underlie performance on the CTMT in children that have brain dysfunction, there are limitations that should be discussed. The current study uses a mixed sample of children with brain dysfunction, and a selected subgroup that have sustained a TBI. While information is known about the overall severity of the injuries, corroborating neuroimaging was not available, and therefore we are unable to make statements regarding specific brain regions affected by the injuries. Additionally, CTMT performance may be mediated by additional abilities not considered by the current evaluation. Future research should include additional predictors, as well as more specific details regarding localization of brain dysfunction in order to better understand the differential effects of those factors on CTMT performance.

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Appendix: Tables

Table 1

*Demographic and clinical information of the sample*

Variable	Overall Sample (n=98)		TBI Sample (n=71)		“Other” Sample (n=27)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	14.7	2.2	15.1	2.1	13.47	1.94
WISC-IV FSIQ	87.5	14.4	89.9	15.7	82.18	12.00
			Median (Mean)	SD		
Glasgow Coma Score	--	--	6 (6.6)	3.62	--	--
	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency
Gender						
Male	65.3	64	67.6	48	59.3	16
Female	34.7	34	32.4	23	40.7	11
Ethnicity						
Caucasian	52.0	51	53.5	38	48.1	13
Hispanic/Latino	22.4	22	19.7	14	14.8	8
African American	16.3	16	16.9	12	29.6	4
Other	1.0	1	1.4	1	--	0
Diagnosis						
TBI	72.4	71	100.0	71	--	--
Anoxia	3.1	3	--	--	11.1	3
ADHD	1.0	1	--	--	3.7	1
AVM/Stroke	10.2	10	--	--	37.0	10
Learning Disorder	6.1	6	--	--	22.2	6
Other	6.1	6	--	--	22.2	6
Comorbid Diagnoses						
ADHD	1.0	1	1.4	1	0	0
Seizure Disorder	1.0	1	0	0	3.7	1
Eating Disorder	2.0	2	4.2	3	0	0
Learning Disorder	1.0	1	0	0	3.7	1
Cause of TBI						
Motor Vehicle Accident	--	--	49.3	35	--	--
Pedestrian Struck by car	--	--	12.7	9	--	--
Gunshot	--	--	2.8	2	--	--
Fall	--	--	15.5	11	--	--
4-Wheeler Accident	--	--	11.3	8	--	--
Skiing Accident	--	--	1.4	1	--	--
Other	--	--	5.6	4	--	--

Note. WISC-IV FSIQ = Wechsler Intelligence Scale for Children-Fourth Edition, Full-Scale IQ; TBI =Traumatic Brain Injury; AVM = Arteriovenous Malformation

Table 2

*Mean and standard deviation for the CTMT variables, factors, and predictor composites*

Variable	Overall Sample (n=98)		TBI Sample (n=71)	
	Mean	SD	Mean	SD
CTMT 1	38.50	13.76	38.55	13.98
CTMT 2	39.01	13.42	39.54	13.03
CTMT 3	38.60	13.12	39.17	12.22
CTMT 4	38.12	13.78	38.21	13.56
CTMT 5	39.85	11.11	40.07	10.84
CTMT COM	37.72	11.69	37.91	11.38
SS TBI	38.76	12.72	39.04	12.57
CS TBI	38.86	11.12	39.15	10.65
SS NS	38.70	11.91	39.08	11.56
CS NS	38.98	11.23	39.14	10.83
PS	6.92	2.32	7.17	2.27
WM	7.41	1.96	7.50	1.99
SA	51.63	6.35	51.42	5.52
MF	36.10	13.02	36.96	13.42

*Note. CTMT 1-5 = Comprehensive Trail Making Test trial 1-5; CTMT COM = Comprehensive Trail Making Test Composite Score; SS TBI = Simple Sequencing Factor using the factor structure found in clinical population; CS TBI = Complex Sequencing Factor using the factor structure found in clinical population; SS NS = Simple Sequencing Factor using the factor structure found standardization factor structure; CS NS = Complex Sequencing Factor using the factor structure found standardization factor structure; PS = Processing Speed, WM = Working Memory, SA = Sustained Attention, MF = Motor Function.*

Table 3

*Principal Components Analyses*

Predictor	Sustained Attention	Motor Functioning	Working Memory	Processing Speed
SA	<b>.86</b>	-.05	-.16	-.05
HI	<b>.82</b>	.18	-.08	-.20
GPD	.17	<b>.87</b>	-.16	-.04
GPN	-.06	<b>.75</b>	-.01	-.39
FS	-.15	-.17	<b>.84</b>	-.11
BS	-.06	.02	<b>.81</b>	.27
SS	-.10	-.14	.22	<b>.84</b>
CD	-.40	-.40	-.16	<b>.65</b>
Eigenvalue	2.83	1.38	1.17	.74
% Variance	35.34	17.25	14.59	9.29

*Note.* SA = Sustained Attention, HI = Hyperactivity/Impulsivity, GPD = Grooved Pegboard Dominant hand, GPN = Grooved Pegboard Non-Dominant hand, FS = Forward Span, BS = Backward Span, SS = Symbol Search, CD = Coding. Correlations in bold indicate the predictor variables loading on each factor.

Table 4

*Correlations between composite predictor scores and CTMT simple and complex sequencing factors*

CTMT Factor Score	Predictor Composite Score			
	PS	WM	SA	MF
Total Sample ( <i>n</i> =98)				
SS TBI	.63**	.30**	-.27**	.52**
CS TBI	.65**	.40**	-.30**	.52**
SS NS	.67**	.33**	-.28**	.52**
CS NS	.62**	.41**	-.30**	.52**
TBI Sample ( <i>n</i> =71)				
SS TBI	.58**	.22	-.35**	-.25*
CS TBI	.62**	.28*	-.38**	-.36**
SS NS	.60**	.23	-.37**	-.25*
CS NS	.63**	.29*	-.38**	-.42**

*Note.* PS = Processing Speed, WM = Working Memory, SA = Sustained Attention, MF = Motor Function; CTMT = Comprehensive Trail Making Test; TBI = Traumatic Brain Injury; SS TBI = Simple Sequencing Factor using the factor structure found in clinical population; CS TBI = Complex Sequencing Factor using the factor structure found in clinical population; SS NS = Simple Sequencing Factor using the factor structure found standardization factor structure; CS NS = Complex Sequencing Factor using the factor structure found standardization factor structure

Table 5

*Results of regression analyses using factor solution for the normative sample and the factor solution obtained for individuals with TBI. Scores listed are t-scores*

Predictor	Factor Score			
	SS NS	CS NS	SS TBI	CS TBI
Overall Group				
WM	1.77	<b>3.15</b>	1.46	<b>2.90</b>
PS	<b>6.89</b>	<b>5.45</b>	<b>6.18</b>	<b>6.06</b>
MF	<b>3.71</b>	<b>3.54</b>	<b>3.67</b>	<b>3.41</b>
SA	-0.05	-0.03	-0.06	0.13
TBI Subgroup				
WM	0.85	1.19	0.65	1.42
PS	<b>4.98</b>	<b>4.47</b>	<b>4.57</b>	<b>5.33</b>
MF	<b>3.68</b>	<b>3.76</b>	<b>3.92</b>	<b>3.45</b>
SA	0.86	<b>-2.04</b>	-0.01	-1.19

*Note.* PS = Processing Speed, WM = Working Memory, SA = Sustained Attention, MF = Motor Function; TBI = Traumatic Brain Injury; SS TBI = Simple Sequencing Factor using the factor structure found in clinical population; CS TBI = Complex Sequencing Factor using the factor structure found in clinical population; SS NS = Simple Sequencing Factor using the factor structure found standardization factor structure; CS NS = Complex Sequencing Factor using the factor structure found standardization factor structure. Scores listed are t-scores. Scores in bold are those that were significant predictors for their respective factor score.

Table 6

*Correlations between predictor scores for the overall group (n=98, above diagonal) and TBI subgroup (n = 71, below diagonal).*

	PS	WM	SA	MF
PS	--	.27**	-.41**	.42**
WM	.15	--	-.29**	.21*
SA	-.38**	-.23	--	-.19
MF	.37**	.26*	-.22	--

*Note.* PS = Processing Speed, WM = Working Memory, SA = Sustained Attention, MF = Motor Function.

Table 7.

*Results of multiple regression analyses performed on the overall group (n=98).*

Variable	Beta	t-score	p-value	Partial	VIF
SS NS					
PS	<b>2.79</b>	<b>6.89</b>	<b>.001</b>	.58	1.22
MF	<b>0.27</b>	<b>3.71</b>	<b>.001</b>	.36	1.22
WM	0.13	1.77	.08	.18	1.09
SA	0.00	-0.05	.96	-.01	1.20
CS NS					
PS	<b>2.13</b>	<b>5.45</b>	<b>.001</b>	0.49	1.27
MF	<b>0.24</b>	<b>3.54</b>	<b>.001</b>	0.34	1.24
WM	<b>1.35</b>	<b>3.15</b>	<b>.01</b>	0.31	1.09
SA	0.00	-0.03	.97	0.80	1.25
SS TBI					
PS	<b>2.77</b>	<b>6.18</b>	<b>.001</b>	0.54	1.22
MF	<b>0.29</b>	<b>3.67</b>	<b>.001</b>	0.35	1.22
WM	0.11	1.46	.15	0.15	1.09
SA	-0.01	-0.06	.95	-0.01	1.20
CS TB					
PS	<b>2.30</b>	<b>6.06</b>	<b>.001</b>	0.53	1.27
MF	<b>0.23</b>	<b>3.41</b>	<b>.001</b>	0.33	1.24
WM	<b>1.20</b>	<b>2.90</b>	<b>.01</b>	0.29	1.09
SA	0.01	0.13	.90	0.01	0.80

*Note.* PS = Processing Speed, WM = Working Memory, SA = Sustained Attention, MF = Motor Function; TBI = Traumatic Brain Injury; SS TBI = Simple Sequencing Factor using the factor structure found in clinical population; CS TBI = Complex Sequencing Factor using the factor structure found in clinical population; SS NS = Simple Sequencing Factor using the factor structure found standardization factor structure; CS NS = Complex Sequencing Factor using the factor structure found standardization factor structure. Scores in bold are those that were significant predictors for their respective factor score.

Table 8.

*Results of multiple regression analyses performed on the TBI sub-group (n=71).*

Variable	Beta	t-score	p-value	Partial	VIF
SS NS					
PS	<b>2.41</b>	<b>4.98</b>	<b>.001</b>	.52	1.16
MF	<b>0.30</b>	<b>3.68</b>	<b>.001</b>	.41	1.16
WM	0.08	0.85	.40	.10	1.08
SA	0.01	0.09	.93	.01	1.18
CS NS					
PS	<b>2.04</b>	<b>4.47</b>	<b>.001</b>	.48	1.31
MF	<b>0.28</b>	<b>3.76</b>	<b>.001</b>	.42	1.17
WM	0.11	1.19	.24	.15	1.11
SA	<b>-0.36</b>	<b>-2.04</b>	<b>.05</b>	-.24	1.18
SS TBI					
PS	<b>2.43</b>	<b>4.57</b>	<b>.001</b>	.58	1.16
MF	<b>0.35</b>	<b>3.92</b>	<b>.001</b>	.54	1.16
WM	0.06	0.65	.52	.08	1.08
SA	-0.01	-0.06	.96	-.01	1.18
CS TB					
PS	<b>2.36</b>	<b>5.33</b>	<b>.001</b>	.54	1.16
MF	<b>0.26</b>	<b>3.45</b>	<b>.001</b>	.39	1.16
WM	0.13	1.42	.16	.17	1.08
SA	-0.11	-1.19	.24	-.14	1.18

*Note.* PS = Processing Speed, WM = Working Memory, SA = Sustained Attention, MF = Motor Function; TBI = Traumatic Brain Injury; SS TBI = Simple Sequencing Factor using the factor structure found in clinical population; CS TBI = Complex Sequencing Factor using the factor structure found in clinical population; SS NS = Simple Sequencing Factor using the factor structure found standardization factor structure; CS NS = Complex Sequencing Factor using the factor structure found standardization factor structure. Scores in bold are those that were significant predictors for their respective factor score.

Curriculum Vitae

**Abigail Mayfield**

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**Education**

**Doctoral Student in APA-Accredited Clinical Psychology Program** 2013-Present

University of Nevada Las Vegas, Las

Vegas, NV

Advisor: Daniel N. Allen, Ph.D.

**Bachelor of Science in Psychology and Biology**

2011

Texas State University, San Marco, Texas

**Austin Community College**

2006-2009

**Awards and Academic Honors**

**Graduate and Professional Student Association** 2014  
**Research Travel Grant** – UNLV \$800

**Magna Cum Laude**- Texas State University

2011

**Dean's List**- Texas State University

2009-2011

**Certificate of Excellence**- Department of Chemistry  
Texas State University

2010-2011

**Research Experience**

**Neuropsychology Research Program**

Fall 2013–Present

University of Nevada, Las Vegas

**Event Related Potentials (ERP) Laboratory Assistant**

2011-2013

Psychology Department- Texas State University

EEG capping, Administration of study protocol, Data collection

**Event Related Potentials (ERP) Data Processing**

2011-2013

Psychology Department- Texas State University

Data pre-processing, Data processing, Data plotting

## Salivary Analysis Laboratory Assistant

2011-2013

Psychology Department- Texas State University

Sample collection and handling, Sample storage techniques,  
Sample assay techniques

## Manuscripts

**Mayfield, A. R.**, Parke, E. M., Barchard, K. A., Zenisek, R. P., Thaler, N. S., Etcoff, L. M., & Allen, D. N. (2016). Equivalence of mother and father ratings of ADHD in children. *Child neuropsychology*, 1-18.

Parke, E. M., **Mayfield, A. R.**, Barchard, K. A., Thaler, N. S., Etcoff, L. M., & Allen, D. N. (2015). Factor structure of symptom dimensions in attention-deficit/hyperactivity disorder (ADHD).

Ceballos, N., **Mayfield, A.**, & Graham, R. (2015). ERPs to alcohol images among Hispanic and non-Hispanic female college freshmen. *AIMS Neuroscience*, 3(1), 1-21. doi:10.3934/Neuroscience.2016.1.1

## Manuscripts in Preparation

**Abigail R. Mayfield**, Bern G. Lee, Joan W. Mayfield, Daniel N. Allen (in preparation) Neurocognitive Correlates of the Comprehensive Trail Making Test (CTMT) in Children with Neurological Disorders.

## Poster Presentations

NAN 2016: **Mayfield, A.R.**, Lee, B.G., Mayfield, J.W., & Allen, D.N., Neurocognitive Correlates of the Comprehensive Trail Making Test (CTMT) in Children with Neurological Disorders.

NAN 2015: **Mayfield, A.R.**, Ciobanu, C., Etcoff, L., & Allen, D.N., Utility of WISC-IV Short Forms in Attention-Deficit/Hyperactivity Disorder (ADHD)

NAN 2014: **Mayfield, A.R.**, Reyes, A., Mayfield, J.W., & Allen, D.N., Improvement in Executive Function Following Traumatic Brain Injury (TBI) in Children

CNS 2013: **Mayfield, A.R.**, Ceballos, N.A., & Graham, R. Alcohol-related attentional biases in female college freshman: A cross-cultural ERP study. Alcohol-related attentional biases in female college freshman: A cross-cultural ERP study.

CNS 2013: Dodwell, G., **Mayfield, A.R.**, Ceballos, N.A., & Graham, R. Gaze cuing elicited by gazing expressive faces and alcoholic/non-alcoholic targets in social drinkers.

Ceballos, N.A., **Mayfield, A.R.**, Paz, J.M., Vela-Gude, M.L., Graham, R. (2012). A cross-cultural study of automatic and controlled processing of alcohol images in female college freshman. Poster presented at the 52<sup>nd</sup> annual meeting of the Society for Psychophysiological Research, New Orleans, Louisiana. 09/2012.

Graham, R., **Mayfield, A.R.**, & Ceballos, N.A. (2012). A longitudinal cross-cultural study of automatic and controlled processing of alcohol images in female college

freshmen. Paper presented at TM's 1st World Neuroscience Online Conference.  
06/2012

Graham, R., **Mayfield, A.R.**, & Ceballos, N.A. (2012). A longitudinal cross-cultural study of automatic and controlled processing of alcohol images in female college freshmen. Paper presented at TM's 1st World Neuroscience Online Conference.  
06/2012

Reiter, K., **Mayfield, A.R.**, & Graham, R. (2012). Event-Related Potentials to Static and Dynamic Expressive Faces. Health Psychophysiology Lab, Department of Psychology. Poster presented at the Cognitive Neuroscience Society Meeting, Chicago, Illinois. 03/2012.

## **Clinical Training**

**Cleveland Clinic- Lou Ruvo Center for Brain Health** July 2016 – Present  
Multidisciplinary Center Specializing in Degenerative Diseases Supervisors: Justin Miller, Ph.D.  
Sarah Banks, Ph.D.

**Doctoral Practicum Student:** Conducted neuropsychological assessment on patients referred by the neurology team due to suspected neurodegeneration. Patient groups included persons with suspected dementia, history of traumatic brain injury or concussion and acquired neurocognitive disorders. Complete approximately two clinical neuropsychological report per week for these patients.

**Supervision and Didactics:** Didactic training included specific education about neuropsychological correlates of Dementia and other movement disorders of neurocognition. Supervision consisted of group and individual meetings during which report writing and patient care were reviewed. Specific patients were discussed in terms of differential diagnosis and accommodations related to their neuropsychological status.

## **The Center for Applied Neuroscience**

July 2015 – Present

Private neuropsychology practice  
Thomas Kinsora, Ph.D.

Supervisors:

Sharon

Jones-Forrester, Ph.D.

**Doctoral Practicum Student:** Conducted neuropsychological assessment on a broad range of patients across the age span within the civilian and military populations. Patient groups included persons with suspected dementia, history of traumatic brain injury or concussion, neurodevelopmental or acquired neurocognitive disorders, and persons with severe mental illness or learning disabilities. Wrote approximately one clinical neuropsychological report per week for these patients.

**Supervision and Didactics:** Didactic training included specific education about neuropsychological correlates of TBI, PTSD, Dementia, and other disorders of

neurocognition. Supervision consisted of group and individual meetings during which report writing and patient care were reviewed. Specific patients were discussed in terms of differential diagnosis and accommodations related to their neuropsychological status.

**The UNLV Partnership for Research, Assessment, Counseling,  
August 2014–2015  
Therapy and Innovative Clinical Education (PRACTICE)  
Supervisor: Jason Holland, Ph.D.  
University of Nevada, Las Vegas**

**Doctoral Practicum Student:** Provided long-term individual therapy to a caseload of approximately 6 clients per week in an outpatient University affiliated mental health clinic. Theoretical approaches used include CBT, ACT, Problem Solving Therapy and Interpersonal Psychotherapy under the supervision of Jason Holland, PhD

**Supervision and Didactics:** Supervision consisted of weekly individual and group meetings with videotape review as well as weekly practicum seminars, which included didactic, group supervision, and case conference components.

**Psychological Assessment & Testing Clinic (PATC) August 2014–Present  
University of Nevada, Las Vegas Supervisor: Michelle G. Paul, Ph.D.**

**PATC Assessment Coordinator:** Conducted intake and screening interviews for all clients tested through the PATC clinic (approx. 20 per week), coordinated case assignments in accordance with skill-set, training need of assessors, and client need. Duties also included client tracking for all active assessments and waitlist, reviewing clinical records and conducting audits for adherence to protocol and appropriate electronic notation, and creating and mailing intake paperwork for clients.

**Doctoral Practicum Student:** Neuropsychological, psychoeducational, and psychodiagnostic assessments using a flexible battery approach with adults referred from the community in an outpatient University affiliated mental health clinic. Responsibilities also included interviewing, scoring, interpretation, report writing, and providing feedback to clients.

**Supervision:** Supervision included reviewing cases, joint determination of assessment battery and interpretation of results, report revisions, and discussion of feedback.

**Pre-Graduate Clinical Experience**

**Austin Neuropsychology- Psychometrist  
2012-2013  
Administration and scoring of psychometric tests (see technical skills)**

**Austin State Hospital- Clinical Volunteer**  
2010-2011  
Alliance Program Unit Manager and Communications Officer

## Teaching Experience

**Introduction to Psychology (PSY101)**, University of Nevada Las Vegas  
2015

Designed and taught two section of Psychology 101 per semester.  
Duties include lecture, designing assignment and tests, grading students and holding office hours.

**Biology Supplemental Instructor**, Texas State University  
2010

Provided Supplemental Instruction for 300 students in the course “Functional Biology”

## Professional Affiliations

**National Academy of Neuropsychology, Student Affiliate** 2014–Present

**Nevada Psychological Association, Student Affiliate** 2014–Present

## Other Relevant Training

**Health Insurance Privacy and Portability Act (HIPPA) Certification**  
Fall 2014-Present

**The Collaborative IRB Training Initiative (CITI) Program** Fall 2011–Present  
(<http://www.citiprogram.org>).

## Technical Skills

### General

Statistical Analysis Programs (SPSS and Excel), NeuroScan (STIM and SCAN), PC and Mac Operating Systems, Laboratory Techniques including Salivary Analysis Techniques, EEG and ERP Techniques including application of EEG electrodes and operation of NeuroScan software

### Tests Fluent in:

Standardized Administration and scoring of Psychometric Tests including, BASC-2 (PRS, TRS, SRP), Beck Anxiety Inventory, Beck Depression Inventory, Beery-

Buktenica VMI , Boston Naming Test, Brief Psychiatric Rating Scale, CPT-II, CVLT -C , CVLT-II, CTOPP, D-KEFS, Finger Tapping, GORT-4, Grip Strength, Grooved Pegboard, KTEA-II, Lateral Dominance, MMPI-2, NEPSY-II, Rey-Osterrieth Complex Figure, SCAN-3, Token Test, TOWL-4, TOMAL, Trail Making Test A & B, WAIS-IV, WISC-IV, WCST, WMS-IV, Wisconsin Card Sorting Test, and Woodcock-Johnson III Tests of Achievement and Cognitive Abilities