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Auditory Consonant Trigrams: Construct And Criterion Validity Update

Katharine Elizabeth Lindberg

AUDITORY CONSONANT TRIGRAMS: CONSTRUCT AND CRITERION VALIDITY UPDATE

By

Katharine Elizabeth Lindberg

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This dissertation, submitted by Katharine E. Lindberg in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Dr. Joseph Miller, Chairperson

Dr. Thomas Petros, Committee Member

Dr. F. Richard Ferraro, Committee Member

Dr. Alan King, Committee Member

Dr. Lindsay Hines, Committee Member

Dr. Virginia Clinton, Member-At-Large

This dissertation is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

Dr. Chris Nelson
Dean of the School of Graduate Studies

Date

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Katharine E. Lindberg
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ABSTRACT

The Auditory Consonant Trigrams (ACT) has historically been used in research and clinical settings as a measure of working memory ability, though previous research has failed to identify the precise cognitive processes and abilities measured by the task. The ACT total score (ACT T) has been shown to be sensitive to numerous clinical neurological and psychological populations (i.e., TBI, ADHD, MS, MDD). Alternatively, little is known about the ACT perseveration score (ACT P), the current study aimed to identity the ACT T and ACT P's relationships to other neuropsychological measures and their clinical utility within diverse clinical/neurological presentations. In a sample of patients referred for neuropsychological evaluation ($N = 448$), an exploratory factor analysis revealed a 2-factor model accounting for 49.54% of the variance within the sample. The ACT T and ACT P loaded on a factor with measures of higher-order executive functioning accounting for 9.99% of the variance within the sample. Further, the clinical utility of the ACT T and ACT P was found to be limited within the current sample with a trend of the ACT T discriminating the severity of brain damage within TBI, while the ACT P tended to discriminate diagnostic groups. These findings suggest that the ACT scoring methods may be too simplistic to identify subtle cognitive changes in clinical populations.

CHAPTER I

INTRODUCTION

The Brown-Peterson task is an assessment measure used in clinical and experimental settings that require test-takers to maintain information throughout a distractor task (e.g., counting backwards; Brown, 1958; Lezak et al., 2012; Strauss et al., 2006). Brown (1958) created the task to assess memory decay after a brief delay (i.e., immediate memory) while limiting test-takers' ability to rehearse information to be remembered. Distractor tasks, such as the Brown-Peterson task, were shown to decrease recall performance over a delay of up to 20 seconds. This finding suggested that information encoded into short-term memory, though initially accurate, rapidly decays especially in situations where rehearsal is not possible (Peterson & Peterson, 1959). Numerous versions of the Brown-Peterson task have been created and studied, with variations in types of information to be remembered (e.g., letters vs. words), types of delays (e.g., no delay, time only delay, distractor task delay), length of delay, and administration method (e.g., auditory and computer). Despite the longevity of the Brown-Peterson paradigm, numerous researchers have failed to converge on a consensus regarding the precise cognitive processes and abilities measured by the task (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016), though the task is generally administered in clinical settings as a measure of working memory ability (Lezak et al., 2012; Strauss et al., 2006).

One of the most common variations of the Brown-Peterson task used in clinical practice is the Auditory Consonant Trigrams (ACT; Boone et al., 1998; Stuss et al., 1987; Stuss et al., 1988), which requires test-takers to listen to a sequence of three letters (i.e., consonant trigrams; e.g., B-T-G), then immediately begin counting backwards by threes. After some period of counting, the test-takers are asked to recall the previously presented consonant trigram. Although conceptualized and commonly used as a measure of working memory ability, empirical evidence suggests performance on the ACT is highly related to other measures of basic and complex attention, processing speed, working memory, impulsivity, and intelligence (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016). Though the ACT has been ranked one of the top 40 tests used by neuropsychologists to measure attention (Rabin et al., 2005), a consistent relationship between the ACT and other neuropsychological assessment measures, nor a clear understanding of the construct the ACT is thought to measure, has emerged.

Throughout the ACT literature and norming samples, many different versions of the ACT have been used, resulting in difficulty interpreting results across studies. One of the most prevalent differences between these versions of the ACT is in the length of the distractor task (e.g., counting backwards by threes) delay, with some versions using a consistent distractor delay (i.e., 20-seconds for all trials; Mertens et al., 2006) and others having a variable distractor delay (i.e., 3-, 9-, 18-seconds or 9-, 18-, 36-seconds; Boone et al., 1998; Stuss et al., 1987; Stuss et al., 1988). In clinical practice, the 3-, 9-, 18-second and the 9-, 18-, 36-second distractor delay versions are used; however, these distractor delays are not specifically used in any particular age groups (e.g., youth, middle age,

older adult) or clinical populations; rather, use is dependent on the normative comparison sample. In addition to the distractor delay time, some versions require participants to write down the recalled trigrams (Mertens et al., 2006), while most others require the participant to report trigrams verbally (Boone et al., 1998; Stuss et al., 1987; Stuss et al., 1988). Finally, one study (Geurten et al., 2016) used a computerized version of the ACT (see description below) and its comparability to either the verbal or written method is unclear.

The most commonly used ACT in clinical practice is the Stuss and colleagues (1987, 1988) version. Stuss and colleagues (1987) used three consonants (i.e., consonant trigram) for the stimulus followed by the presentation of a 2- or 3-digit number. Participants then immediately began counting backwards out loud by threes from the number presented. After the distractor task (i.e., counting backwards by 3s from the number presented) delay of either 9-, 18-, or 36-seconds, participants were asked to verbally report the stimulus consonants remembered. Five trials of each distractor task delay were administered in random order (i.e., 15 total trials). The score was derived from the number of correct consonants reported by the participant. Stuss and colleagues (1987) normed this ACT version on 60 Canadian individuals, ages 16 to 69, and provided normative data based on either gender and education or age for each of the three distractor delay times. In 1988, Stuss and colleagues extended their normative sample to include 90 Canadian individuals. While, the clinical version of the Stuss and colleagues (1987, 1988) ACT includes five 0-second trials (i.e., with no distractor task) administered consecutively before the 9-, 18-, and 36-second distractor delay trials, these trials were

not added (i.e. to administration but not to scoring) until Stuss and colleagues (1989) examined the ACT's utility in a sample of patients with traumatic brain injury (TBI).

Regarding the clinical utility of the ACT, previous studies have shown the ACT is sensitive to numerous clinical neurological and psychological populations (Anile et al., 2003; Oral et al., 2012; Stuss et al., 1989; Merkley et al., 2013; Shura et al., 2016; Dige & Wik, 2005; Ozakbas et al., 2004), thus the ACT may aid in the detection or identification of these groups in clinical neuropsychological evaluations. More specifically, Stuss and colleagues (1989) found the ACT to be sensitive to cognitive dysfunction in recent mild TBI and more severe TBI. Merkley and colleagues (2013) found, when comparing patients with severe TBI to controls, that the ACT (i.e., Boone et al., 1998 version) showed a moderate effect of the total score discriminating between the two groups' performance. Alternatively, Shura and colleagues (2016) found no difference in ACT total performance between remote (>11 months since injury) mild TBI and no history of mTBI in a sample of veterans, in the context of adequate performance validity. With regard to attention deficit hyperactivity disorder (ADHD), the ACT was found to distinguish between individuals with adult ADHD and control subjects with moderate to large effects (Dige & Wik, 2005). With regards to multiple sclerosis (MS), a study of Turkish patients found significant differences between patients with relapsing-remitting MS and secondary progressive MS, as well as between clinically isolated syndrome and secondary progressive MS on ACT performance, but not between relapsing-remitting MS and clinically isolated syndrome (Ozakbas et al., 2004). With regard to post-traumatic stress disorder (PTSD), Shura and colleagues (2016) found no relationship between the

presence of PTSD in a sample of veterans and ACT total score performance. With regards to major depressive disorder (MDD), both Oral et al. (2012) and Shura et al. (2016) found significantly lower scores for participants with MDD than individuals without MDD. In sum, the ACT total score may aid in differentiating numerous clinical neurological and psychological populations; however, limited research has elucidated the effectiveness of the ACT total score in differentiating clinical presentations from their relevant differential diagnoses. Additionally, no previous studies have evaluated the utility of the ACT perseveration score in clinical neurological and psychological presentations.

Given that the ACT does not require a timed response and is sensitive to disorders with white matter disturbance, some have suggested it may be a desirable measure of executive functioning not confounded by declines in mental speed (Mitrushina et al., 2005). For example, lower scores on other measures of executive function (e.g., Trail Making Test Trial B and Stroop Color Interference) may easily be confounded by slowed information processing speed making interpretation of executive functioning on these tasks difficult (Mitrushina et al., 2005). In order to determine the utility of the ACT in the context of clinical disorders with slowed processing speed, an understanding of the task's relationship to measures of executive functioning, general intellectual ability, and psychomotor speed must first be established (Boone et al., 1998; Shura et al., 2006; Mertens et al., 2006).

In the context of the reported popularity of the ACT in clinical practice (Rabin et al., 2005), relatively few studies have assessed the psychometric properties and construct

validity of the ACT, with the result being an unclear consensus as to what cognitive abilities the ACT measures. In the following paragraphs, studies completed in which the construct validity of the ACT is assessed will be reviewed.

Two previous factor analytic studies have assessed the relationship of ACT performance to test-takers' performance on other neuropsychological assessment measures/cognitive domains; however, these factor structure results are only partially congruent (see Table 1 for a review of previous studies including the ACT). First, Boone and colleagues (1998) aimed to assess validated measures (i.e., Wisconsin Card Sorting Test, WCST [Heaton, 1981]; Stroop Test [Comalli et al., 1962]; Verbal Fluency, FAS version [Boone et al., 1998]; and ACT [Boone et al., 1998]) of frontal lobe function to understand the specific functions assessed, the relationship between tests, and if the measures were redundant in neuropsychological assessment batteries. The sample was comprised of older adults from inpatient, outpatient, and control patients/non-patients groups (Boone et al., 1998). The inpatient and outpatient groups were largely psychiatric in presentation, with the top three diagnoses consisting of obsessive-compulsive disorder, late-life psychosis, and major depression (Boone et al., 1998). The 3-, 9-, and 18-second interference delay version of the ACT was used. Ultimately, a three-factor model was proposed, including factors labeled “cognitive flexibility,” “speeded processing,” and “basic/divided attention and short-term memory” (Boone et al., 1998, pg. 590). ACT performance (i.e., total score, perseveration score, sequence score) loaded on the "basic/divided attention and short-term memory" (Boone et al., 1998, pg. 590) factor, which included verbal and performance intelligence quotients (IQ; i.e., Wechsler Adult

Intelligence Scale-Revised, WAIS-R, Verbal Intelligence Quotient, VIQ; WAIS-R Performance Intelligence Quotient, PIQ; Adams et al., 1984), auditory and visual working memory (i.e., WAIS-R Digit Span, Adams et al., 1984; Rey-Osterrieth Complex Figure, Rey-O, percent retention), and processing speed (WAIS-R Digit Symbol; Adams et al., 1984). Thus, providing convergent validity of the ACT as a measure of IQ, working memory, and processing speed, though Boone and colleagues (1998) seemed to deemphasize the ACT's relationship to measures of IQ. This finding was not entirely novel, as the ACT had been previously used clinically as a measure of short-term memory and/or divided attention (Lezak, 1995). Of note, this assessment of the ACT was the only one found which assessed additional scores on the ACT, namely the ACT perseveration score; however, little emphasis was placed on interpreting these scores.

Table 1

List of Previous Studies Evaluating the ACT

Study	Participants	ACT Version	Analysis Type	Measures Related to ACT
Boone et al. (1998)	• 138 outpatients and inpatients referred for neuropsychological testing ○ Age = 51.15 (16.25) ○ Education = 13.50 (2.88) • 112 controls ○ Age = 60.87 (12.74) ○ Education = 14.50 (2.56)	3-, 9-, 18-second [a]	EFA	• WAIS-R VIQ • WAIS-R PIQ • WAIS-R DS • WAIS-R DSC • RCFT % Retention

Mertens et al. (2006)	• Younger participants
	  ○ Age = 20.83 (.27)
	  ○ Education = 14.64 (0.16)
	• Older participants
	  ○ Age = 70.14 (0.83)
	  ○ Education = 15.55 (0.34)
	  ○ MMSE = 28.66 (0.13)
	  ○ All part of a study evaluating the impact of glucose regulation on cognitive functions
		"modified Brown-Peterson task" [b]	EFA	• WAIS-III DS
				• WAIS-III LN
				• WAIS-III AR

Shura et al. (2016)	• Veterans
	  ○ Age=35.54 (9.42)
	  ○ Education=13.74 (1.97)
	  ○ 85.3% male
	• Controls
	  ○ Age=36.41 (10.33)
	  ○ Education=13.81 (2.18)
	  ○ 84.5% male
		9-, 18-, 36-second [c]	hierarchical linear regression	• Education
				• WTAR
				• TMT A
				• WAIS-III LN
				• CPT-II COM

Geurten et al. (2016)	• French speaking
	• TBI
	  ○ Age = 37.7 (12.89)
	  ○ Education = 13.00 (2.26)
	• Controls
	  ○ Age = 37.77 (12.86)
	  ○ Education = 13.11 (2.98)
	• Whole health
	  ○ Age = 49.78 (19.94)
	  ○ Education = 12.64 (3.51)
		computerized Brown-Peterson test [d]	correlations	• PASAT
				• Stroop In
				• WAIS-III DS
				• Stroop C
				• fNART

Aita et al. (2019)	• Healthy college students • Age=19.82 (1.45) • Education=12.98 (0.97)	3-, 9-, 18-second [a]	EFA	• RSpan • OSpan

Notes. ACT = Auditory Consonant Trigrams test; MMSE = Mini–Mental State Examination; TBI = Traumatic Brain Injury; WAIS-R = Wechsler Adult Intelligence Scales - Revised; WAIS-III = Wechsler Adult Intelligence Scales - III; VIQ = Verbal Intelligence Quotient; PIQ = Performance Intelligence Quotient; DS = Digit Span; DSC = Digit-Symbol Coding; RCFT = Rey Complex Figure Test; % Retention = Percent Retention; LN = Letter-Number Sequencing; AR = Arithmetic; WTAR = Wechsler Test of Adult Reading; TMT A = Trail Making Test Part A; CPT-II = Conners' Continuous Performance Test-II; COM = Commission Errors; PASAT = Paced Auditory Serial Addition Task; In = Inhibition; C = Color-Naming; fNART = National Adult Reading Test; RSpan = Reading Span; OSpan = Operation Span

[a]Boone et al. (1990), [b]Mertens et al. (2006), [c]Stuss et al. (1987) & Stuss et al. (1988), [d]Geurten et al. (2016)

With regards to divergent validity for the ACT, the other two factors contained 1) a measure of abstract concept formation and set-shifting (i.e., Wisconsin Card Sorting Test, WCST; Heaton, 1981) and 2) measures of executive functioning and processing speed (i.e., Verbal Fluency, FAS; Stroop A, Stroop B, Stroop C, Comalli et al., 1962; and WAIS-R Digit Symbol; Adams et al., 1984). Thus, the distinction between the "speeded processing" and "basic/divided attention and short-term memory" (Boone et al., 1998, pg. 590) was somewhat unclear and seemed to represent some overlap in cognitive processes (i.e., processing speed).

Given the persisting ambiguity of the ACT, a second factor analytic study was completed by Mertens and colleagues (2006). An exploratory factor analysis (EFA) was conducted to determine the neuropsychological measures related to the "modified Brown-Peterson task" (MBPT, Mertens et al., 2006). Two samples were collected, 1) healthy young adults and 2) older adults, and were both screened for health issues (i.e., diabetes, hypoglycemia, chronic hepatitis, neurological problems, depression, and alcohol or drug abuse). Four versions of the MBPT were used, each using different letters; however, all consisted of three conditions (i.e., baseline, waiting without counting, interference), though the order of conditions was varied between versions (Mertens et al., 2006). Unlike other versions of the MBPT or ACT, (a) participants were asked to write down the consonants remembered, instead of verbally reporting them, and (b) every trial of the interference condition had a distractor task delay of 20-seconds (i.e., instead of alternating delay time). All other aspects of the MBPT were consistent with Stuss and colleagues' (1987, 1988) previously described version. After completing a factor analysis

including neuropsychological assessment variables and the MBPT interference trial total number of consonants recalled, the researchers found the MBPT loaded on a factor with the working memory subtests from the Wechsler Adult Intelligence Scale - III (WAIS-III; i.e., Digit Span Forwards and Backwards, Letter-Number Sequencing, and Arithmetic, Wechsler, 1997) described as an "auditory/visual working memory and complex attention factor" (Mertens et al., 2006, pg.736). These findings agreed in part with Boone and colleagues' findings (1998), in that both found measures of working memory to load on the same factor as ACT performance; however, Mertens and colleagues (2006) did not find a relationship between ACT performance, IQ, and processing speed. Of note, Mertens and colleagues (2006) did not include IQ or Rey-O performance in their factor analysis; however, Wechsler Memory Scale-III (WMS-III, Wechsler, 1997) Spatial Span was included as a measure of visual working memory but was not shown to be related to ACT performance. Additionally, a measure of processing speed (i.e., WAIS-III Digit Symbol Coding, Wechsler, 1997) was included; however, loaded on a separate factor from ACT performance in direct contrast to Boone and colleagues' (1998) findings (Mertens et al., 2006). In sum, Mertens and colleagues' (2006) results suggested the ACT was similar to other measures of working memory; however, they did not replicate Boone and colleagues' (1998) relationship between ACT, IQ, and processing speed.

As Boone and colleagues' (1998) and Mertens and colleagues' (2006) results failed to provide a clear consensus regarding the cognitive processes measured by the ACT, Shura and colleagues (2016) and Geurten and colleagues (2016) concurrently aimed to provide a psychometric update for the ACT.

In Shura and colleagues' (2016) study, a hierarchical regression analysis was conducted, including measures of cognitive domains identified by Boone and colleagues (1998) and Mertens and colleagues (2006) as related to ACT performance (i.e., processing speed, IQ, and executive functioning) and measures relating to attention and verbal learning. Stuss and colleagues' (1987, 1988) version of the ACT was used. Here, ACT performance was predicted by education, premorbid intelligence (i.e., Wechsler Test of Adult Reading, WTAR, a measure of reading ability for phonemically irregular words; The Psychological Corporation, 2001), processing speed (Trail Making Test Part A; Reitan & Wolfson, 1985), verbal working memory (WAIS-III Letter-Number Sequencing, LNS; Wechsler, 1997a), and impulsivity (Conners' Continuous Performance Test-II, CPT-II, Commission Errors; Conners & MHS Staff, 2004). Shura and colleagues (2016) suggested these results did not provide convergent validity for the ACT as a measure of executive functioning or working memory, as previously described (Boone et al., 1998; Mertens et al., 2006), rather suggested the ACT may be more adequately described as a measure of general intellectual ability and psychomotor speed.

In Geurten and colleagues' (2016) study, a computerized version of the Brown-Peterson test, unique to the study, was used. Participants were presented with three letters, one at a time on the screen, and asked to read each letter aloud. Then, participants were shown pairs of numbers, one pair per screen, which they were to repeat backwards for delays of either 0-, 5-, 10-, or 20-seconds. After this interference delay, participants were asked to enter the three letters in the correct order. While there are potentially numerous benefits to a computerized version of the ACT (e.g., more accurate delay

intervals, more consistent administration), Geurten and colleagues (2016) did not establish the relationship of this new computerized version to any of the non-computerized versions. More specifically, it remains unclear the extent to which the visual presentation of the consonant trigrams, the difference in distractor tasks, and the impact of requesting participants to enter responses in the correct order have on the equivalency of the computerized to non-computerized version. Convergent validity measures indicated relationships (i.e., significant correlations) between the Brown-Peterson test and measures of attention (i.e., a computer version of the Paced Auditory Serial Addition Task, PASAT; Gronwall, 1977) and executive functioning/working memory (i.e., Stroop Interference score; Regard, 1981; WAIS-III forward and backward Digit Span; Wechsler, 1997) while controlling for age and education (Geurten et al., 2016). Measures used for divergent validity indicated relationships between the Brown-Peterson test and measures of processing speed (i.e., Stroop Color-Naming; Regard, 1981) and vocabulary (i.e., National Adult Reading Test, fNART; Geurten et al., 2016).

In sum, numerous domains of cognitive function have been related, rationally or empirically, to ACT performance with no consistent relationship established. These domains have included intelligence/word reading ability, executive functioning, working memory, attention, and processing speed (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016; Geurten et al., 2016). The following section offers a brief review of the aforementioned domains of cognitive function, with the goal of providing the reader with a general understanding of the concepts/abilities conceptualized within these domains. The discussion here is minimally descriptive, rather than exhaustive.

Intelligence

Intelligence is a complex construct used to describe mental processes underlying adaptive behavior (Goleman, 1995; Greenspan & Driscoll, 1997), complex problem-solving (Sternberg, 1997), and/or stable traits or trait-like competencies predictive of performance on specified tasks (Sternberg, 1997; Gardner, 1983; Horn & Noll, 1998). Wechsler (1944) specifically defined intelligence as the "capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment" (pg. 3). Wechsler (1944) did not limit his definition to solely cognitive descriptors, as intelligence is also comprised and impacted by characteristics such as goal awareness, enthusiasm, persistence, etc., which are not routinely assessed in cognitive tasks (Wechsler, 1975).

Three general theoretical perspectives of intelligence are identified by McGrew and Flanagon (1998): the psychometric or structural theories, information processing theories, and the cognitive modifiability theories. The information processing and cognitive modifiability theories are often used to explain performance on a cognitive task by identifying ability areas represented by test performance (McGrew & Flanagon, 1998).

Alternatively, the psychometric or structural approach identifies stable population-level traits or competencies based on individual differences in cognitive test performance (McGrew & Flanagan, 1998). Correlational methods (i.e., factor analysis) identify latent ability domains within and across psychological tests. Individual differences can be detected and test-takers placed at different points along one or more dimensions based on their test performance relative to the population. The psychometric

approach emphasizes the structure of latent abilities and classification of individual test-takers over explanation of cognitive performance. Intelligence models based on this approach have the longest history of empirical support and have become popular measures of intelligence in clinical practice settings (McGrew & Flanagan, 1998).

While numerous psychometric theories of intelligence have been assessed historically, one of the most widely accepted is Carroll's (1993) hierarchical model of intelligence, which expanded the Horn-Cattell *Gf-Gc* model through factor analytic research. Carroll's (1993) model included three levels: stratum III (*g*), stratum II (broad abilities), and stratum I (narrow abilities). In this model, *g* is the all-encompassing cognitive ability, broad abilities represent different intellectual domains within *g*, and narrow abilities represent specialized intellectual abilities within each broad domain (Carroll, 1993). Stratum II contained intelligences familiar to most psychologists, e.g., "*Gv*", representing visual-spatial ability, "*Gs*" representing speed and efficiency of simple information processing, etc. Stratum I contained specific cognitive processes deemed relevant to the superordinate Stratum II broad abilities; e.g., inductive and deductive reasoning skills for the domain of Fluid Reasoning (*Gf*).

As conceptualized by Carroll (1993) within this framework, the rest of the cognitive domains to be discussed would fall within stratum II or stratum I abilities and theoretically should load on the overarching cognitive ability, *g*, or in the context of neuropsychological assessment measures of IQ.

Executive Functioning

The concept of executive function (EF) is highly diverse and is defined more broadly depending on the context. In the clinical literature, EF is defined more broadly as a system of supervisory capacities of overall brain processing and is comprised of abilities needed for purposeful or goal-directed behavior (Lezak, 2004; Strauss et al., 2006). As such, EF abilities are more frequently used in novel or unfamiliar contexts, rather than during routine or well-learned problem-solving, as the individual needs to develop new effective strategies (Shallice, 1990). EF deficits may appear in assessment performance as poor initiation, poor planning/organization, poor inhibition, inability to shift, poor working memory, inflexibility, perseveration, difficulty generating or using strategies, difficulty correcting mistakes, difficulty using feedback, and overall carelessness (Strauss et al., 2006). Given the broad nature of EF in this context, many confounds have presented themselves, specifically, that by definition EF tasks or functions must use other lower-level cognitive processes (Miyake et al., 2000; Strauss et al., 2006). In addition, numerous studies assessing tasks of frontal lobe function (Boone et al., 1998) and planning/problem solving (Kafer & Hunter, 1997) have resulted in factor structures or models in which multiple, and sometimes seemingly divergent, constructs appear as related to EF. Thus, the construct validity of executive tests is often not well established (Strauss et al., 2006).

As a result of the ambiguity of EF in the clinical literature, experimental models of EF have frequently aimed to identify simpler, more discrete, functional components of EF. While there are numerous models of EF in the literature, a commonly accepted model

proposes three underlying abilities: shifting, updating, and inhibition (Miyake et al., 2000). The shifting function relates to one's ability to shift between multiple tasks or mental sets (Miyake et al., 2000). Tests of shifting require participants to switch back and forth between tasks, such as the Trail Making Part B test and the Wisconsin Card Sorting Test. The updating function relates to one's ability to update and monitor working memory representations and is almost synonymous with the term working memory (Miyake et al., 2000; Miyake & Shah, 1999). This function requires one to monitor and code new information while revising the information contained in one's working memory by replacing information no longer relevant with more relevant information (Miyake et al., 2000). Tests of updating require participants to actively manipulate information held in working memory, such as WAIS-IV Digit Span Backwards and Letter-Number Sequencing. The inhibition function relates to one's ability to intentionally inhibit more automatic or dominant responses when necessary (Miyake et al., 2000). Tests of inhibition require participants to deliberately stop a more automatic response, in order to provide the requested response, such as the Color Word trial of the Stroop task. While these three components are most commonly accepted as central tenants of EF, it should be noted they are not comprehensive and other more complex aspects of EF are still largely unresolved in both the clinical and experimental literature.

Working Memory/Updating

Of specific interest to the current study is working memory (WM) or updating (Miyake et al., 2000; Miyake & Shah, 1999), as the ACT was originally developed to assess memory encoding (Brown, 1958) and given the historical categorization of the

ACT as a measure of WM by most neuropsychological texts (Strauss et al., 2006; Lezak, et al., 2012). WM may be classified both in the context of EF (Lezak et al., 2012) and in memory (Strauss et al., 2006).

WM is the most current in a series of terms, replacing older terms like short-term and immediate memory, and is generally accepted as a limited-capacity store for information over a short period of time (i.e., seconds to minutes) in which one can also perform complex cognitive operations on said information (Strauss et al., 2006; Lezak et al., 2012). The information assessed in WM may come from new sensory inputs or retrieved from long-term memory (Strauss et al., 2006). While numerous models of WM exist, one of the most prominent is from Baddeley and Hitch (1974). In this model of WM, the *central executive*, a supervisory controlling system, is assisted by the *phonological loop* and the *visuospatial sketchpad* (Baddeley & Hitch, 1974). The phonological loop is used to temporarily store and process verbal material, while the visuospatial sketchpad is used to temporarily store and process visual material (Baddeley & Hitch, 1974). In addition, Baddeley (2003) added an additional component to this model, the *episodic buffer*, which is described as a limited-capacity store of information that binds/integrates information. The central executive is in control of these subordinate systems (i.e., phonological loop, visuospatial sketchpad, and episodic buffer) and determines how the information they contain and process will be used (Straus et al., 2006). In this model, working memory is conceptualized as an attentional control system that is responsible for strategy selection and coordination of cognitive processes to enable

completion of cognitively complex activities, such as learning, comprehending, and reasoning (Strauss et al., 2006).

As such, WM refers to the use of both executive control and memory to complete an activity or task (Vandierendonck, 2016). More specifically, WM is the ability to sustain memory representations, while at the same time processing alternative information, distractions, and/or shifts in attention (Conway et al., 2002; Engle et al., 1999; Vandierendonck, 2016). WM is a heterogeneous construct, which includes, but is not limited to, tasks involving language, mental arithmetic, reasoning, attentional control, etc. (Vandierendonck, 2016).

Perseveration

Perseveration is another central concept to the current study, given the proposed evaluation of the perseveration score on the ACT (see below in methods section). Perseveration is the impaired ability to shift responses, typically presented as repetition of the same activity and/or response (Lezak, 2012). Perseveration errors can present in a variety of ways, including verbal, motor, visual, etc. The construct is often conceptualized as a central disruption within the shifting function; however, Miyake and colleagues (2000) conceptualized shifting through only Wisconsin Card Sorting Test (WCST) scores (Lezak, 2012). However, perseverative responses present in many additional ways throughout a neuropsychological testing battery (i.e., word repetitions in word fluency, inability to discontinue motor responses or patterns, providing similar or the same responses to subsequent items on a variety of tests), thus it is unclear if these different presentations of preservation form a unitary empirical construct. While

numerous neuropsychological assessments are used to identify different types (i.e., verbal, motor, visual, etc.) of perseveration, many do not provide normative data for which to compare these responses, rather are qualitatively evaluated as positive or negative for perseveration (Lezak, 2012; Strauss et al., 2006). The lack of assessment measures in different response types (i.e., verbal, motor, visual, etc.) with quantitative or normative scoring of perseveration presents difficulty in the evaluation of perseveration across the neuropsychological assessment battery, thus the development of scoring methods of perseveration across the battery will aid in both the empirical and clinical understanding of perseveration.

Attention

Attention is a multifaceted term comprising multiple basic processes, including sensory selection, response selection, attentional capacity, and sustained performance (Cohen, 1993; Strauss et al., 2006). Overall, attention is conceptualized as a system of interacting processes that allow individuals to identify relevant and irrelevant information, hold and modify mental representations, and monitor responses to information (Straus et al., 2006). The construct of attention is most commonly divided into component processes (i.e., alertness/arousal, focused attention, selective attention, divided attention, and sustained attention/vigilance; Strauss et al., 2006); however, there is variability in the exact definition of each of these processes and some tend to represent overlapping processes (i.e., focused attention and selective attention). It is important to note that tests of attention often measure more than one type of attention and other motor and cognitive aspects as well (i.e., motor speed, information processing speed, verbal

responding, etc.; Strauss et al., 2006). The construct of attention shares overlap with other domains of cognitive functioning, namely EF and WM. More specifically, many tests of attention, especially divided attention tests, require individuals to use inhibition, switching, and WM (i.e., aspects contained in models of executive functioning; Strauss et al., 2006). Thus, the distinction between tests of attention (i.e., EF and WM) is somewhat arbitrary and often defined based on the extent to which these processes are required to complete a task and/or the relative difficulty of the task. Although arguably loosely defined, tests of attention are often very sensitive measures and crucial to the diagnosis of many neurological disorders, as many of these patients initially present with attentional disorders (Strauss et al., 2006).

Processing Speed

Processing speed (PS) is a term, one of many, used to describe the speed at which individuals can execute cognitive processes (Kail, 1986; Kail, 2000). PS has been shown to be related to mental capacity (Kail & Salthouse, 1994), reading performance (Kail & Hall, 1994), reasoning, and WM (Fry & Hale, 1996; Kail, 2000). Concepts relating to speed factors more broadly have been included in numerous theories of intelligence, such as Carroll's (1993) three-stratum theory and Horn and Noll's (1998) theory of fluid (*Gf*) and crystallized (*Gc*) intelligence. PS has also been identified as an important domain of cognitive functioning through factor analytic analyses (Carroll, 1993; Horn & Noll, 1998). Though, a clear structure of PS has largely been unresolved, as much of the research on PS has focused on its relationship with age-related changes (Danthiir et al., 2005). Danthiir and colleagues (2005) completed a study to assess if PS is a unitary or

multidimensional concept. Results revealed a general mental speed factor that loaded four subfactors (i.e., Switching, Odd-Mann-Out, Substitution, and Hick task); however, Danthiir and colleagues (2005) acknowledged the variance associated with each subfactor is limited in interpretability. Thus, while PS seems to be related to a wide array of cognitive processes and potentially overall cognitive functioning, the lack of consistency in the measurement of PS throughout the experimental and clinical psychology literature may be impeding a more comprehensive understanding of this domain of cognitive functioning.

Present Study

With regards to the current study, there are three main goals: 1) explore the construct validity of the ACT by consolidating previous findings, 2) identify the relationship of the ACT perseveration score to other measures of cognitive functioning, and 3) add to the literature on the discriminant ability of the ACT total and perseveration scores within a clinical/neurological population referred for neuropsychological assessment.

With regards to construct validity, previous research has suggested the ACT shares relationships with a variety of cognitive domains and premorbid abilities, including: education, IQ, premorbid IQ, EF, WM, Attention, and PS (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016; Geurten et al., 2016). In sum, these previous findings have not resulted in a consistent relationship between the ACT and other neuropsychological assessment measures/constructs, resulting in ambiguity regarding the ACT's utility in clinical practice. Although the ACT is seemingly most consistent (i.e.,

face validity) with tasks of EF function, specifically WM/updating, previous research has not consistently identified and has even challenged the ACT's relationship to WM (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016; Geurten et al., 2016). The current study aims to add to the construct validity of the ACT by conducting an EFA in a diverse clinical/neurological sample and including neuropsychological measures of IQ, EF, PS, and attention, as well as, education. Based upon previous factor analytic research, it is hypothesized the ACT will load on the same factor with measures of intelligence, processing speed, and executive functioning (i.e., specifically measures of working memory) within the current study (Boone et al., 1998; Mertens et al., 2006).

The evaluation of the relationship between the ACT perseveration score to the ACT total score and other neuropsychological measures has been especially limited in scope (Boone et al., 1998). As such, the current study will include the ACT perseveration score and total score in an EFA, to identify the ACT perseveration score's relationship to other neuropsychological measures and relevant latent variables. Based on Boone et al.'s (1998) finding, it is hypothesized that the ACT perseveration score will load on the same factor as the ACT total score.

Finally, the assessment of the ACT total score, and, certainly, the ACT perseveration score, in a largely neurological sample, has been limited, with previous studies having limited numbers and/or clinical presentations. Though the ACT's construct validity is suboptimal, the ACT has been shown to have promising discriminant ability between clinical populations of interest (Anile et al., 2003; Oral et al., 2012; Stuss et al., 1989; Merkley et al., 2013; Shura et al., 2016; Dige & Wik, 2005; Ozakbas et al.,

2004). No previous study has assessed the clinical utility of the ACT perseveration score in discriminating clinical presentations. Through criterion-related validity analyses, the current study aims to assess the clinical utility of the ACT perseveration score and further assess the clinical utility of the ACT total score in discriminating clinical groups within a diverse clinical/neurological sample of patients referred for neuropsychological evaluation.

CHAPTER II

METHOD

Participants

A total of 448 patients' neuropsychological assessment data, clinical diagnoses, and demographic information were collected from Sanford Health Neuropsychology department, Fargo, ND, for the current study. These patients were a clinically referred group with comprehensive neuropsychological evaluations. Patients' data were obtained by chart review of patient files and electronic medical record systems. To meet inclusion criteria for the current study, (1) patients must have previously undergone a neuropsychological evaluation at Sanford Health Neuropsychology department between January 1, 2012, and April 13, 2018, (2) have completed the ACT during their neuropsychological assessment, and (3) were 18 to 90 years of age at the time of assessment. After a review of patient records at Sanford Health Neuropsychology, 448 patients were identified who met the current study inclusion criteria.

The majority of patients were white (92.2%), right hand dominant (90.4%), and female (56.7%). The mean patient age was 45.5 (range = 18 – 78, *SD* = 14.6) and the

mean highest achieved education was 13.5 years (range = 6 – 20, *SD* = 2.3) with 10% achieving below a high school education, 36.6% earning a high school diploma, 27.6% attending college without a degree or earning an associate's degree, 19.4% earning a bachelor's (4-year) degree, and 6.2% attending post-graduate education and/or earning a master's or doctoral degree. A total of 20 primary diagnostic groups were identified within the sample. Of those, the 5 largest clinical presentations (in order from highest to lowest) were a primary psychiatric diagnosis, multiple sclerosis (MS), moderate to severe TBI, cognitive disorder not otherwise specified (NOS) and mild TBI (i.e., concussion). See Table 2 for more detailed demographic information. The groups represented a highly diverse clinical population with numerous comorbidities, see Table 3 for the most common comorbidities within each clinical group.

Table 2

Patient Demographics

Variable	
Sex	
Female	56.7 [a]
Male	43.3 [b]
Race (%)	
White	92.2
Native American or Alaskan Native	3.8
Black or African American	2.2 [c]
Hispanic or Latino	1.4
Asian	0.2 [d]
Native Hawaiian or other Pacific Islander	0.2
Age (Mean; *SD*)	45.5 (14.6)
Education (Mean; *SD*)	13.5 (2.3)
Handedness (%)	
Right hand dominant	90.4

Left hand dominant	9.4
Unknown	0.2
Primary Clinical Diagnosis (%; number of cases)[e]	
MS [f]	19.4 (87)
Seizure Disorder	2.2 (10)
Autism Spectrum Disorder	1.8 (8)
Attention Disorder	4.7 (21)
Psychiatric diagnosis	20.1 (90)
moderate to severe TBI [g]	13.6 (61)
TIA and Cerebrovascular Disease	3.1 (14)
No diagnosis	0.7 (3)
Cognitive Disorder NOS	8.5 (38)
mild TBI [g]	6.9 (31)
Renal Failure	3.1 (14)
Mild Cognitive Impairment	1.1 (5)
Anoxic Brain Injury and Encephalopathy	1.8 (8)
Cerebrovascular Accident and Aneurysm	6.5 (29)
Major Neurocognitive Impairment [h]	2.0 (9)
Parkinson's Disease	0.7 (3)
Central Nervous System Tumor	0.4 (2)
Neurodevelopmental Disorder, Intellectual Disability, Fetal Alcohol Syndrome	1.6 (7)
Substance Induced Cognitive Disorder	0.9 (4)
Specific Learning Disorder	0.9 (4)

Notes. [a] The female group contained one female-to-male transgender individual. [b] The male group contained two male-to-female transgender individuals. [c] The African American group contained one biracial African American and White individual. [d] The Asian group contained one biracial Asian and White individual. [e] Primary clinical diagnoses were identified from the neuropsychologists' primary diagnostic classification. [f] multiple sclerosis. [g] TBI = traumatic brain injury, [h] dementia

Table 3

Common Comorbidities within Clinical Groups

Clinical Group	1st Comorbidity (%)	2nd Comorbidity (%)	3rd Comorbidity (%)
MS	Mood Disorder (54.0)	Anxiety Disorder (26.4)	Sleep Diagnosis (10.3)
Seizure Disorder	Mood Disorder (90.0)	Anxiety Disorder (60.0)	Sleep Diagnosis (30.0)
Autism Spectrum Disorder	Mood Disorder (50.0)	Anxiety Disorder (37.5)	Learning difficulty (25.0)
Attention Disorder	Anxiety Disorder (71.4)	Mood Disorder (47.6)	Learning difficulty (14.3)
Psychiatric Diagnosis [a]	Chronic pain (16.7)	Headaches/Migraines (11.1)	Self-reported history of head trauma (11.1)
moderate to severe TBI	Mood Disorder (44.3)	Anxiety Disorder (14.8)	Sleep Diagnosis (11.5)
TIA and Cerebrovascular Disease	Mood Disorder (71.4)	Anxiety Disorder (64.3)	Sleep Diagnosis (57.1)
No Diagnosis	Self-reported history of head trauma (33.3)		
Cognitive Disorder NOS	Mood Disorder (50.0)	Sleep Diagnosis (36.84)	Chronic Pain (26.3)
mild TBI [b]	Mood Disorder (71.0)	Headaches/Migraines (58.1)	Anxiety Disorder (48.39)
Renal Failure	Learning difficulty (35.7)	Mood Disorder (28.6)	Anxiety Disorder (21.4)
Mild Cognitive Impairment	Mood Disorder (60.0)	Kidney Disease (20.0)	Structural Changes on Imaging (20.0)
Anoxic Brain Injury and Encephalopathy	Mood Disorder (37.5)	Seizure Disorder (12.5)	Trauma Disorder (12.5)
Cerebrovascular Accident and Aneurysm	Mood Disorder (48.3)	Sleep Diagnosis (24.1)	Headaches/Migraines (20.7)

Major Neurocognitive Impairment [c]	Mood Disorder (55.56)	Sleep Diagnosis (22.2)	Diabetes Mellitus (11.1)
Parkinson's Disease	Anxiety Disorder (33.3)		
Central Nervous System Tumor	Visual Deficit (50.0)		
Neurodevelopmental Disorder, Intellectual Disability, Fetal Alcohol Syndrome	Attention Disorder (57.1)	Mood Disorder (57.1)	Anxiety Disorder (14.3)
Substance Induced Cognitive Disorder	Mood Disorder (50.0)	Anxiety Disorder (25.0)	Sleep Diagnosis (25.0)
Specific Learning Disorder	Anxiety Disorder (100.0)	Mood Disorder (75.0)	Attention Disorder (75.0)

Notes. [a] Comorbidities are the 3rd, 4th, and 5th most common disorders after mood disorder and anxiety disorder., [b] i.e., concussion, [c] i.e., dementia

Materials

Demographics

Information from patients' records were collected regarding their age, sex, ethnicity, and education level at the time of their neuropsychological evaluation. The patients' cognitive and/or physical diagnosis(es) associated with their neuropsychological assessment were collected.

Neuropsychological Assessment Measures

Neuropsychological assessment measures were collected from a standard battery that was completed as part of referral-based clinical care. Neuropsychological evaluations in this clinical setting include various measures administered by trained technicians using standard procedures for each test. Neuropsychological testing is generally completed in one or two sessions. Neuropsychological test measures included in these batteries are

largely similar, with only minimal deviation. Additional measures may have been included at the discretion of the neuropsychologist and relate to the patient's need and medical necessity. See Table 4 for a list of the selected tests by domain.

Table 4

List of Tests by Domain

Domain [1]	Measure
Executive Functioning	**ACT T** **ACT P** IVA + Auditory Prudence WAIS-IV LN **WAIS-IV AR** **WAIS-IV DS** CVLT-II 1 **CVLT-II 1-5** **RCFT % Retention** **STROOP In** **WCST PE** **COWAT**
Processing Speed	**WAIS-IV CD** **WAIS-IV SS** **STROOP C** **STROOP W**
Attention	IVA + Auditory Vigilance **TMT A** **TMT B** VSAT Time
IQ	WAIS-IV FSIQ WRAT4 WR

Notes. **Bold** items were included in final analyses, alternatively non bolded items were planned but ultimately not included due to missing data or influence on factor structure.
ACT T = Auditory Consonant Trigrams Total score; ACT P = Auditory Consonant Trigrams Perseveration score; IVA + = Integrated Visual and Auditory Continuous Performance Test; WAIS-IV = Wechsler Adult Intelligence Scales - IV; LNS = Letter-Number Sequencing; AR = Arithmetic; DS = Digit Span; CVLT-II = California Verbal Learning Test -II; 1 = Trial 1; 1-5 = Trials 1-5; RCFT = Rey Complex Figure Test; % Retention = Percent Retention; WCST = Wisconsin Card Sorting Test; PE = Perseverative Errors; COWAT = Controlled Oral Word Association test; CD = Coding; SS = Symbol

Search; In = Interference; C = Color-naming; W = Word-reading; TMT A = Trail Making Test Part A; TMT B = Trail Making Test Part B; VSAT = Verbal Series Attention Test; FSIQ = Full Scale Intelligence Quotient; WRAT4 = Wide Range Achievement Test: Fourth Edition; WR = Word Reading

[1] Based on domains as described in Strauss et al. (2006), with the exception of measures of working memory which were conceptualized as measures of Executive Functioning (see discussion in-text), and test sources.

Measures of Executive Functioning (EF).

Auditory Consonant Trigrams Test (ACT). The ACT used in the current study is a variation of the Brown-Peterson test (Brown, 1958; Peterson & Peterson, 1959) developed by Stuss and colleagues (1987, 1988). During the first five trials, test-takers are verbally presented with a consonant trigram (e.g., L-B-D), one letter per second, and asked to immediately recall the consonant trigram, with no delay. These initial trials act as a practice for the delay trials. Then, test takers are presented with a consonant trigram, one letter per second, immediately followed by a two- or three-digit number. The test-taker must immediately begin counting backwards out loud by threes from the number presented (e.g., 98-95-92...). After a delay of 9, 18, or 36 seconds, the test-taker is asked to recall the consonant trigram they were presented with prior to the delay. The delays are varied in order throughout the test until five trials for each delay time are administered. The total number of correct letters recalled are scored for each delay interval (i.e., 0, 9, 18, and 36 seconds) and a total sum of all correct letters recalled were used as the ACT total score (ACT T). Additionally, as outlined by Boone and colleagues (1990), a total perseveration score (ACT P) will be calculated by summing the number of perseverations on all 20 trials of the ACT task (i.e., including the 0-second delay trials). Perseveration will be defined as "the reporting of an incorrect letter which was used as an answer on the

preceding trial, (Boone et al., 1990)" with a total of 57 perseverations possible on the Stuss et al. (1987, 1988, 1989) version of the ACT.

Weschler Adult Intelligence Scale, Fourth Edition (WAIS-IV) Digit Span Forwards and Backwards (WAIS-IV DSF & WAIS-IV DSB). In the WAIS-IV DSF, participants are verbally administered sequences of 2 to 9 numbers, in ascending trials (two trials of each number sequence, i.e., two trials of a sequence of 2 numbers, two trials of a sequence of 3 numbers...two trials of a sequence of 9 numbers), at a rate of one number per second (Wechsler, 2008). Participants are subsequently asked to repeat the stimulus numbers aloud as they heard them, in the same order (Wechsler, 2008). Thus, if a patient was administered a trial consisting of the stimulus 3-5-2, the correct response of the patient would be 3-5-2. Each trial is scored as correct (if all the numbers are reported in the same order as the stimulus) or incorrect (if all the numbers are not reported in the same order as the stimulus) and the task ending when both trials of an item are incorrect or all trials are administered (Wechsler, 2008). The total score is the sum of the number of correct trials throughout the test.

In the WAIS-IV DSB test, participants are verbally administered sequences of 2 to 8 numbers, in ascending trials (two trials of each number sequence, i.e., two trials of a sequence of 2 numbers, two trials of a sequence of 3 numbers...two trials of a sequence of 8 numbers), at a rate of one number per second (Wechsler, 2008). Participants are subsequently asked to repeat the stimulus numbers aloud backwards (Wechsler, 2008). Thus, if a patient was administered a trial consisting of the stimulus 3-5-2, the correct response of the patient would be 2-5-3. Each trial is scored as correct (if all the numbers

are reported in the backwards order) or incorrect (if all the numbers are not reported in the backwards order) and the task is ended when both trials of an item are incorrect or when all trials are administered (Wechsler, 2008). The total score is the sum of the number of correct trials throughout the test.

Integrated Visual and Auditory Continuous Performance Test (IVA +)

Auditory Prudence. The IVA + is an auditory and visual continuous performance test, measuring sustained attention and response inhibition (Sandford & Turner, 2004a, 2004b; Strauss et al., 2006). The test includes four sections: "warm-up" (i.e., two one-minute tests consisting of simple visual and auditory reaction time tests for baseline reaction time), a 1.5-minute practice session, the main test which consists of five sections of 100 visual and 100 auditory trials, and a "cool-down" (the same as the practice session; Strauss et al., 2006). While numerous scores can be derived from the IVA + administration, of specific interest is the Auditory Prudence IVA + scaled score, which is reported to measure impulsivity/response inhibition by scoring commission errors throughout the test administration (Sandford & Turner, 2004a, 2004b; Strauss et al., 2006).

WAIS-IV Letter Number Sequencing (WAIS-IV LN). In the WAIS-IV LN, patients are read a sequence of numbers and letters, then asked to recall the numbers in ascending order and the letters in alphabetical order (Wechsler, 2008). Each trial is scored as correct (all the stimulus numbers reported in correct ascending order and all the stimulus letters reported in correct alphabetical order) or incorrect (any other response; Wechsler, 2008). The test consists of 10 items with 3 trials each (i.e., a total of up to 30

trials) and patients are administered trials until they incorrectly answer all 3 trials of a test item (Wechsler, 2008). The sum of correct trials is used to calculate a scaled score.

WAIS-IV Arithmetic (WAIS-IV AR). In the WAIS-IV AR, patients are verbally administered up to 22 arithmetic problems and are asked to mentally solve each problem (Wechsler, 2008). Each response is scored as correct (correct answer provided within <31 seconds) or incorrect (any incorrect answer and correct answers provided after 30 seconds), then the sum of correct responses is used to calculate the scaled score (Wechsler, 2008).

California Verbal Learning Test-II Trial 1 and Trials 1-5 scores (CVLT-II 1 & 1-5). In the CVLT-II, patients are verbally presented with a 16-word list and asked to report all the words remembered from the presented list (Delis et al., 2000; Strauss et al., 2006). The patient is presented with the same word list, in the same order, for 5 trials. Next, the patient is presented with a second 16-word list, an interference list, and asked to report all the words remembered from this second list of words. Next, the participant is asked to report all the words remembered from the first list, the list presented 5-times, not the second list. Then, the patient is presented with four categories (i.e., the four categories of words presented in the first list: furniture, vegetables, ways of traveling, and animals) and asked to report all the words from the first list remembered from each category. After a 20-minute delay, the patient is asked to recall all the words remembered from the first list and then subsequently is asked to report all the words remembered from the first list from the presented categories again. Then, words are presented one at a time (i.e., words from the first list, words from the second list, and words not in either list) and the patient

is asked to respond “yes” if the word was from the first list or “no” if the word was not from the first list. After a 10-minute delay, the patient is presented with two words at a time (i.e., one word from the first list and a second word they have not heard before) and asked to report which word was from the first list. Numerous scores are derived from this verbal list-learning task; however, for the purpose of the current study, the Trial 1 and Trials 1-5 scores are of interest. The Trial 1 score is the total of correctly reported words from the first list after its first presentation to the patient (Delis et al., 2000). The Trial 1-5 score is the sum of the correctly reported words from the first list from each of the five learning trials (Delis et al., 2000).

Rey Complex Figure Test (RCFT) Percent Retention (% Retention). In the RCFT, patients are asked to copy a complex geometric figure (copy trial; Meyers & Meyers, 1995). After a 3-minute delay, the patient is asked to draw the same complex figure from memory (immediate recall trial). After a 30-minute delay (from the end time of the copy trial), the patient is asked to draw the complex figure again from memory (delayed recall trial). Then, the patient is presented with 24-designs and asked to select each of the designs they believe were part of the complex geometric figure they copied before (recognition trial). Each RCFT figure drawn was scored in accordance with the Meyers and Meyers (1995) scoring criteria. While numerous scores can be generated from the RCFT, the percent retention score is of interest in the present study. Given the percent retention score was not calculated for clinical use, the score will be calculated by dividing the immediate recall trial total score (ranging from 0-36) by the copy trial total score (ranging from 0-36), then multiplying by 100.

Stroop Test Interference Score (Stroop In). In the Stroop Test (i.e., Golden Version; Golden & Freshwater, 2002), patients are first asked to read words (i.e., red, blue, and green) that are printed on the page (Word-Reading trial). In the next trial (Color-Naming trial), patients are asked to name the color (i.e., red, blue, and green) of the ink the XXXX are printed in on a second page. In the last trial (Color-Word Interference trial), patients are asked to name the color ink (i.e., red, blue, and green) the words (i.e., red, blue, and green) are printed in on a third page. On all trials, the patient is told if they make an error and are directed back to the incorrectly answered item and asked to correct the mistake, then continue the trial. Each trial is administered for 45-seconds and the score for each trial is the number of the last correctly answered item. While there are numerous scores calculated on this test, the interference score is a calculated score (i.e., color-word interference trial score minus a predicted color-word score based on age and education level of the participant) of interest in the current study (Golden & Freshwater, 2002).

Wisconsin Card Sorting Test Perseverative Errors score (WCST PE). During the WCST (Heaton et al., 1993; Kongs et al., 2000), participants are tasked with matching response cards, one at a time, to one of 4 stimulus cards. Participants are told if a response card match is correct or incorrect based on rules known to the administrator but not the participant (i.e., matching based upon color, form, or number of figures). Patients are administered consecutive trials until all the cards are used (either 64- or 128-cards depending on the version) or all rules are solved by the patient. While there are a number of different scores within this test, of concern to the present study is the *perseveration*

errors (WCST PE) score. The perseveration errors score is a multifaceted faceted score, summing numerous types of perseveration errors patients can make while matching cards (Heaton et al., 1993). In general, a perseveration error on the WCST is when a patient continues to respond to a stimulus characteristic (i.e., color, form, or number) which is incorrect for the current rule (Strauss et al., 2006). All perseverations on the WCST were scored according to the Heaton and colleagues (1993) scoring guidelines.

Controlled Oral Word Association Test (COWAT). In the COWAT, patients are verbally presented with a letter and asked to verbally produce as many words as possible that begin with the administered letter, until they are told to stop (i.e., after 60-seconds; Heaton et al., 2004). The patients are told that they cannot use proper nouns (i.e., names of people or places) or use the same word again with a different ending (i.e., eat, eats, eating). The patients complete three trials (i.e., letters administered are F, A, and S). The COWAT score is the total number of words (minus repetitions, proper nouns, and items with only a different ending than another item) the patient generates over the three trials (Heaton et al., 2004).

Measures of Processing Speed (PS).

WAIS-IV Coding (WAIS-IV CD). In the WAIS-IV CD subtest, patients are required to transcribe, using a key, the symbol associated with each number, one number at a time, within a 2-minute time limit (Wechsler, 2008). The patient is provided with a record form with the key at the top and rows of boxes beneath. For each row of boxes, the top of the top box has a number in it and the bottom box is empty, so the participant can

draw in the associated symbol. The total number of correctly drawn symbols is used to calculate the scaled score (Wechsler, 2008).

WAIS-IV Symbol Search (WAIS-IV SS). In the WAIS-IV SS subtest, patients are required to scan rows of symbols (target group) one row at a time for two target symbols (for each row) and indicate whether either of the target symbols is in the target group (Wechsler, 2008). The patient is told to either mark the target symbol within the target group or mark the "NO" box if neither of the target symbols are in the target group (Wechsler, 2008). The total number of correctly marked target symbols and correctly marked "NO" boxes are summed. The total number of incorrectly marked non-target symbols and incorrectly marked "NO" boxes summed. The incorrect total is subtracted from the correct total, then this calculated number is used to calculate the scaled score (Wechsler, 2008).

Stroop Test Word-reading score (W) and Color-naming score (C). See Stroop Test Interference Score (above) for a full explanation of the Stroop Test. Additional scores for the current study on the Stroop Test are the word-reading score (i.e., number of items completed correctly on the word-reading trial) and the color-naming score (i.e., number of items completed correctly on the color-naming trail; Golden & Freshwater, 2002).

Measures of Attention.

Trail Making Test Part A and Part B (TMT A & TMT B). The TMT A test is a paper and pencil test, where the participant is to connect circles containing the numbers 1 through 25 in sequential order as quickly as they are able without making mistakes. If a

mistake is made (e.g., connecting the circle containing 23 to 25), the administrator informs the participant of the error and directs them back to the last correct connection (e.g., 23) and instructs the participant to continue. The total time (in seconds) is recorded for the score on the TMT A (Heaton et al., 2004).

The TMT B test is a paper and pencil test, where the participant is to connect circles containing the numbers 1 through 13 and letters A through L alternately (e.g., connecting the circle containing 1 to A to 2 to B... L to 13) as quickly as they are able without making mistakes. If a mistake is made (e.g., connecting the circle containing 2 to 3 or 2 to D), the administrator informs the participant of the error and directs them back to the last correct connection (e.g., B) and instructs the participant to continue. The total time (in seconds) is recorded for the score on the TMT B (Heaton et al., 2004).

IVA + Auditory Vigilance. See above for a full description of the IVA + assessment. The IVA + Vigilance scaled score is reported to measure attention by scoring omission errors throughout the test administration (Sandford & Turner, 2004a, 2004b; Strauss et al., 2006).

Verbal Series Attention Test (VSAT). The VSAT is a verbal test of attention, developed as a screening measure (Mahurin & Cooke, 1996). The VSAT consists of nine items: 1) reciting the alphabet, 2) counting backwards from 20 to 1, 3) counting backwards by 3's from 100 to 70, 4) reciting the days of the week forwards, 5) reciting the days of the week backwards, 6) reciting the months of the year forwards, 7) reciting the months of the year backwards, 8) alternately sequencing numbers and letters from 1 to 10 (i.e., 1-A, 2-B,…,10-K), and 9) an auditory vigilance task where the patient is asked

to signal each time a specific letter is reported in a sequence of 60 letters (Mahurin & Cooke, 1996). The total time (in seconds) is recorded, with a maximum time of 60 seconds per item, then the time (in seconds) for the first eight items (item number nine is untimed) is recorded and scored (Mahurin & Cooke, 1996).

Measures of IQ and Premorbid IQ.

WAIS-IV Full Scale Score (WAIS-IV FSIQ). The WAIS-IV FSIQ is not a specific test administered to patients, rather the FSIQ is a composite score derived from all the index scaled scores on the WAIS-IV (i.e., Verbal Comprehension Index Scale, Perceptual Reasoning Index Scale, Working Memory Index Scale, Processing Speed Index Scale; Wechsler, 2008). Each index scaled score is derived from the core subtest scores (or supplemental subtest scores if all core subtests are not administered) within each index score. The WAIS-IV FSIQ provides a measure of general intellectual functioning (FSIQ), which is based on current cognitive performance on the WAIS-IV subtests (Wechsler, 2008).

Wide Range Achievement Test: Fourth Edition Word Reading (WRAT4 WR). In the WRAT4 WR, participants are asked to read up to 55-words printed on a card (Wilkinson & Robertson, 2006). The administrator immediately scores each word read aloud as correct (i.e., responses read correctly) or incorrect (i.e., any incorrect reading of a word) and, at the end of the test, sums the total number of correctly read words (Wilkinson & Robertson, 2006). If the participant cannot read at least 5-words correctly, then they are administered the Letter Reading trial, where they are to read aloud 15 letters (Wilkinson & Robertson, 2006). If the patient can correctly read at least 5 words, the 15-

points from the Letter Reading trial is automatically added to the total points from the Word Reading trail. The sum of the Letter and Word Reading trails are used to calculate a scaled score (Wilkinson & Robertson, 2006). While the Word Reading test was created to measure letter and word recognition (Wilkinson & Robertson, 2006), word reading tests are frequently used as estimates of premorbid intelligence (Stevens & Price, 1999), as reading tests are relatively more immune to the effects of many types of brain damage than other neuropsychological tests (Strauss et al., 2006). Thus, the WRAT4 WR score will be used as a premorbid intelligence estimate in the current study.

Procedure

A waiver of informed consent was approved from Sanford Health Institutional Review Board. Patients meeting inclusion criteria (see Participants section) were identified through a review of patient files and electronic medical record systems at Sanford Health Neuropsychology department. Once identified, code-linked identifiers were assigned to each patient, thus patients' protected health information (PHI; i.e., name and medical record number) were kept separate from the study database in a secure electronic file. All aforementioned materials (i.e., demographics and neuropsychological assessment measures) were collected for each patient and entered into a second secure electronic file, which was used for statistical analyses.

CHAPTER III

RESULTS

Prior to planned statistical analyses, missing data points were addressed in two ways, i.e., first, variables with greater than 10 percent missing data were eliminated (i.e.,

WAIS-IV LN, IVA + Auditory Vigilance, IVA + Auditory Prudence, VSAT Time, CVLT-II 1, and WRAT4 WR) and second, two data substitution methods were used (i.e., overall mean substitution and group x variable mean substitution). Two data sets were created to accommodate both mean substitution methods. In the first version of the data set, overall variable means were substituted for missing data points, alternatively in the second version of the data set group x variable mean substitutions were substituted for missing data points. These methods of data substitutions were chosen as even after eliminating variables with greater than or equal to 10 percent missing data, there continued to be missing data points throughout the variables, ranging from 8.7% to 0.7%, with the exception of the ACT total and perseveration scores which evidenced no missing data points due to study inclusion criteria. Case deletion for missing variables was not used, as this method would have reduced the sample below 200 unique individuals. Per Tabachnick and Fidell's (2013) recommendation regression or prediction based estimation procedures were not used to reduce the likelihood of inflating variable correlations and thus potentially creating factors. As the overall variable mean substitution was likely to underrepresent the variability within the sample and group x variable mean substitution was likely to overrepresent the variability within the sample, both methods were employed to gain a diverse picture of variable relationships within this clinical database.

Reliable correlations were verified using Bartlett's test of sphericity. Normality was assessed with some variables evidencing a skewed distribution. Data transformation was not conducted, which may knowingly degrade the factor solution (Tabachnick &

Fidell, 2013). To assess linearity of variable combinations, correlation matrices were produced, within both groups. For variable relationships that did not have a significant correlation, the scatter plots of these variable relationships were assessed for linearity. In these cases, variable relationships were scattered without an identifiable relationship, but did not evidence other forms of nonlinear relationships. Univariate and Multivariate outliers were assessed, though outliers were present given the aim of the current study to understand variable relationships within a broad clinical sample, deletions were not conducted.

Exploratory Factor Analyses (EFA)

Regarding sample size, adequate sampling estimates for factor analytic analyses vary depending on the number of variables, strength of factor loadings, and commonality, thus require specific analysis of these variables while conducting a factor analysis on one's data post hoc (Field, 2013). A priori predictions are limited in utility; however, numerous sources suggested a sample size of 300 should provide a stable factor solution unless the aforementioned variables suggest otherwise in a sample (Tabachnick & Fidell, 2007; Field, 2013). Alternatively, a review article of PsychINFO articles using either principal components or EFA recommended a 10:1 ratio of cases per variable, sighted a majority (63%) of studies resulted in adequate factor structures with this ratio (Costello & Osborne, 2005). Thus, a priori, the current study aimed for overall data collection of approximately 240 cases based upon the 10:1 ratio of cases to variables. Final data collection

resulted in 448 unique patients being collected, exceeding the recommended sample size estimates.

The factors were extracted using principal factors (also called principal axis factoring), such that the shared variability between variables could be assessed through estimated communalities (Tabachnick & Fidell, 2007). This particular data extraction procedure attempts to eliminate or reduce both unique and error variance from variables entered. A priori, an oblique promax rotation was planned, allowing for the correlation between factors, which was expected given the results of previous factor analytic studies (Boone et al., 1998; Mertens et al., 2006). Based on the recommendations of Tabachnick and Fidell (2007), .32 was used as the minimum loading of a variable on a factor acceptable for inclusion. Factors with fewer than three variable loadings were eliminated. The factor structures for the overall mean and group x variable mean substitution data did not differ in factor structure outcomes, loadings, or variance accounted for, thus are described simultaneously.

Prior to performing the EFA, data were screened for normality, univariate outliers, and homogeneity of variance among entered variables. Results revealed all statistical assumptions of EFA were met. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .893, indicating a sufficient proportion of common variance among variables for EFA. Bartlett's test of sphericity was significant, indicating sufficient covariances among variables for factor analysis ($p < .001$). Concerning sample size, the cases to variables ratio (N/k) was approximately 30:1, which is adequate (Costello & Osborne, 2005). See Table 5 and Table 6 for EFA data screening summaries.

Table 5

Overall Mean Factor Structure Variables

Variable	Principle Axis Factoring	
	2 Factor Model	3 Factor Model
KMO	.893	.893
Bartlett's test of sphericity	Significant	Significant
% Variance	49.538%	56.494%
Double Loadings	0	2
Items Eliminated	1 (WCST PE)	2 (ACT P & WCST PE)
Smallest # Items per Factor	7	3

Table 6

Group x Variable Mean Factor Structure Variables

Variable	Principle Axis Factoring	
	2 Factor Model	3 Factor Model
KMO	.893	.893
Bartlett's test of sphericity	Significant	Significant
% Variance	49.538%	56.494%
Double Loadings	0	2
Items Eliminated	1 (WCST PE)	2 (ACT P & WCST PE)
Smallest # Items per Factor	7	3

EFA was initially conducted including variables for executive functioning (i.e., ACT total and perseveration; WAIS-IV DS, AR; CVLT-II 1-5; RCFT % Retention;

Stroop In; WCST PE; COWAT), processing speed (i.e., WAIS-IV CD and SS; Stroop W and C), attention (i.e., TMT A and B), and IQ/premorbid IQ (i.e., WAIS-IV FSIQ; see Table 4 for a complete list of tests by domain). WAIS-IV FSIQ was ultimately removed from the final factor analyses due to its strong correlation with WAIS-IV subtests, negatively impacting the factor structure.

A 2-factor structure was retained using the principle factors extraction method with an oblique promax rotation, while a 3-factor structure was rejected due to multiple double loadings, a 2 variable third factor, and the elimination of the ACT perseveration and WCST PE variables from the factor loadings. See Table 5 and Table 6 for factor structure variables. The 2-factor model accounted for 49.54% of the overall variance while eliminating the WCST PE. The smallest number of variables per factor was 7 with no double loadings. The first factor, accounting for 39.55% of the variance, included Stroop W, TMT A, Stroop C, WAIS-IV CD, TMT B, WAIS-IV SS, and COWAT, while the second factor, accounting for 9.99% of the variance, included ACT total, WAIS-IV AR, CVLT-2 1-5 Total, WAIS-IV DS, Stroop In, Rey-O % Retention, and ACT perseveration. See Table 7 for the factor structure and loadings, as well as the factor correlation matrix.

Table 7

Principle Axis Factoring 2-Factor Pattern Matrices

	Overall Mean substitution		Group x Variable Mean substitution	
	Factor		Factor	
	1	2	1	2
Stroop W	**.918**	-.208	**.918**	-.208
TMT A	**.860**	-.189	**.860**	-.189
Stroop C	**.842**	-.079	**.842**	-.079
WAIS-IV CD	**.715**	.104	**.715**	.104
TMT B	**.626**	.122	**.626**	.122
WAIS-IV SS	**.617**	.192	**.617**	.192
COWAT	**.406**	.215	**.406**	.215
ACT T	-.041	**.745**	-.041	**.745**
WAIS-IV AR	.115	**.630**	.115	**.630**
CVLT2 1-5	.162	**.528**	.162	**.528**
WAIS-IV DS	.255	**.528**	.255	**.528**
Stroop In	-.152	**.487**	-.152	**.487**
Rey-O % Retention	-.119	**.429**	-.119	**.429**
ACT P	.024	**-.327**	.024	**-.327**
WCST PE	.140	.308	.140	.308
% Variance	39.55	9.99	39.55	9.99
Eigenvalue	5.93	1.50	5.93	1.50
Cronbach's Alpha	.83	.48	.83	.48
	Factor Correlation Matrix		Factor Correlation Matrix	
Factor	1	2	1	2

1	1.000	.667	1.000	.667
2	.667	1.000	.667	1.000

Receiver Operating Characteristic Analyses (ROC)

The ACT's criterion-related validity in actual clinical application was evaluated via receiver operating characteristic (ROC; McFall & Treat, 1999) analyses. ROC analyses produce a quantitative index of prediction accuracy between two groups on test by plotting the hit rate (i.e., sensitivity) on the y-axis and the false alarm rate (i.e., 1-specificity) on the x-axis for all possible cutoff values of the test/score (McFall & Treat, 1999). The area under the curve (AUC; McFall & Treat, 1999) statistic was used to assess the accuracy of group prediction in all ROC analyses. AUC ranges from 0-1, with 0.50 representing prediction no better than chance, and higher scores reflecting better overall prediction of criterion groups. Hosmer and colleagues (2013) indicated that $0.5 < AUC < 0.7$ represents poor discrimination, $0.7 \leq AUC < 0.8$ represents acceptable discrimination, $0.8 \leq AUC < 0.9$ represents excellent discrimination, and $AUC \geq 0.9$ represents outstanding discrimination between groups. Specific goals were to identify clinical groups, which previous research on the ACT total score has indicated discriminant ability (i.e., TBI, ADHD, MS, PTSD, MDD; see above for a review of studies) when possible in the archival data set, and new clinical groups yet to be assessed using the ACT. Given, the relatively little information regarding adequate sample size for ROC analyses it was determined that a priori clinical groups with 30 or more patients would be

compared using the ROC analyses. As such, ROC analyses were conducted between all possible combinations of clinical groups of 30 or more patients for both the ACT total and perseveration scores instead of predetermined comparisons, which included the MS, psychiatric diagnosis, moderate to severe TBI, cognitive disorder NOS, and mild TBI (i.e., concussion) clinical groups. See Table 8 and Figure 1 for the ACT total and ACT perseveration means and standard deviations within these aforementioned clinical groups for reference.

Table 8

ACT Total and ACT Perseveration Score Means and Standard Deviations for Clinical Groups of 30 or More Patients

Primary Clinical Group Comparison	ACT T		ACT P	
	M	*SD*	*M*	*SD*
MS	41.62	7.92	6.64	4.90
Psychiatric Diagnosis	42.24	7.48	4.96	3.82
moderate to severe TBI	40.20	8.46	7.92	6.64
Cognitive Disorder NOS	39.53	8.68	4.71	3.32
mild TBI	43.71	7.83	5.68	4.35

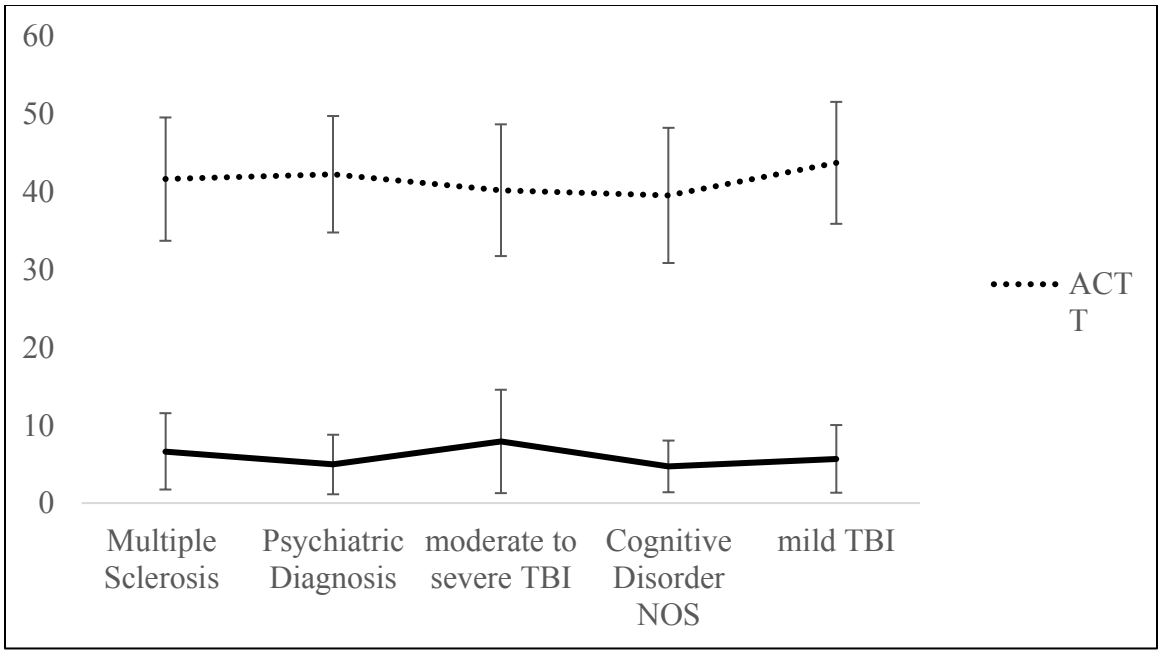


Figure 1. ACT Total and ACT Perseveration score Means with Standard Deviations within Clinical Groups of 30 or More Patients

Prior to ROC analyses, one-way fixed factor ANOVAs were conducted to evaluate group differences in age and education. The results revealed significant group differences in age, $F(4, 302) = 6.78$, $p < 0.0001$, $\eta_{p2} = .082$, and education, $F(4, 302) = 3.23$, $p = .013$, $\eta_{p2} = .041$ across the five clinical groups. Subsequent pairwise comparisons (i.e., Bonferroni) revealed significant age differences between the MS and mild TBI groups ($p = 0.007$), the psychiatric diagnosis and cognitive disorder NOS groups ($p = 0.005$), the moderate to severe TBI and cognitive disorder NOS groups ($p = 0.003$), and the cognitive disorder NOS and mild TBI groups ($p < 0.0001$). Further, pairwise comparisons also revealed a significant education difference between the MS and moderate to severe TBI groups ($p = 0.009$).

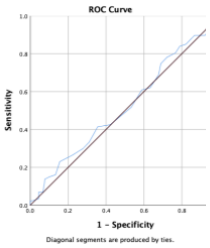
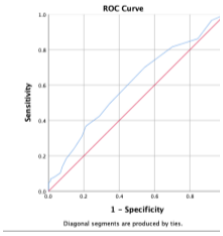
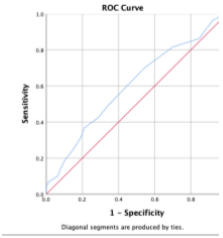
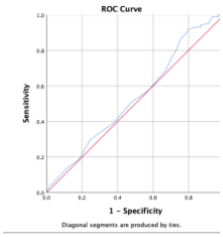
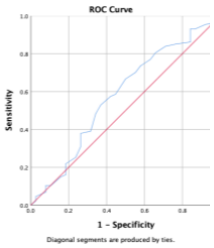
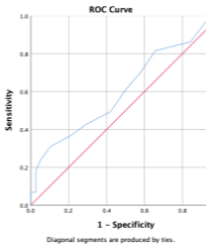
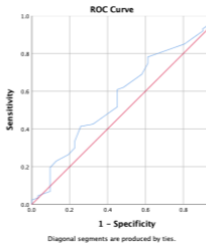
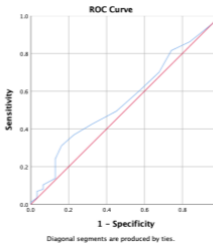
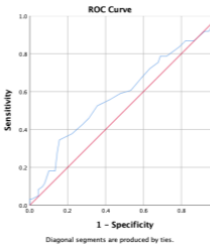
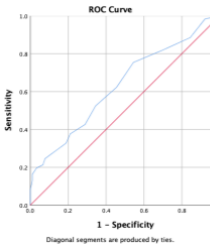
Significant ROCs between these group comparisons were further assessed to understand the impact of age and education on ACT total and ACT perseveration prediction.

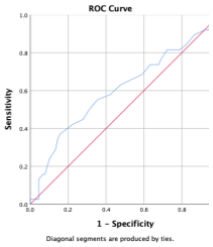
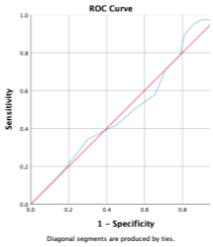
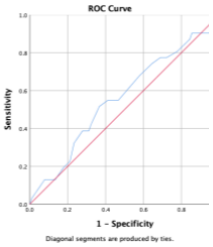
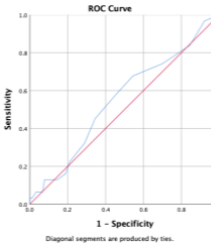
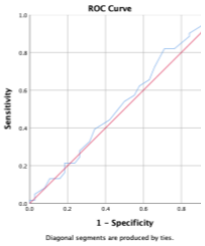
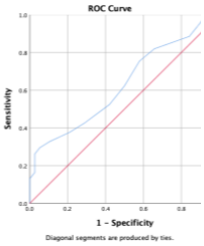
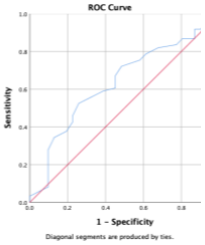
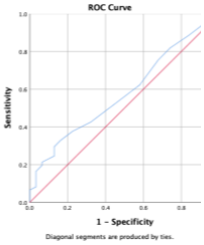
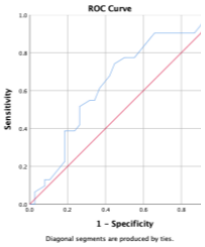
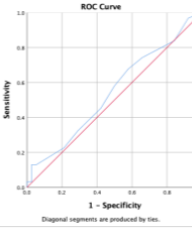
A total of ten comparisons were made with results as follows. See Table 9 for a tabular view of these results. 1) In the comparison between patients in the MS group and those in the psychiatric diagnosis group, ACT perseveration was found to be a significant predictor of diagnostic group (AUC = .60, p = .019); however, ACT total was not (AUC = .521, p = .637). 2) In the comparison between patients in the MS group and those in the moderate to severe TBI group, neither the ACT perseveration (AUC = .54, p = .463) or ACT total (AUC = .558, p = .232) were significant predictors of diagnostic group. 3) In the comparison between patients in the MS group and those in the cognitive disorder NOS group, neither the ACT perseveration (AUC = .61, p = .053) or ACT total (AUC = .58, p = .153) were significant predictors of diagnostic group. 4) In the comparison between patients in the MS group and those in the mild TBI (i.e., concussion) group, neither the ACT perseveration (AUC = .55, p = .375) or ACT total (AUC = .58, p = .190) were significant predictors of diagnostic group. 5) In the comparison between patients in the psychiatric diagnosis group and those in the moderate to severe TBI group, ACT perseveration was found to be a significant predictor of diagnostic group (AUC = .63, p = .006); however, ACT total was not (AUC = .58, p = .086). 6) In the comparison between patients in the psychiatric diagnosis group and those in the cognitive

disorder NOS group, neither the ACT perseveration (AUC = .50, p = .960) or ACT total (AUC = .61, p = .062) were significant predictors of diagnostic group. 7) In the comparison between participants in the psychiatric diagnosis group and those in the mild TBI (i.e., concussion) group, neither the ACT perseveration (AUC = .55, p = .394) or ACT total (AUC = .56, p = .321) were significant predictors of diagnostic group. 8) In the comparison between patients in the moderate to severe TBI group and those in the cognitive disorder NOS group, ACT perseveration was found to be a significant predictor of diagnostic group (AUC = .63, p = .030); however, ACT total was not (AUC = .53, p = .630). 9) In the comparison between patients in the moderate to severe TBI group and those in the mild TBI (i.e., concussion) group, ACT total (AUC = .64, p = .036) was found to be a significant predictor of diagnostic group; however, ACT perseveration (AUC = .58, p = .198) was not. 10) In the comparison between patients in the cognitive disorder NOS group and those in the mild TBI (i.e., concussion) group, ACT total (AUC = .65, p = .035) was found to be a significant predictor of diagnostic group; however, ACT perseveration (AUC = .55, p = .070) was not.

Table 9

ROC Results Between Clinical Groups of 30 or More Patients

Primary Clinical Group Comparison	ACT T (AUC; *p*)		ACT P (AUC; *p*)	
MS x Psychiatric Diagnosis	.521 (.627)		.602 (.019*)	
MS x moderate to severe TBI	.558 (.232)		.536 (.463)	
MS x Cognitive Disorder NOS	.580 (.153)		.609 (.053)	
MS x mild TBI	.580 (.190)		.554 (.375)	
Psychiatric Diagnosis x moderate to severe TBI	.583 (.086)		.632 (.006**)	

Psychiatric Diagnosis x Cognitive Disorder NOS	.605 (.062)		.503 (.960)	
Psychiatric Diagnosis x mild TBI	.560 (.321)		.551 (.394)	
moderate to severe TBI x Cognitive Disorder NOS	.529 (.630)		.630 (.030*)	
moderate to severe TBI x mild TBI	.635 (.036*)		.582 (.198)	
Cognitive Disorder NOS x mild TBI	.649 (.035*)		.546 (.070)	

Notes. *significant (<.05) difference between scores, **significant (<.01) difference between scores

Given the significant group difference in age and significant ROC between the moderate to severe TBI and the cognitive disorder NOS groups (see ANOVA and ROC results above), the relationship between ACT perseveration and age was evaluated

more thoroughly to understand if the ACT perseveration improved discrimination between these groups above and beyond age alone. A hierarchical binary logistic regression was conducted where age was entered into the model followed by ACT perseveration. The addition of ACT perseveration significantly added to the model (Block Chi-Square = 9.173, df = 1, p = .002), as the age only model explained 14.4% of the variability in clinical group placement (Nagelkerke RSquare = .144). The final model revealed that age and ACT perseveration were significant predictors of clinical group (moderate to severe TBI vs. cognitive disorder NOS), which improved upon the intercept only model (Model Chi-Square = 20.270, df = 2, p < .001). This final model explained 25.2% of the variability of clinical group placement (Nagelkerke RSquare = .252). Age and ACT perseveration were significant at or below the 1% level (age Wald = 10.019, p = .002; ACT perseveration Wald = 6.723, p = .010). The model predicted 73.8% of the moderate to severe TBI cases and 50.0% of the cognitive disorder NOS cases, giving an overall percentage correct prediction rate of 64.6% though this is less than the desired standard of 25% greater accuracy rate than having no model (greater than 65.875% accuracy rate). However, the age only model correctly predicted 80.3% of the moderate to severe TBI cases and 44.7% of the cognitive disorder NOS cases with an overall percentage correct prediction rate of 66.7%, thus the final model resulted in a slight decrease in prediction accuracy. In sum, the ACT perseveration was found to be a significant predictor of clinical group beyond age alone; however, its addition into the model

slightly reduced (by 2.1%) the overall discriminative accuracy of the age alone model.

Given the significant difference in age and significant ROC between the cognitive disorder NOS and mild TBI groups (see ANOVA and ROC results above), the relationship between ACT total and age was evaluated more thoroughly to understand if the ACT total improved discrimination between these groups above and beyond age alone. A hierarchical binary logistic regression was conducted where age was entered into the model followed by ACT total. The final model was significant with age as the significant predictor of clinical group identification between cognitive disorder NOS and mild TBI groups than the intercept only model (Model Chi-Square = 17.939, df = 1, $p < .001$), explaining 30.6% of the variability of clinical group placement (Nagelkerke RSquare = .306). Age was significant below the 1% level (age Wald = 14.037, $p < .001$). The model predicted 76.3% of the cognitive disorder NOS cases and 64.5% of the mild TBI cases, giving an overall percentage correct prediction rate of 71.0% which is above the than the desired standard of 25% greater accuracy rate than having no model (greater than 63.15% accuracy rate). The addition of ACT total did not significantly add to the model (Block Chi-Square = 2.332, df = 1, $p = .127$), thus was not retained. In sum, the ACT total was not found to be a significant predictor of clinical group beyond age alone, thus did not add to the overall discriminative accuracy of the age alone model.

CHAPTER IV

DISCUSSION

Previous research aimed to understand the relationship between the ACT and other neuropsychological assessment measures to gain a better understanding of the domains of cognitive function involved in ACT performance; however, this research did not reveal a consistent relationship, with some finding relationships with measures of intelligence/word reading ability, executive functioning, working memory, attention, and/or processing speed (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016; Geurten et al., 2016). The present study aimed to improve upon the construct validity of the ACT by consolidating previous findings with specific emphasis on identifying the relationship of the ACT perseveration score with other measures of cognitive functioning, which had only been previously assessed in one prior study (i.e., Boone et al., 1998). To accomplish this, the present study aimed to conduct an EFA including neuropsychological assessment measures within all domains of cognitive functioning previously identified to be related to ACT performance (i.e., IQ, EF, WM, Attention, and PS). Further, to add to the literature on the discriminant ability of the ACT total and perseveration scores within a largely neurological sample, the present study aimed to validate and expand upon previous research regarding the clinical utility of the ACT total score within a clinical/neurological population referred for neuropsychological assessment (Anile et al., 2003; Oral et al., 2012; Stuss et al., 1989; Merkley et al., 2013; Shura et al., 2016; Dige & Wik, 2005; Ozakbas et al., 2004), while generating a novel understanding of the clinical utility of the ACT perseveration score within the same

sample. To accomplish this, the present study planned to conduct ROC analyses between all sufficiently large (i.e., greater than 30 cases) clinical groups within the collected sample for both the ACT total and perseveration scores.

Construct Validity

Regarding the planned EFA analysis, the a priori hypothesis predicted that the ACT total and perseveration scores would load on the same factor with measures of intelligence, processing speed, and executive functioning, specifically measures of working memory, as indicated by previous research (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016; Geurten et al., 2016). Results from the present study revealed a 2-factor model. The first factor included measures of verbal and visual processing speed (i.e., Stroop W, Stroop C, WAIS-IV CD, and WAIS-IV SS), attention (i.e., TMT A, TMT B), and verbal executive functioning (i.e., COWAT), while the second factor included measures of executive functioning (i.e., ACT total, WAIS-IV AR, CVLT-II 1-5, WAIS-IV DS, Stroop In, Rey-O Percent Retention, and ACT perseveration). Given these findings, the first factor, accounting for the most variance within the sample (i.e., 39.55%), appeared to be most indicative of the domains of latent attention and processing speed, whereas the second factor, which the ACT total and perseveration scores loaded on, appeared to relate latent higher-order EF functions, accounting for less variance within the current sample (i.e., 9.99%).

The EFA within the present study accounted for a similar amount of variance within the sample as in the Boone and colleagues' (1998) and Mertens and colleagues' (2006) EFAs at 49.54% variance accounted for compared to 55% and 46.7%,

respectively. In addition, in all cases (i.e., the present study; Boone et al., 1998; Mertens et al., 2006) the factor loading the ACT accounted for the least amount of variance within the factor structure at 9.99% in the present study, 13% (Boone et al., 1998), and 10.61% (Mertens et al., 2006). These results are not surprising given the inclusion by all three studies of similar overlapping neuropsychological measures within the EFAs, suggesting some consistency across studies even in the context of different samples.

Congruent with previous findings, the present study found a consistent relationship between the ACT total and perseveration scores with WAIS-IV DS, WAIS-IV AR, RCFT % Retention, and Stroop In (Boone et al., 1998; Mertens et al., 2006; Geurten et al., 2016). In contrast, the present study did not reveal significant relationships between the ACT total and perseveration scores with WAIS-IV CD, TMT A, and Stroop C as found in previous studies, in that the ACT total and perseveration scores did not load on the same factor as these measures (Boone et al., 1998; Shura et al., 2016; Geurten et al., 2016). These findings provide convergent validity for the ACT as a measure of executive functioning as opposed to a measure of processing speed or attention, as previously suggested (Boone et al., 1998; Shura et al., 2016).

With regard to measures of IQ and premorbid IQ, though previous research found significant relationships in EFA analysis, regression, and correlational research, these measures were ultimately not included in the present study's EFA. The planned measure of premorbid IQ (i.e., WRAT4 WR) evidenced greater than 10% missing data points, thus was eliminated during data screening. Additionally, the planned measure of IQ (i.e., WAIS-IV FSIQ) was initially included in the EFA; however, it was ultimately removed

due to overlapping variance with other WAIS-IV measures, as the score is derived from other WAIS-IV subtests used in the EFA. This variable relationship pooled WAIS-IV measures onto the same factor, thus limiting the expression of WAIS-IV subtests relationships with the ACT total and perseveration scores in the EFA. Though a limitation of the current study, an independent measure of IQ was not identified within the current sample, thus general intelligence was eliminated as a domain assessed.

A novel finding of the current study was that the ACT total and perseveration scores loaded on the same factor with verbal learning (i.e., CVLT-II 1-5 Total), an EF measure, which had not been previously identified by other researchers. While previous research had included multiple measures of verbal learning and memory, these measures were found to load on a "memory and tracking of information" factor separate from the ACT total score performance (Mertens et al., 2006). Mertens and colleagues' (2006) previous finding was not surprising given the inclusion of numerous measures of verbal memory with multiple sub-scores from each measure, resulting in strong relationships leading to high amounts of shared variance. Given that the present study only included one measure of verbal learning, the relationship between verbal learning and aspects of executive functioning was elicited.

The ACT total and perseveration scores' evidenced relationship with measures of EF in the present study is not a novel finding as previous studies have suggested relationships with measures of short-term memory, working memory, and executive functioning (Boone et al., 1998; Mertens et al., 2006; Geurten et al., 2016). Further, a recent article by Aita and colleagues (2019) included the ACT total

score in an EFA of measures of EF to assess the construct validity of verbal fluency measures (i.e., semantic and phonemic) as measures of executive functioning within healthy college students. The EFA revealed the ACT total score loaded with measures of working memory (i.e., Reading Span, requires the participant to mentally hold series of letters of increasing length with a distraction task of reading and identifying the truthfulness of sentence; and Operation Span, requires the participant to remember series of letters of increasing length with a distraction task of simple mathematical problems) on a factor that accounted for 34.25% of variance out of 61% total variance within their sample (Aita et al., 2019). Alternatively, the ACT total score did not load with measures of "fluid reasoning" (i.e., WAIS-IV Block Design, WAIS-IV Matrix Reasoning, Raven's Progressive Matrices) or measures of "shifting/updating" (i.e., TMT B, Paced Auditory Serial Addition Test, Shifting Attention Test; Aita et al., 2019). This study further validated the ACT total score as a measure of EF, more specifically a measure of working memory.

Previous research on the ACT proposed that the ACT total score and in some cases the Perseveration score likely represent a variety of cognitive domains and premorbid abilities, including: education, IQ, premorbid IQ, EF, WM, Attention, and PS (Boone et al., 1998; Mertens et al., 2006; Shura et al., 2016; Geurten et al., 2016). The present study suggested that ACT total and perseveration score performances are more closely related to other measures of executive functioning within the current clinical population, which was also validated by Aita and colleagues (2019), who, within a

healthy sample, reported the ACT total score's relationship with measures of working memory. Though direct comparison between the two studies is limited, given the use of measures of processing speed and attention in the present study, as well as sample differences (i.e., healthy versus clinical), future research is indicated to replicate a similar EFA of EF measures with the inclusion of both the ACT total and perseveration scores within healthy and clinical samples. The purpose of this prospective study would be to aid in further differentiating the ACT total and perseveration scores within only measures of EF, which may aid in identifying differential executive processes between the two scores. Though Boone and colleagues (1998) reportedly assessed "measures of prefrontal lobe functioning," their inclusion of EF factors was limited and did not represent an extensive sampling of EF measures or subdomains. Future research should strategically include EF measures covering the broad EF subdomains of shifting, updating, and inhibition established by Miyake and colleagues (2000), as well as other higher-order mental processes, that is, planning, problem-solving, and abstract reasoning routinely considered within the EF domain of cognitive functioning (Collins & Koechlin, 2012).

Implications of Principle Factors Extraction Method and Promax Rotation on the EFA

An EFA using principle factors (also called principal axis factoring) with a promax rotation was selected for the current study based upon the congruence of the extraction method with study goals and variable characteristics, as well as correspondence with previous research. Alternatively, other extraction and rotation methods may have yielded different results and interpretations. Principal factor was selected in order to assess the shared variance between variables as this extraction

method attempts to eliminate both unique and error variance from each of the variables entered (Tabachnick & Fidell, 2013). Alternatively, Principle Component Analysis (PCA) would have also been a reasonable extraction method for the current data and research questions, as both are methods aimed at maximizing the variance extracted by orthogonal components or factors. In contrast, in PCA, the final solution includes common, unique, and error variance within the components, which may contaminate the final factor solution resulting in a factor structure that is more difficult to interpret (Tabachnick & Fidell, 2013). Given the nature of the present study's sample with diverse clinical presentations and overlapping comorbidities, the more conservative principle factors method was selected to reduce the impacts of unique and error variance, in order to simplify interpretation of the factor structure. The reader should be aware that the communalities used in the principle factors extraction method are an estimation of the common variance between variables with potential for error in underestimating this variance, whereas the PCA extraction more closely aligns with the direct correlations seen in the original correlation matrices within the sample (Tabachnick & Fidell, 2013). This discussion serves to highlight the strengths and weaknesses of both extraction methods for the reader and to serve as an explanation for why the principle factors extraction method was selected.

Further, regarding the rotation method, the oblique promax rotation method was planned and performed as it allowed for the correlation between factors, which was expected within the current sample, given the results from previous similar EFAs (Boone et al., 1998; Mertens et al., 2006). This method was selected as its specific goal is to

rotate orthogonal factors into oblique rotations, allowing for correlations among factors and maximizing clarity by identifying which variables do and do not correlate with the factors (Tabachnick & Fidell, 2013). Thus, this method was identified as best suited given previous EFA findings and the goals of the current analysis; however, other alternative oblique rotation methods may have revealed differing results and interpretations as they simplify or rotate the factor structure using differing methods (e.g., minimizing cross-products of loadings, rescale factor loadings; Tabachnick & Fidell, 2013).

Additional Limitations and Future Directions of the EFA

The impact of variable deletions (i.e., IVA + Auditory Prudence, IVA + Auditory Vigilance, WAIS-IV LN, CVLT-II 1, VSAT Time, WRAT4 WR) and elimination of WAIS-IV FSIQ is somewhat unknown. If retained in the EFA as planned, these variables may have had a significant impact on the overall factor structure. It is known that the reduction in planned variables reduced the number of EF, attention, and IQ measures included in the present study analyses, which may have underrepresented relationships that exist within the clinical sample. Similarly, the use of mean substitution methods for other retained variables (i.e., WAIS-IV AR, DS, CD, and SS; CVLT-II 1-5; RCFT % Retention; STROOP C, W, In; WCST PE; COWAT; and TMT A and B) reduced the overall variability within these variables, which may have limited additional factor identification or clarity. As EFA methods are highly influenced by the variables included, variability within the sample, and relationships between variables, it is likely the deletion of planned variables and the use of mean substitution methods impacted the underlying

factor structure in unforeseen ways (Tabachnick & Fidell, 2013). Given the archival nature of the current study with a priori test selection and extensive missing data not at random, the reduction in variables was unplanned, thus future research is indicated to understand the ACT total and perseveration score relationships within a more extensive sampling of EF measures.

Regarding the sample within the present study and its impact on the EFA, the heterogeneous nature of the overall sample and heterogeneity within each of the clinical groups may have negatively impacted the EFA. In the EFA, though the present study aimed to understand the relationship of the ACT scores with other measures in a clinical data set, it is possible that the factor structure of these variables may be different within each clinical group included, thus rendering the resulting overall factor structure less meaningful. Further, within each clinical group, there was extensive heterogeneity due to differences in clinical presentation and severity, as well as differing comorbidities. Thus, the current factor structure may represent variable loadings that are not necessarily consistent between all groups included. As such, future research may aim to understand the unique factor structures within diagnostic categories or clinical presentations, i.e., more homogeneous groups, rather than an overall clinical group. A more homogeneous clinical sample may have yielded a substantially different factor structure and variable relationships with the ACT total and perseveration scores. While assessing neuropsychological measures within a clinical sample can be useful, as there may be more pervasive deficits and differing relationship patterns, this same variability may also

confound cumulative analyses or non-group specific analyses such as EFA. This limitation should be considered when assessing the results of the current EFA.

Criterion Validity

Previous research on the ACT had assessed the discriminant ability of the ACT total score in predicting clinical group membership with numerous significant results, though mixed. Within TBI samples, previous research on the predictive ability of the ACT total score reported discriminant ability between mild and severe TBI (Stuss et al., 1989; Merkley et al., 2013) but no difference in performance between mild TBI and no TBI samples. With regard to MS samples, previous findings revealed the ACT total score differentiated relapsing-remitting MS and clinically isolated syndrome from secondary progressive MS (Ozakbas et al., 2004). Within psychiatric presentations, the ACT total score had been shown to not predict PTSD symptoms (Shura et al., 2016); however, alternatively, it did predict symptoms of MDD (Shura et al., 2016; Oral et al., 2012) and ADHD (Dige & Wik, 2005). In sum, previous research assessing the clinical utility of the ACT total score was limited with mixed findings, while the clinical utility of the ACT perseveration score had not been previously assessed.

Regarding the present study, given the exploratory nature of the planned ROC analyses within unknown clinical/neurological populations, no a priori hypotheses were made for the comparisons between clinical groups with regard to the predictive utility of the ACT total and perseveration scores. After conducting all ROC analyses with the ACT total and perseveration scores between all possible combinations of the MS, psychiatric diagnosis, moderate to severe TBI, cognitive disorder NOS, and mild TBI clinical groups,

the results revealed that the ACT total score significantly differentiated between the moderate to severe TBI and mild TBI groups, and between the cognitive disorder NOS and mild TBI groups, though it was a poor predictor. Follow-up analysis between the cognitive disorder NOS and mild TBI groups was necessary due to the significant group difference in age. The results revealed that age alone accounted for the previous finding without significant discriminant utility added by the ACT total score. This finding suggests that the significant AUC for the ACT total score between the cognitive disorder NOS and mild TBI groups is rather subsumed by variation in age between the two groups resulting in limited discriminate ability of the ACT total score in this clinical group comparison.

Further, the results revealed the ACT perseveration score significantly predicted between the MS and psychiatric diagnoses groups, the psychiatric diagnosis and moderate to severe TBI groups, and the moderate to severe TBI and cognitive disorder NOS groups, though was a poor predictor. Follow-up analysis between the moderate to severe TBI and cognitive disorder NOS groups was necessary due to the significant group difference in age. The results revealed that age and unique variance from the ACT perseveration score accounted for the previous finding, with age being the strongest predictor of group membership. This finding suggests that the ACT perseveration score is useful as a predictor between the moderate to severe TBI and cognitive disorder NOS groups, though there is a significant group difference in age within the current sample. No other group comparisons revealed the ACT total or ACT perseveration scores to be significant predictors of clinical group membership.

An overall interpretation of these findings within the current sample suggests that while the ACT total score may have limited utility in discriminating the severity of brain damage within TBI, the ACT perseveration score evidenced a trend of more consistent utility in discriminating diagnostic groups. More specifically, The ACT perseveration score discriminated between those groups with acquired executive functioning deficits (i.e., MS and moderate to severe TBI) from those without (i.e., psychiatric diagnosis and cognitive disorder NOS) in most cases (i.e., except in the comparison between MS versus cognitive disorder NOS). While there are potentially numerous explanations for these findings, two recent publications from the same longitudinal study may provide insight into the current results. These studies revealed that the ACT total score alone was not sensitive to subjective cognitive changes in mild TBI (Karr et al., 2019). Alternatively, fMRI data revealed differential resting state functional connectivity in the frontal-temporal brain regions between the mild TBI group and controls, with increased activation in the mild TBI group being significantly related to improved ACT total score performance, representing a compensatory change (Pagulayan et al., 2018). These results indicate that while the ACT total score was not effective in discriminating between the clinical and control groups, ACT total score performance was associated with significant changes in brain activation. Of note, the ACT perseveration score was not assessed within the two aforementioned studies. Thus, condensing the findings of the present study with these two studies may indicate that, though there are likely declines in EF or working memory, the ACT total score is not effective in identifying these changes; whereas the ACT perseveration score may be more clinically useful, especially in

discriminating clinical groups with more significant EF dysfunction (i.e., in MS and moderate to severe TBI) from those without. Though, even the ACT perseveration score may not be effective in identifying mild EF dysfunctions, suggesting that the ACT scoring methods may be too simplistic to identify subtle cognitive changes in clinical populations. This is reiterated by the current study as evidenced by the inability of the ACT total and perseveration scores to discriminate between mild TBI and psychiatric groups, as well as between mild TBI and cognitive disorder NOS groups.

No previous studies had evaluated the clinical utility of the ACT perseveration score, thus the present study revealed novel discriminative ability between clinically relevant presentations (i.e., MS and psychiatric diagnoses, psychiatric diagnoses and moderate to severe TBI, and moderate to severe TBI and cognitive disorder NOS) using this sub-score of the ACT. Though previous factor analytic research (Boone et al., 1998) and the present study found the ACT total and perseveration scores to load on the same factor with each other, the ACT total and perseveration scores shared 27.04% (r = -0.52; Boone et al., 1998) and 11.49% (r = -0.339, $p < .001$; present study) variability, respectively, suggesting medium to large effects but with limited overlapping variability (Field, 2013). These findings suggest that though there is a strong relationship between the two scores, there remains variance unaccounted for (i.e., 72.96% and 88.51%) by this relationship, comprised of unique and error variance. Research to date has been unable to differentiate the specific differences in latent construct relationships which may account for the unique variance between the ACT perseveration and ACT total scores. These combined results may suggest that the two scores, though significantly related, are

measuring different aspects of underlying cognitive performance on the ACT task resulting in the differential discriminant ability seen between clinical presentations in the current study.

Limitations and Future Directions of ROC Analyses

In the ROC analyses, the clinical groups were highly heterogeneous with many stages/types of the overarching medical conditions, as well as many comorbidities. Notably, as examples, the brain injury groups included individuals at different stages of recovery and the MS group contained all types of MS at all stages of the disease process. Including such variability within each clinical group likely reduced the discriminative utility of the ACT scores, whereas ideally, the study would have had enough patients/information within each group to understand differences between acute vs. post-acute, in severity, and different subtypes of clinical presentation, etc. Future research within subsets of these clinical groups may aid in understanding the ACT's clinical utility further beyond the results of the current study.

Due to the archival nature of the present study, criterion contamination may be present, that is, the ACT total and perseveration scores may have significantly influenced the subject's inclusion in their clinical group. If this were the case, the ROC results may have been inflated. Though possible, given the multifaceted nature of neuropsychological evaluations with use of many data points, e.g., history, physical presentation, neuropsychological assessment results, imaging, lab results, etc., it is unlikely that the ACT total score, the only score used clinically within this sample, would have been used

as a sole or even significant determinant of diagnostic group within the clinical determination.

Limitations and Future Directions

Regarding the scoring of the ACT perseveration variable, though the utilized scoring method has been used by other authors (i.e., Boone et al. 1998), theoretically there are alternative or additional ways to score perseveration within this measure. Notably, one could choose to score perseverations based upon the length the perseverative response is maintained rather than all instances of perseverations, as was the case in the present study. Though this scoring method was not selected, future research may be indicated to identify the costs and benefits of both scoring methods, as well as differences in discriminant usefulness.

In conclusion, the present study aimed to clarify the construct and criterion validity of the ACT total and perseveration scores, within a clinically referred sample. Results suggested that the ACT total and perseveration scores load on the same factor with other measures of executive functioning. These findings indicate that though previous research has suggested the ACT loads with other domains of cognitive functioning, the current study and a recent study by Aita and colleagues (2019) suggest the ACT total and perseveration scores are more closely related to other measures of executive functioning in healthy and clinical samples. Further, relating to criterion validity, the present study revealed that the ACT total and perseveration scores evidence differential discriminative utility between clinical

groups, a novel finding. Such that the ACT perseveration score may be more useful in discriminating diagnostic groups. Considering the limitations within the present study (i.e., deletion of variables due to missing data, heterogeneity within the sample and diagnostic groups), future studies are warranted to address the construct and criterion validity more thoroughly with a more comprehensive measure of EF and within more clinical presentations (e.g., ADHD, subsets of clinical presentations, dementias).

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