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THE ALPHABACK: A NOVEL PROCESSING SPEED TEST

By

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Dissertation

Presented in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in Clinical Psychology

The University of Montana
Missoula, MT

May 2019

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Acknowledgements

I would like to thank my graduate school advisor, Dr. Stuart Hall, who dedicated considerable time and energy to my training and research in clinical neuropsychology. Thank you for your mentorship and for believing in me. I hope I can make a meaningful contribution to the field of neuropsychology as the 21st graduate student of the Hall lab legacy. I would also like to thank the clinical psychology faculty, clinical supervisors, and committee members at the University of Montana for their part in my development throughout my graduate training.

Thank you to my friends and colleagues for their support and assistance over the years. A special thank you to Phoebe, Heather, and Brook - I would not have made it through graduate school without you. I would also like to acknowledge all of the help I received from undergraduate research assistants, as well as participants, who made my research including this dissertation possible.

Thank you to my mom, dad, Judy, and Shana for providing unending love and support. This dissertation is dedicated to you. I hope I made you proud. I would also like to thank my best friend, Linden. Thank you for editing my papers, answering my stats questions, and sharing in my laughter and tears from the other side of the continent. The Dream Team is still going strong after all of these years. A thank you and an arm stretch goes out to Sally for always being there to provide comfort. And last but not least, thank you to Graham for your love, support, and humor during the most difficult and grueling part of my academic career. Here's to many more happy years together.

Reynolds, Meredith, Ph.D., May 2019 Clinical Psychology

The Alphaback: A Novel Processing Speed Test

Chairperson: Stuart Hall, Ph.D.

Processing speed is a sensitive indicator of normal aging, as well as neurological impairment. Despite the importance of assessing this cognitive domain in neuropsychological assessments, few tests of processing speed are available. The purpose of the current study was to establish the operating characteristics, as well as the convergent and divergent validity of a novel processing speed test, the Alphaback, on a healthy college student population ($N = 91$). The Alphaback is a 2 min computerized task in which examinees must orally state the alphabetical letter that precedes the letter presented on a screen as fast as possible. Cognitive tests included as measures of convergent and divergent validity included WAIS-IV Coding, WAIS-IV Symbol Search, WASI-2 FSIQ-2, WASI-2 Vocabulary, COWA, CTOPP-2 Rapid Naming, Beery VMI, and WASI-2 Matrix Reasoning. Correlation analyses revealed significant correlations between total correct scores on the Alphaback and WAIS-IV Coding ($r = .32$, $p < .01$), WAIS-IV Symbol Search ($r = .21$, $p < .05$), COWA ($r = .28$, $p < .01$), and WASI-2 Matrix Reasoning ($r = .21$, $p < .05$). The Alphaback was also rated the least likable (equal to WASI-2 Vocabulary) and the most difficult compared to other cognitive tests. The findings strongly suggest that the Alphaback is a test of processing speed, establishing the convergent validity of the test. With further validation, the Alphaback may be a new test of processing speed that clinical neuropsychologists can use to assess processing speed deficits in a wide variety of clinical populations.

Keywords: processing speed, the Alphaback, neurological disease

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The Alphaback: A Novel Processing Speed Test

Processing speed – the speed at which an individual can carry out mental activities or motor responses – has long been considered an important part of intelligence and general cognitive abilities (Lezak, Howieson, Bigler, & Tranel, 2012). As far back as 1890, Cattell used tests of rudimentary psychomotor speed tests such as reaction time to an auditory stimulus (Cattell & Galton, 1890). Processing speed tests are still a part of modern neuropsychological test batteries.

Measuring processing speed is important because it is considered a major contributor to individual differences in psychometric intelligence, the type of intellectual abilities that are measurable with intelligence tests such as the traditional Wechsler Adult Intelligence Scale (e.g., Deary, 2001). Deary pointed out that although researchers argue there are many types of intelligence, psychometric intelligence is a particularly important indicator of cognitive abilities because it has high predictive validity for educational and occupational success (e.g., Jensen, 1998; Schmidt & Hunter, 1998). General cognitive and reasoning abilities (also known as *g*) are a large source of variance (50%) in psychometric intelligence, and performance on processing speed tests loads highly ($r = .78$) with *g* in factor analytic studies (Deary, 2001).

Processing speed is also considered a major component in the *development* of intelligence in childhood and adolescence (Coyle, Pillow, Snyder, & Kochunov, 2011). Kail (2007), for instance, demonstrated that increases in children's processing speed enhance the function of working memory. Working memory is a type of short-term memory storage that allows one to mentally manipulate information such as when problem solving or rotating/sequencing different items (Lezak et al., 2012). When the capacity of these children's working memory grew, their reasoning ability (or *g*) improved. Thus, enhances in processing speed throughout childhood appeared to have a positive impact on intelligence. Coyle et al. (2011) also showed that increases in processing speed mediated improvements in intelligence throughout adolescence. The authors repeated Thorndike, Bregman, Cobb, and Woodyard's (1927) argument that processing speed *is* intelligence. Coyle et al. (2011) then used their findings to extend that argument to state that processing speed is also a major contributor to the development of intelligence throughout childhood and adolescence.

Processing speed also has been shown to play an important role in memory. In a review of the literature, Dempster (1981) found that the speed with which a person could identify individual items in a series explained individual differences in memory span length. In other words, fast processing speed – and not various memory-enhancing strategies like rehearsal, grouping, chunking, or a large capacity to process information – contributed to an ability to remember a long series of items such as numbers, letters, or words.

Processing Speed and Aging

Processing speed has been shown to be a sensitive indicator of the subtle cognitive declines associated with normal aging. Although many cognitive functions such as verbal abilities, autobiographical memory, and emotional processing remain stable across the lifespan, other functions including working memory and processing speed decline throughout life beginning at approximately age 20 (Hedden & Gabrieli, 2004; Wisdom, Mignogna, & Collins, 2012). These declines in processing speed have functional implications in older adults' everyday life. For example, slowed processing speed is related to reduced mobility (Zettel-Watson, Suen, Wehbe, Rutledge, & Cherry, 2017), poor driving performance (Anstey, Wood, Lord, & Walker, 2005; McInerney & Suhr, 2016), difficulty completing activities of daily living (Bezdicek, Stepankova, Novakova, & Kopecek, 2016; Reppermund et al., 2010), and reduced quality of life

(Barker-Collo, 2006). Processing speed is such a sensitive indicator of aging that deficits in processing speed are predictive of earlier death even after controlling for factors known to affect longevity (Deary & Der, 2005). Some evidence suggests that processing speed is an even better biological marker of aging than chronological age (Deary, Johnson, & Starr, 2010).

A debate exists within the field of cognitive aging as to whether processing speed concurrently *shows* age-related declines along with other cognitive domains, or slowed processing speed is the *cause* of age-related declines in other domains. Salthouse (1985, 1996) first proposed the latter theory of slow processing speed causing declines on cognitive tests, and there is evidence to support this idea. Using cross-sectional methodology, Park et al. (1996) demonstrated that processing speed mediated performance on long-term free recall, cued recall, and spatial memory tests in adults aged 20-60. The authors argued that age-related declines on long-term memory tasks across the adult lifespan are explained by age-related decreases in processing speed. Park et al. (2002) then followed up their 1996 study by examining the effect of processing speed on short-term memory stores, working memory, and long-term memory using a cross-sectional design. Again, Park et al. (2002) found that processing speed accounted for age-related differences seen on the short-term, long-term, and working memory tasks.

There is longitudinal evidence; however, to support the theory that processing speed declines simultaneously with other cognitive domains and is not the underlying cause of these declines. When people are studied longitudinally, the mediating effect of processing speed on other cognitive domains is substantially reduced. For example, Lemke and Zimprich (2005) found that 37% of the variance associated with changes in verbal, non-verbal, and implicit memory performance was accounted for by changes in processing speed. This result indicates that although decrements in processing speed do play a substantial role in decreased memory ability over time, there is also a large portion of variance in memory performance that is related to other factors.

Zimprich and Martin (2002) similarly examined changes in processing speed and fluid intelligence in older adults. Fluid intelligence is typically conceptualized as abstract reasoning used in novel situations and/or with novel stimuli on which general knowledge and education have little bearing. Deary (2001) noted that fluid intelligence is akin to *g*. Zimprich and Martin (2002) found that changes in processing speed accounted for 28% of the variance in changes in fluid intelligence over 4 years. The authors reiterated the argument that although processing speed *does* account for some of the declines seen in other cognitive domains, the effect of processing speed is attenuated when examined in longitudinal studies versus cross-sectional methodology.

Processing Speed and Neurological Impairment

Much like with normal aging, processing speed declines with subtle neurological impairment. For example, Hawkins (1998) demonstrated that the processing speed index on the Wechsler Adult Intelligence Scale – III (WAIS-III; Wechsler, 1997) was a particularly sensitive index score of neurological dysfunction on the WAIS-III for a variety of clinical populations including Alzheimer's disease, Huntington's disease, Parkinson's disease, traumatic brain injury (TBI), alcohol use disorders, alcohol-related dementia, and schizophrenia.

Martin, Donders, and Thompson (2000) investigated cognition in people who had sustained TBIs. They examined the sensitivity to impairment of two intelligence tests, the WAIS-III and the General Ability Measure for Adults (GAMA; Naglieri & Bardos, 1997), and found that overall measures of intelligence on either intelligence test were insensitive to impairment related to TBI. The processing speed index; however, distinguished between healthy controls, people with mild TBI, and those with moderate-to-severe TBI. Those in the moderate-to-severe TBI group had significantly slower processing speed than those in the mild TBI or healthy control group.

Like Martin et al.'s (2000) earlier findings, Donders, Tulsky, and Zhu, (2001) found that people with a moderate-to-severe TBI scored significantly lower on WAIS-III processing speed subtests (i.e., Digit Symbol Coding and Symbol Search) along with a measure of working memory (i.e., Letter-Number Sequencing), compared to those with a mild TBI or healthy controls. The other WAIS-III subtests measuring verbal comprehension and perceptual reasoning showed no difference. The authors argued that processing speed measures could be used as part of a neuropsychological battery of tests to establish neurological impairment in populations with TBIs.

Sawamoto, Honda, Hanakawa, Fukuyama, and Shibasaki (2002) examined processing speed in patients with mild Parkinson's disease. The authors assessed patients on processing speed tasks that did not involve a motor component in order to control for the effect of bradykinesia (slow movements) and other movement problems that are associated with the progressive disorder (Kolb & Whishaw, 2009). They found that even those with early stage Parkinson's disease exhibited slowed processing speed independent of any motor slowing.

Deficits in processing speed have long been detected in patients with multiple sclerosis (MS), a disorder of the immune system that causes demyelination in the central nervous system (Kolb & Whishaw, 2009). Archibald and Fisk (2000) found that processing speed was the only cognitive domain that was significantly decreased in those with MS compared to controls after controlling for the effects of depression, fatigue, and functional disability. Only those with a more severe progression of MS had additional deficits in working memory. DeLuca, Chelune, Tulsky, Lengenfelder, and Chiaravalloti (2004) later replicated Archibald and Fisk's (2000) finding that processing speed is the primary cognitive deficit in MS with working memory deficits appearing later in the disease progression.

Llorente et al. (1998) also found that processing speed was depressed in a group of patients with human immunodeficiency virus-1 (HIV-1), the most prevalent form of HIV that causes compromised immune system functioning that eventually leads to acquired immune deficiency syndrome (AIDS) and death (Parsons, 1996). Llorente et al. (1998) compared those with symptomatic HIV-1, asymptomatic HIV-1, and those who were HIV-1 negative. The researchers found that only those who were symptomatic demonstrated slowed processing speed, leading to the conclusion that HIV-1 affects processing efficiency only in the later stages of the viral infection.

These results demonstrate that processing speed is usually the first neuropsychological domain to reveal subtle neurological deficits in a wide range of clinical populations. The array of populations that experience slowed processing speed cannot be overstated. Even systemic diseases that do not directly damage to the central nervous system (e.g., chronic fatigue syndrome, sickle cell anemia) are associated with processing speed deficits (DeLuca et al., 2004; Vichinsky et al., 2010).

The Factor Structure of Processing Speed

Once thought to be a unitary construct, there is some evidence to suggest that processing speed is multi-factorial. Using factor analysis, Chiaravalloti, Christodoulou, Demaree, and DeLuca (2003) demonstrated that various processing speed tests loaded onto "simple" and "complex" factors. Tests of simple processing speed involve a motor response following recognition of a stimulus such as a reaction time test. Conversely, complex processing speed tasks require mental manipulation, concentration, and attention. It is noteworthy; however, that Chiaravalloti et al. used different versions of the Paced Auditory Serial Addition Test (PASAT; Gronwall & Sampson, 1974), a notoriously demanding test of processing speed, attention, and working memory, as their processing speed measures. Chiaravalloti et al.'s (2003) result may speak to the multifactorial nature of the PASAT, in particular, and not necessarily processing speed, in general.

Tests of Simple Processing Speed

Tests of simple processing speed, simple and choice reaction time and inspection time, are rarely used in neuropsychological evaluations and are typically used in experimental cognitive psychology studies (Deary et al., 2010). Inspection time involves visual discrimination of stimuli without requiring a motor response. As mentioned earlier, reaction time tests involve a simple motor response following the recognition of a stimulus. Choice reaction tests add a layer of complexity to the task such that examinees must respond to certain stimuli while inhibiting responses to others. Lezak et al. (2012) consider both simple and choice reaction time tests as a proxy for measuring processing speed and attention. Reaction time tests are sensitive to injury and cognitive slowing in a variety of clinical populations including depression, severe TBI, MS, and Parkinson's disease; however, the usefulness of these tests in clinical settings is limited due to a lack of established normative data.

The N-Back task is another test of processing speed, as well as working memory, frequently used in functional magnetic resonance imaging (fMRI) studies. Items are presented in a series and the examinee must respond whether the current item is the same as the item "n" (typically 1 to 3) steps back (Lezak et al., 2012). In a 2-back condition, for example, the examinee would respond "yes" following the second 2 for the series: 5-4-3-2-1-2. The N-Back task is sensitive to normal aging and distinguishes those with MCI from people who are cognitively intact (Lezak et al., 2012). As with reaction time tests, the usefulness of the N-Back task in clinical settings is limited given a lack of normative data.

Tests of Complex Processing Speed

Tests that measure relatively more complex processing speed are used in neuropsychological evaluations. Commonly used psychometric tests of processing speed are symbol substitution tests such as the Coding subtest of the WAIS-IV (Wechsler, 2008) and the Symbol Digit Modalities Test (SDMT; Smith, 1982). The Coding subtest has a key of nine digits that are paired with different symbols. A random series of the nine digits is presented on the paper, and the examinee must copy the symbol that corresponds with the number as fast as possible within the specified time (120 s for Coding and 90 s for SDMT). For the SDMT, the presentation is reversed and the examinee must copy the number that corresponds with the symbol. An oral version of the SDMT also exists and it is recommended that examinees complete both versions to allow comparison between the modalities (Lezak et al., 2012).

Both symbol substitution tests are sensitive to minimal brain damage and is one of the first tests to reveal subtle cognitive decline in people with MCI. Slow performance on the tests also distinguishes people with vascular disease, pre-symptomatic Huntington’s disease, chronic alcoholism, or HIV from people who are neurologically intact (Lezak et al., 2012). Despite the sensitivity of WAIS-IV Coding subtest, its reliance on visuomotor skills and manual agility make it a less than ideal test of processing speed for elderly populations or those with physical disabilities. The SDMT, on the other hand, is advantageous since comparisons between the oral and visuomotor versions are available.

The Symbol Search subtest of the WAIS-IV (Wechsler, 2008) is another commonly used paper and pencil test of processing speed that contains rows of symbols on the page. Each row contains two “target” symbols on the left of the page and five other symbols and a box with the word “no” next to these target symbols. Examinees must mark the symbol that matches one of the target symbols, or mark the “no” box if none of the symbols match the target symbols, as fast as possible within a specified amount of time (120 s).

Slow performance on the Symbol Search subtest distinguishes those with borderline intellectual functioning, mild intellectual disability, moderate-to-severe intellectual disability, moderate-to-severe TBI, autism spectrum disorder, and mild Alzheimer’s disease from healthy controls (Wechsler, 2008). Problems with the test arise; however, with its reliance on motor movement and manual dexterity much like the symbol substitution tests.

The Paced Auditory Serial Addition Test (sometimes referred to as the Paced Auditory Serial Addition Task [PASAT]; Gronwall & Sampson, 1974) was once considered the gold standard of processing speed tests due to its sensitivity to mild neurological impairment and ability to detect subtle age-related cognitive slowing (e.g., Brittain, La Marche, Reeder, Roth, & Boll, 1991; Spikman, Deelman, & van Zomeren, 2000). The PASAT consists of four aurally presented trials of a series of 61 random digits from one to nine in each trial and the examinee must continuously orally state the sum of the last two digits of the series. For example, the examinee sums the second number of the series, five, to the first number, seven, and responds, “12,” then sums the third number of the series, one, to the second number of the series, five, and responds, “six,” and so on. The inter-stimulus interval pace of the aural presentation of the digits increases in each trial from 2.4 s, 2.0 s, 1.6 s, to 1.2 s, respectively.

Despite the PASAT's ability to detect mild neuropsychological deficits, it is a long, difficult test that is fraught with a number of problems (Tombaugh, 2006). Its problems include its correlation with mathematical abilities (e.g., Crawford, Obonsawin, & Allan, 1998; Sherman, Strauss, & Spellacy, 1997) and intelligence (e.g., Deary, Langan, Hepburn, & Frier, 1991; Crawford et al., 1998), its stress-inducing paradigm (e.g., Diehr et al., 2003; Mathias, Stanford, & Houston, 2004) and significant practice effects (e.g., Gronwall, 1977; Schächinger, Cox, Linder, Brody, & Keller, 2003). Various alternative versions of the PASAT have attempted to correct for these problems albeit unsuccessfully for the most part (e.g., Dyche & Johnson, 1991; Levin et al., 1987; Tombaugh, 1999). Lezak et al. (2012) recommended "…deficits can be elicited in less painful ways, it seems rarely necessary to give the PASAT" (p. 412).

The Computerized Test of Information Processing (CTIP; Tombaugh & Rees, 2008) is a relatively new test of processing speed. It has three progressively more complex subtests of simple reaction time, choice reaction time, and semantic search reaction time that involves determining whether a word belongs to a category (e.g., spoon belongs to the category of utensils). Although the CTIP is well tolerated by examinees (Walker et al., 2012) and shows promise as a sensitive measure of processing speed (e.g., Smith et al., 2012; Tombaugh, Berrigan, Walker, & Freedman, 2010; Tombaugh, Rees, Stormer, Harrison, & Smith, 2007), research demonstrating the effectiveness and sensitivity of the CTIP has been conducted on only two clinical populations (i.e., MS and TBI) thus far.

The CTIP also has embedded symptom validity measures to detect those exaggerating or malingering attentional deficits. In fact, Lezak et al. (2012) conceptualize the CTIP primarily as a symptom validity test that provides an alternative from the typical forced-choice paradigms. Longer response latencies and specific subtest profiles on the CTIP detect malingering as well as, or even better than, the Test of Memory Malingering (TOMM; Tombaugh, 1996), a commonly used symptom validity test (Willison & Tombaugh, 2006).

The National Institutes of Health (NIH) has also recently validated a new processing speed test, the NIHTB Pattern Comparison Processing Speed Test (Carlozzi et al., 2014), as part of the NIH Toolbox Cognitive Battery (NIHTB-CB). The NIHTB-CB is an attempt to create a standardized, well-validated, brief, and inexpensive battery of neuropsychological tests that will enhance cross-study comparisons of cognitive functioning (Gershon et al., 2010). The NIHTB Pattern Comparison Processing Speed Test requires examinees to respond whether two visual stimuli are the same or different as fast as possible within a specified timeframe (90 s). The stimuli vary on dimensions of color, missing pieces, or number.

Initial validation of the NIHTB Pattern Comparison Processing Speed Test shows stable test-retest reliability for a period of 15.5 days ($r = .73$) with small practice effects. The test is sensitive to normal aging and demonstrates convergent validity with WAIS-IV Coding ($r = .50$), Symbol Search ($r = .52$), and Processing Speed Index ($r = .54$; Carlozzi et al., 2014). Much like the CTIP, however, the NIHTB Pattern Comparison Processing Speed Test has been validated on a limited number of clinical populations, namely a small sample ($N = 18$) of people with diffuse gliomas (Lang et al., 2016).

The Present Study

The literature shows that processing speed is an important cognitive domain that reveals subtle neurological deficits. Despite the importance and sensitivity of processing speed, there is a relatively few number of processing speed tests and each have associated problems (e.g., a lack of or limited normative data, reliance on manual dexterity, practice effects, reliance on IQ or mathematical abilities, or aversive experience of taking the test; Crawford et al., 1998; Deary et al., 1991; Diehr et al., 2003; Gronwall, 1977; Lezak et al., 2012; Mathias et al., 2004; Schächinger et al., 2003; Sherman et al., 1997; Wechsler, 2008). There is a clear need for alternative processing speed tests that: (a) are sensitive to mild neurological deficits, (b) do not have a motor component, and (c) address the problems of other processing speed tests. Thus, the current study will establish the operating characteristics and validity of a novel processing speed test, the Alphaback, in a healthy college student population. The Alphaback is a task in which examinees must orally state the alphabetical letter that precedes the letter presented on a screen as fast as possible.

The current study will establish the difficulty level and experience of undergoing the Alphaback by obtaining total scores, errors, longest sequence of consecutive correct responses, and participant feedback. The Alphaback will be administered and validated with other well-established tests of cognition. Previous research shows that gender differences in performance occur based on the type of neuropsychological test. Women, for example, tend to perform better than men on tests that measure verbal ability and verbal memory (Bleecker, Bolla-Wilson, Agnew, & Meyers, 1988; Loonstra, Tarlow, & Sellers, 2001; Strauss, Sherman, & Spreen, 2006). Thus, gender differences in performance on the Alphaback will also be investigated given its verbal nature. The hypotheses of the study are:

1. Scores on the Alphaback will have a moderate-to-strong significant relationship with scores on a processing speed measure, the WAIS-IV Coding subtest.
2. Scores on the Alphaback will have a moderate-to-strong significant relationship with scores on a processing speed measure, the WAIS-IV Symbol Search subtest.

3. Scores on the Alphaback will have a significant relationship with estimated overall intellectual ability, as measured by the two-subtest form (FSIQ-2) of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-2).
4. Scores on the Alphaback will have a significant relationship with verbal ability, as measured by the Vocabulary subtest of the WASI-2.
5. Scores on the Alphaback will have a significant relationship with phonemic verbal fluency, as measured by the Controlled Oral Word Association (COWA) test.
6. Scores on the Alphaback will have a significant relationship with rapid automatized naming as measured by the Rapid Naming subtest of the Comprehensive Test of Phonological Processing – Second Edition (CTOPP-2).
7. Scores on the Alphaback will have a significant relationship with scores on a measure of visuospatial ability, The Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI).
8. Scores on the Alphaback will have a significant relationship with scores on a measure of visuospatial reasoning, the Matrix Reasoning subtest of the WASI-2.

Method

Participants

A power analysis using G Power statistical software determined that a minimum convenience sample size of 85 was required to obtain a medium effect size ($r = .3$) with power ($1 - \beta$) set at 0.8 and $\alpha = .05$ (two-tailed) for a bivariate correlation. In contrast, the power analysis also revealed that a minimum convenience sample size of 129 was required for a medium effect size ($\eta^2 = .06$) with power ($1 - \beta$) set at 0.8 and $\alpha = .05$ (two-tailed) for a *t*-test.

Students enrolled in undergraduate psychology classes completed the Screening Form to determine if they were eligible to participate in the study during designated screening days at the beginning of each semester, as well as throughout the semester at a medium-sized university in the northwestern United States. Those who completed the Screening Form during the designated screening days, but endorsed items related to the study exclusion criteria were subsequently not recruited for the study. Students were excluded from participating in the study if they were older than 24 years old to control for the effects of age of processing speed performance. Other exclusion criteria included a reported a history of birth difficulties, current learning difficulties or diagnosed learning disorders, neurological impairments or current psychological symptoms, a history TBI, or endorsed possible problems with drug or alcohol use. Participants were also excluded from the study if they were unable to understand the instructions of the study (n = 0) or if they failed a manipulation check at the end of the study (n = 0). After the screening days, eligible students were invited via email to participate in the study. Eligible students who participated in the study received 3 credits towards an eligible psychology course.

A total convenience sample of 91 undergraduate student participants between the ages of 18 and 23 (M = 18.81, SD = 1.13) was collected. Of the sample, 22% was male (n = 20) and 78% were female (n = 71), which represented the typical proportion of genders for a psychology class at this university. Eighty-nine percent of the sample was White (n = 81), 4.4% was multiracial (n = 4), 2.2% was American Indian, Native American, or Alaskan Native (n = 2), 2.2% was Hispanic/Latino (n = 2), and 2.2% was Asian (n = 2). Almost the entire sample (98.9%; n = 90) identified English as their first language, whereas 1.1% (n = 1) identified Japanese as a first language. The mean reported years of education was 12.38 (SD = 0.71), mean reported GPA was 3.56 (SD = 0.43), and mean estimated IQ was 103.64 (SD = 10.75) for the sample.

Materials

Screening form. The screening questionnaire includes questions regarding the participant's age, gender, ethnicity, education, language, and history of TBI. The questionnaire also includes questions regarding the participant's developmental, medical, psychological, and neurological health (see Appendix A).

Novel processing speed test: The Alphaback. The Alphaback, the novel processing speed test developed for this study, is a 120 s computerized test. All letters of the alphabet (except for 'A') are individually and visually presented on the screen. The examinee must orally state the letter that precedes the letter that is presented on the screen as fast as possible. For example, if 'T' is presented on the screen, the examinee must state 'S' as the correct answer. When the examinee provides a response, the examiner clicks the left mouse button and another letter immediately appears on the screen.

Three scores are calculated from the examinee's performance during the 120 s test: total correct score, total errors, and longest sequence of consecutive correct responses. Total correct scores comprise the total amount of correct letters the examinee states, whereas total errors comprise the total amount of skipped letters or incorrect letters the examinee states. Longest sequence of consecutive correct responses comprises the total amount of consecutive correct responses before an error is committed.

Prior to the start of the test, the instructions for the task are visually presented on the computer screen (see Appendix B). The examiner reads the instructions aloud and asks the examinee if there are any questions. A practice trial of five letters (i.e., B, Z, R, O, and D) is then conducted with corrective feedback to ensure the examinee understands the task. Pilot testing of the Alphaback ($n = 6$) determined that these practice letters were the easiest to complete, as measured by short response latencies and participant feedback. The test begins when the examiner clicks the left mouse button. A random series of letters is then presented individually on the screen. To establish the random series of letters, each letter of the alphabet was paired with a two-digit number. A random numbers table was then used. If a number was repeated, that number was skipped until an un-used number occurred. Each examinee is presented with the same order of letters. If an examinee completes all 25 letters prior to the 120 s end of the test, the series of letters repeats until the time limit is complete. The time limit was determined as the optimal test administration time based on pilot testing. An initial time limit of 90 s was deemed too short due lower than expected scores.

The test was developed using Microsoft PowerPoint. Black letters in size 400 Calibri font (approximately 4 in. [10.16 cm] tall and 3 in. [7.62 cm] wide) are displayed on a white screen and remain on the screen until the examinee provides a response. The test will be presented on a PC computer using Windows 7 on an 18 in. (45.72 cm) monitor with a 1920 x 1080 resolution to ensure consistent presentation of the stimuli.

Wechsler Abbreviated Scale of Intelligence – second edition (WASI-2). The Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-2; Wechsler, 2011) is a four subtest (i.e., Block Design, Similarities, Matrix Reasoning, and Vocabulary) version of the WAIS used to estimate IQ. These subtests were selected due to their strong correlations with general intellectual abilities (i.e., *g;* Wechsler, 2011). An estimate of overall, or full scale, IQ (FSIQ) can be produced using only two subtests: Matrix Reasoning and Vocabulary (FSIQ-2). The WASI-2 FSIQ-2 will be used as an estimate of overall IQ in the current study.

The WASI-2 was normed on a nationally representative (for age, sex, race/ethnicity, education level, and geographic region) standardization sample of 2,300 people aged 6 to 90 in the United States (see Wechsler, 2011 for more detailed description of standardization sample). Correlational studies (*n* = 182) found that the correlation between the WASI-2 FSIQ-2 and the WAIS-IV full scale IQ was .86 (Wechsler, 2011). Inter-rater reliability is quite high (*r* = .94 – .99) for all four WASI-2 subtests.

The Vocabulary subtest of the WASI-2 is considered a measure of crystalized word knowledge and conceptual verbal abilities. Words are presented visually and orally and the examinee must provide the definition of the word. The score comprises of the total amount of correct items ranging from 0 to 59. There is no time limit on this subtest.

The Vocabulary subtest demonstrates good internal consistency (Cronbach's alpha ranges from .85 to .95 across different age groups) and shows stable test-retest reliability (*r* = .94) for a period of 12 to 88 days (*M* = 10 days). The Vocabulary subtest has a moderate correlation with the WASI-2 FSIQ-2 (*r* = .54). Factor analytic studies (*n* = 2,300) demonstrated that the Vocabulary subtest loads highly onto the verbal comprehension factor (*r* = .98) and does not load onto the perceptual reasoning factor (*r* = -.14; Wechsler, 2011).

The Matrix Reasoning subtest of the WASI-2 is considered a measure of fluid intelligence and perceptual reasoning. Items are either an incomplete matrix or horizontal series of shapes or patterns. The examinee must point to the response option that completes the matrix or series. The score comprises of the total amount of correct items ranging between 0 and 30. There is no time limit on this subtest.

The Matrix Reasoning subtest demonstrates good internal consistency (Cronbach's alpha ranges from .85 to .93 across different age groups) and shows stable test-retest reliability (*r* = .83). The Matrix Reasoning subtest has a moderate correlation with the WASI-2 FSIQ-2 (*r* = .54). Factor analytic studies (*n* = 2,300) demonstrated that the Matrix Reasoning subtest loads moderately onto the perceptual reasoning factor (*r* = .59) and does not load onto the verbal comprehension factor (*r* = .22; Wechsler, 2011).

Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV) Coding subtest. As described previously, the Coding subtest of the WAIS-IV (Wechsler, 2008) is a commonly used paper and pencil test to measure processing speed. There is a key of nine digits that are paired with different symbols. There are rows of boxes on the page that contain a random series of the nine digits, and the examinee must copy the symbol in the box below that corresponds with the number as fast as possible. Total score comprises of the total number of correct symbols written by the examinee in 120 s (Wechsler, 2008).

The WAIS-IV was normed on a nationally representative (for age, sex, race/ethnicity, education level, and geographic region) standardization sample of 2,200 people aged 16 to 90 in the United States (see Wechsler, 2008 for more detailed description of standardization sample). Inter-rater reliability is quite high (*r* = .98 - .99) for all WAIS-IV subtests. The Coding subtest demonstrates good internal consistency (Cronbach's alpha ranges from .84 to .89 across different age groups) and shows stable test-retest reliability (*r* = .86) for a period of 8 to 82 days (*M* = 22 days). The Coding subtest moderately correlates with full scale IQ (*r* = .59). Finally, factor analytic studies have demonstrated that the Coding subtest loads highly (*r* = .83) with a processing speed factor (Wechsler, 2008).

Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV) Symbol Search subtest. As described previously, the Symbol Search subtest of the WAIS-IV is a commonly used paper and pencil test of processing speed. There are rows of symbols on the page with two "target" symbols on the left of the page and five other symbols and a box with the word "no" next to these target symbols. Examinees must mark the symbol that matches one of the target symbols, or mark the "no" box if none of the symbols match the target symbols, as fast as possible within the 120 s timeframe. The score comprises of the number of correct symbols marked by the examinee with errors subtracted from this number (Wechsler, 2008).

Like the Coding subtest, the Symbol Search subtest also demonstrates good internal consistency (Cronbach's alpha ranges from .73 to .86 across different age groups), stable test-retest reliability (r = .81), and loads highly (r = .77) onto the processing speed factor (Wechsler, 2008). The Symbol Search subtest moderately correlates with full scale IQ (r = .65).

The Controlled Oral Word Association (COWA) Test. The Controlled Oral Word Association (COWA) test (Benton & Hamsher, 1989) is an orally-administered measure in which the examinee must generate as many words as possible that begin with a certain letter within a 1 min timeframe. The test is comprised of three 1-min trials, and examinees must produce words beginning with a different letter (i.e., 'F,' 'A,' and 'S') in each trial. Certain rules limit the types of words examinees can produce. The examinee cannot state proper nouns, numbers, or repeat the same word with a different ending (e.g., if examinees say "eat," they cannot later say "eating").

The total score is comprised of the total admissible words produced for the three letters; however, education and gender have been shown to influence performance on COWA with more education and female gender associated with better performance (Loonstra et al., 2001; Tombaugh, Kozak, & Rees, 1999). Thus, an education- and gender-based correction for the total score on the COWA calculated by Ruff, Light, Parker, and Levin (1996) was used in the current study.

COWA demonstrates good internal consistency (Cronbach's alpha = .83) across the three letter trials and stable test-retest reliability for periods of one year (r = .80; Basso, Bornstein, &

Lang, 1999) and even over five years (*r* = .74; Tombaugh et al., 1999). Performance on COWA tends to have stronger correlations with performance on tests of verbal reasoning (*r* = .42 - .48) compared to performance on tests of non-verbal reasoning (*r* = .29 - .36; Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Steinberg, Bieliauskas, Smith, & Ivnik, 2005).

The Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI). The Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI; Beery & Beery, 2010) is a paper booklet that contains increasingly complex geometric designs that the examinee must copy. The test assesses visuoconstructional skills for examinees aged 2 to 100 years. The score comprises of total correctly drawn designs with scores ranging from 0 to 30.

The Beery VMI was normed on a sample of 1,021 healthy adults aged 19 to 100 from all major regions of the United States and was reasonably representative of the 2000 U.S. Census (see Beery & Beery, 2010 for more detailed description of standardization sample). It demonstrates good internal consistency (Cronbach's alpha = .82), and stable test-retest reliability for a 1-week period (*r* = .88). Inter-rate reliability is quite high (*r* = .94; Beery & Beery, 2010).

The Beery VMI correlated highly (*r* = .70) with performance IQ and moderately (*r* = .40) with verbal IQ on an earlier version of the WAIS (the Wechsler Adult Intelligence Scale – Revised [WAIS-R]; Wechsler, 1981). Finally, no significant differences in performance were found between people of different national origin, ethnicity, or race; thus, Beery and Beery (2010) argue that the test is "culture free."

Comprehensive Test of Phonological Processing – second edition (CTOPP-2) Rapid Naming subtest. The Comprehensive Test of Phonological Processing (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013) is a measure of phonological awareness, phonological memory, and rapid automatized naming. A deficit in any of these constructs is predictive of learning disabilities, particularly in reading. Rapid automatized naming – the construct that will be included in the current study – is the ability to name various stimuli (e.g., objects, colors, and digits). Rapid automatized naming requires speeded processing of both visual and phonological information; thus, a long latency in rapid naming is associated with problems in reading fluency (Wagner et al., 2013).

The CTOPP-2 was normed on a nationally representative standardization sample of 1,900 people aged 6 to 24 in the United States (see Wagner et al., 2013 for more detailed description of standardization sample). Two subtests of the CTOPP-2 will be used in the current study: Rapid Digit Naming and Rapid Letter Naming. Rapid Digit Naming involves a page with 36 digits that the examinee must say as fast as possible. The score comprises of the number of seconds it takes the examinee to say all of the digits. Similarly, Rapid Letter Naming involves a page with 36 letters that the examinee must say as fast as possible. The score comprises of the number of seconds it takes the examinee to say all of the letters. These two subtests constitute the Rapid Naming composite score, which will be used as a measure of rapid automatized naming in the current study.

The Rapid Naming composite demonstrates good internal consistency (r = .91) for adults aged 18 to 24, stable test-retest reliability (r = .79) for people aged 8 to 17 for a 2-week period, and inter-rater reliability is quite high (r = .99).

Although the Alphaback and the Rapid Naming composite were presumed to measure different constructs, the Rapid Naming composite warranted inclusion in the current study given the similarity of the task demands between the two tests. That is, the Rapid Naming subtests require the examinee to quickly name the item displayed on the page, whereas the Alphaback requires the examinee to quickly name the item that *precedes* the item displayed on the screen, adding a substantial and additional processing speed component.

Manipulation check. A manipulation check questionnaire (see Appendix C) was used to assess compliance and comprehension of the study instructions and content. One dichotomous ("yes" or "no") item assesses compliance with instructions (i.e., "did you understand the instructions provided in this study?" If this first question was answered "no", the participants were excluded from the study. One question assesses the participants' effort using a 10-point Likert scale ranging from 1 ("Didn't try at all") to 10 ("Tried very hard"). Another question assesses perceived success for following the instructions of the study using a 10-point Likert scale ranging from 1 ("Not at all successful") to 10 ("Very successful"). If participants rated that either their effort at following the instructions of the study or their success at producing the requested results was 3 or below, the participants were excluded from the study.

This questionnaire was used in previous neuropsychological studies and was a valid measure for assessing participants' compliance and effort (Reynolds, 2016). There are no other psychometric properties available for this measure.

Test acceptability questionnaire. A test acceptability questionnaire (see Appendix D) was used to assess participants' perceptions of each test in the neuropsychological battery. One question assesses the perceived difficulty of the test using a 10-point Likert scale, ranging from 1 ("Extremely easy") to 10 ("Extremely difficult"). Another question assesses the general experience of the test using a 10-point Likert scale, ranging from 1 ("Hated it") to 10 ("Loved it"). These questions were not used to exclude participants from the study.

Procedures

Participants participated in the study in a designated research room and completed the neuropsychological battery in private. At the time of the study, the researcher presented a letter of informed consent to the participants (see Appendix E). Participation was voluntary and participants were able to drop out of the study at any time without penalty. After the participant read and signed the letter of informed consent, the researcher administered the neuropsychological battery to the participant. The order of the tests (i.e., the Alphaback, Beery VMI, WASI-2 Vocabulary, WASI-2 Matrix Reasoning, WAIS-IV Coding, WAIS-IV Symbol Search, and CTOPP Rapid Naming) were counter-balanced using a Latin Square. The Test Acceptability Questionnaire was completed after each test in the battery. The Manipulation Check was completed last.

Results

The Effect of Gender on Alphaback Performance

In an effort to determine the operating characteristics of the Alphaback, and given the verbal nature of the test, it was deemed necessary to examine gender differences in performance. Thus, the first set of analyses examined the influence of gender on Alphaback performance.

Alphaback total correct score. Examination of the data revealed equal variances for total correct scores on the Alphaback, $F(1, 89) = 1.43$, *ns*, as well as normal distributions for males' total correct scores, $D(20) = .18$, *ns*, and for females' total correct scores, $D(71) = .09$, *ns*. An independent samples *t*-test revealed no significant difference in total correct scores on the Alphaback due to gender, $t(89) = 1.77$, $p = .08$, $\eta^2 = .03$. The results, along with the means, standard deviations, and confidence intervals for each gender, are reported in Table 1.

Table 1

Descriptive and Inferential Statistics for Total Correct Score on the Alphaback

Gender	*n*	*M (SD)*	95% CI	*t*(89)	*p*	η^2
Males	20	29.20 (9.55)	[24.73, 33.67]	1.77	.08	0.03
Females	71	33.04 (8.27)	[31.08, 35.00]			
Total	91	32.20 (8.66)	[30.39, 34.00]			

Note. Higher scores indicate greater number of total correct answers.

Alphaback total errors. Although examination of the data revealed equal variances for total errors on the Alphaback, *F*(1, 89) = 0.41, *ns*, distributions for males' total errors, *D*(20) = .24, *p* < .01, and for females' total errors, *D*(71) = .19, *p* < .001, were significantly non-normal. As a parametric assumption was breached, a Mann-Whitney *U* was conducted. A Mann-Whitney *U* revealed no significant difference between males' and females' total errors on the Alphaback, *U* = 672.5, *z* = -.36, *p* = .71, *r* = .04. The results, along with the medians and confidence intervals for each gender, are reported in Table 2.

Table 2

Descriptive and Inferential Statistics for Total Errors on the Alphaback

Gender	*n*	*Mdn (IQR)*	95% CI	*U*	*p*	*r*
Males	20	3.00 (3.00)	[2.23, 6.47]	672.50	.71	.04
Females	71	3.00 (4.00)	[3.41, 5.13]			
Total	91	3.00 (4.00)	[3.49, 5.08]			

Note. Higher scores indicate greater number of errors.

Alphaback longest sequence of correct responses. Although examination of the data revealed equal variances for the longest sequence of consecutive correct responses on the Alphaback, *F*(1, 89) = 1.85, *ns*, the distribution for males' longest sequence correct was significantly non-normal with skewness of 2.02 (*SE* = 0.51) and kurtosis of 5.15 (*SE* = 0.99). The distribution for females' longest sequence correct, *D*(71) = .14, *p* < .01, was also significantly non-normal. As a parametric assumption was breached, a Mann-Whitney *U* was conducted. A Mann-Whitney *U* revealed no significant difference between males' and females' longest sequence correct on the Alphaback, $U = 587.0$, $z = -1.18$, $p = .24$, $r = .12$. The results, along with the medians and confidence intervals for each gender, are reported in Table 3.

Table 3

Descriptive and Inferential Statistics for Longest Sequence of Consecutive Correct Responses on the Alphaback

Gender	*n*	*Mdn (IQR)*	95% CI	*U*	*p*	*r*
Males	20	12.50 (8.00)	[10.87, 18.43]	587.00	.24	.12
Females	71	15.00 (5.75)	[15.18, 19.53]			
Total	91	15.00 (13.00)	[14.88, 18.63]			

Note. Higher scores indicate longer sequences of consecutive correct responses.

Analysis of parametric assumptions for pooled variables. Given the lack of gender-based differences in performance, males' and females' scores were collapsed into one pooled set of scores for each variable for subsequent statistical analyses. Exploration of the data revealed that the distribution of the collapsed Alphaback total correct scores, $D(91) = .08$, *ns*, was normal. In contrast, the distributions of the collapsed Alphaback total errors, $D(91) = .2$, $p < .001$, and collapsed Alphaback longest sequence of correct responses, $D(91) = .15$, $p < .001$ were significantly non-normal. For subsequent analyses, correlations were completed using these pooled variables.

The Effect of Gender on Established Tests of Cognition

Another set of analyses examined whether gender-based differences existed for performance on established tests of cognition for the sample.

Analysis of parametric assumptions. Examination of the data revealed no violations of parametric assumptions (i.e., equal variances and normal distributions) for both males' and females' total scores on WAIS-IV Coding, total scores on WAIS-IV Symbol Search, standard scores on WASI-2 FSIQ-2, and corrected total scores on COWA. Although examination of the data revealed equal variances, distributions were significantly non-normal for males' and females' standard scores on CTOPP-2 Rapid Naming, females' total scores on Beery VMI, and females' total scores on WASI-2 Matrix Reasoning. Examination of the data also revealed both unequal variances and significantly non-normal distributions for males' and females' total scores on WASI-2 Vocabulary. See table in Appendix F for the results of the tests of parametric assumptions.

Parametric analyses of gender differences on established tests of cognition. Independent samples *t*-tests revealed no significant difference between males' and females' total scores on WAIS-IV Coding, total scores on WAIS-IV Symbol Search, standard scores on WASI-2 FSIQ-2, and corrected total scores on COWA. The results along with the means, standard deviations, and confidence intervals for each gender, are reported in Table 4.

Table 4

Descriptive and Inferential Statistics (Parametric) for Gender Differences on Established Tests of Cognition

Cognitive Test	*n*	*M (SD)*	95% CI	*t*	*p*	η^2
WAIS-IV Coding						
Males	19	77.79 (13.97)	[71.06, 84.52]	1.22	.23	0.02
Females	71	81.39 (10.74)	[78.85, 83.94]			
WAIS-IV Symbol Search						
Males	20	34.40 (7.23)	[31.02, 37.78]	0.56	.57	0.003
Females	71	35.38 (6.77)	[33.78, 36.98]			
WASI-2 FSIQ-2						
Males	18	101.67 (7.36)	[98.00, 105.33]	0.95	.35	0.01
Females	70	104.39 (11.53)	[101.64, 107.14]			
COWA						
Males	20	38.45 (10.08)	[33.73, 43.17]	0.29	.77	0.001
Females	70	39.09 (8.26)	[37.12, 41.05]			

Non-parametric analyses of gender differences on established tests of cognition. Mann-Whitney *U*s revealed no significant difference between males' and females' total scores on WASI-2 Vocabulary, standard scores on CTOPP-2 Rapid Naming, total scores on Beery VMI, and total scores on WASI-2 Matrix Reasoning. The results, along with the medians and confidence intervals for each gender, are reported in Table 5.

Table 5

Descriptive and Inferential statistics (Non-Parametric) for Gender Differences on Established Tests of Cognition

Cognitive Test	*n*	*Mdn (IQR)*	95% CI	*U*	*p*	*r*
WASI-2 Vocabulary						
Males	20	40.00 (3.00)	[38.78, 40.62]	669.50	.70	.04
Females	71	39.00 (6.00)	[37.81, 40.22]			
CTOPP-2 Rapid Naming						
Males	20	102.50 (11.25)	[93.11, 104.59]	515.50	.06	.20
Females	71	95.00 (19.00)	[89.81, 96.50]			
Beery VMI						
Males	20	28.00 (2.75)	[27.21, 28.69]	689.00	.84	.02
Females	71	28.00 (2.00)	[27.43, 28.21]			
WASI-2 Matrix Reasoning						
Males	18	19.50 (4.50)	[18.13, 21.43]	495.00	.16	.15
Females	71	21.00 (4.00)	[20.19, 21.73]			

Analysis of parametric assumptions for pooled variables. Given the lack of gender-based differences in performance on established tests of cognition, males' and females' scores were collapsed into one pooled set of scores for each variable for subsequent statistical analyses. Examination of the data revealed normal distributions for the collapsed WAIS-IV Coding total scores, WAIS-IV Symbol Search total scores, WASI-2 FSIQ-2 standard scores, and COWA corrected total scores. The distributions for the collapsed WASI-2 Vocabulary total scores, CTOPP-2 Rapid Naming standard scores, Beery VMI total scores, and WASI-2 Matrix

Reasoning total scores were significantly non-normal. See table in Appendix F for the results of the tests of parametric assumptions and see table in Appendix G for the means and standard deviations of the pooled variables. For subsequent analyses, correlations were completed using these pooled variables.

The Relationship Between Performance on the Alphaback and Performance on Established Tests of Cognition

Alphaback total correct score. Total correct scores on the Alphaback significantly correlated with WAIS-IV Coding (r = .32, p < .01), WAIS-IV Symbol Search (r = .21, p < .05), COWA (r = .28, p < .01), and WASI-2 Matrix Reasoning (r_s = .21, p < .05). There was no significant correlation between total correct scores on the Alphaback and WASI-2 FSIQ-2 (r = .11, p = .33), WASI-2 Vocabulary (r_s = .05, p = .63), CTOPP-2 Rapid Naming (r_s = .07, p = .52), and Beery VMI (r_s = .17, p = .11). See correlation matrix in Appendix H and Figures I1 – I8 in Appendix I for the respective scatterplots for each correlation.

Alphaback total errors. There were no significant correlations between total errors on the Alphaback and WAIS-IV Coding (r_s = .12, p = .27), WAIS-IV Symbol Search (r_s = .13, p = .24), WASI-2 FSIQ-2 (r_s = -.02, p = .84), WASI-2 Vocabulary (r_s = .02, p = .83), COWA (r_s = -.03, p = .76), CTOPP-2 Rapid Naming (r_s = -.08, p = .47), Beery VMI (r_s = -.02, p = .87), and WASI-2 Matrix Reasoning (r_s = -.11, p = .33). See correlation matrix in Appendix H and Figures J1 – J8 in Appendix J for the respective scatterplots for each correlation.

Alphaback longest sequence of correct responses. There were no significant correlations between longest sequence of correct responses on the Alphaback and WAIS-IV Coding (r_s = .09, p = .38), WAIS-IV Symbol Search (r_s = .02, p = .86), WASI-2 FSIQ-2 (r_s = .07, p = .50), WASI-2 Vocabulary (r_s = -.02, p = .83), COWA (r_s = .06, p = .54), CTOPP-2 Rapid

Naming (r_s = -.09, p = .39), Beery VMI (r_s = .10, p = .33), and WASI-2 Matrix Reasoning (r_s = .13, p = .22). See correlation matrix in Appendix H and Figures K1 – K8 in Appendix K for the respective scatterplots for each correlation.

Perceptions of Cognitive Test Likability and Difficulty

A one-way repeated measures multivariate analysis of variance (RM MANOVA) was conducted to assess participants' perceptions of the likability and difficulty for each cognitive test.

Analysis of parametric assumptions. Although the distributions of the likability and difficulty ratings for each test were significantly non-normal, the RM MANOVA is robust to violations of multivariate normality when each cell contains greater than 20-30 cases (Field, 2009). Similarly, although the assumption of sphericity was violated for ratings of likability, $\chi^2(27) = 100.26$, $p < .001$, and for ratings of difficulty, $\chi^2(27) = 55.47$, $p < .01$, the RM MANOVA is robust to violations in sphericity and no correction to the degrees of freedom was applied. See table in Appendix L for the results of the tests of parametric assumptions.

Analysis of cognitive test likability and difficulty. The RM MANOVA revealed a significant difference between the cognitive tests' ratings of likability and difficulty, $\Lambda = .41$, $F(14, 1188) = 47.61$, $p < .001$, $\eta^2 = .36$.

Analysis of cognitive test likability. Given the violations of parametric assumptions, follow-up Friedman's analysis of variance (ANOVA) was conducted to evaluate differences in ratings of likability across cognitive tests. The Friedman's ANOVA revealed a significant difference in likability ratings across cognitive tests, $\chi^2(7) = 102.17$, $p < .001$, $r = .38$. The results along with the medians and confidence intervals presented in ascending order are reported in Table 6.

Table 6

Descriptive and Inferential Statistics for Likability Ratings Across Cognitive Tests

Cognitive Test	*n*	*Mdn (IQR)*	95% CI	$\chi^2(7)$	*p*	*r*
Alphaback	86	5.00 (2.25)	[4.98, 5.71]	102.17	<0.001	.38
WASI-2 Vocabulary	86	5.00 (3.00)	[4.99, 5.90]			
WAIS-IV Coding	86	6.00 (3.00)	[6.18, 6.86]			
Beery VMI	86	6.00 (2.25)	[5.80, 6.52]			
WASI-2 Matrix Reasoning	86	6.00 (3.00)	[5.88, 6.64]			
WAIS-IV Symbol Search	86	7.00 (2.00)	[6.74, 7.33]			
COWA	86	7.00 (3.00)	[6.31, 6.95]			
CTOPP-2 Rapid Naming	86	7.00 (2.00)	[6.81, 7.41]			

Note. The likability ratings range from 1 to 10, with higher scores indicating greater likability.

Post-hoc pairwise comparison analyses were conducted to evaluate whether likability ratings for the Alphaback significantly differed from established tests of cognition. The alpha level for these comparisons was set at $p = .007$ using a Bonferroni adjustment to account for the possible inflation of Type I error due to the multiple comparisons (.05 / 7 = .007).

The Wilcoxon Signed Rank Test revealed that the Alphaback was rated significantly less likable compared to WAIS-IV Coding ($z = -5.03$, $p < .001$, $r = .53$), WAIS-IV Symbol Search ($z = -5.79$, $p < .001$, $r = .61$), COWA ($z = -5.60$, $p < .001$, $r = .59$), CTOPP-2 Rapid Naming ($z = -6.37$, $p < .001$, $r = .67$), Beery VMI ($z = -3.61$, $p < .001$, $r = .38$), and WASI-2 Matrix Reasoning ($z = -3.76$, $p < .001$, $r = .40$). The Wilcoxon Signed Rank Test revealed no significant difference in likability ratings between the Alphaback and WASI-2 Vocabulary, $z = -0.78$, $p = .44$, $r = .08$. Overall, the Alphaback and WASI-2 Vocabulary were rated the lowest in likability, and all cognitive tests except for WASI-2 Vocabulary were rated significantly more likable compared to the Alphaback.

Analysis of cognitive test difficulty. A Friedman's ANOVA revealed a significant difference in difficulty ratings across cognitive tests, $\chi^2(7) = 324.31$, $p < .001$, $r = .38$. The results along with the medians and confidence intervals presented in ascending order are reported in Table 7.

Table 7

Descriptive and Inferential Statistics for Difficulty Ratings Across Cognitive Tests

Cognitive Test	*n*	*Mdn (IQR)*	95% CI	$\chi^2(7)$	*p*	*r*
CTOPP-2 Rapid Naming	86	2.00 (2.00)	[2.12, 2.90]	324.31	<0.001	.38
WAIS-IV Symbol Search	86	3.00 (3.00)	[3.02, 3.82]			
WAIS-IV Coding	86	5.00 (3.25)	[4.42, 5.28]			
COWA	86	6.00 (2.00)	[5.67, 6.42]			
WASI-2 Vocabulary	86	7.00 (2.00)	[6.46, 7.24]			
Beery VMI	86	7.00 (3.00)	[5.98, 6.77]			
WASI-2 Matrix Reasoning	86	7.00 (2.00)	[6.47, 7.16]			
Alphaback	86	8.00 (1.00)	[7.15, 7.76]			

Note. The difficulty ratings range from 1 to 10, with higher scores indicating greater difficulty.

Post-hoc pairwise comparison analyses were conducted to evaluate whether difficulty ratings for the Alphaback significantly differ from established tests of cognition. The alpha level for the comparisons was again adjusted using the Bonferroni adjustment (.05 / 7 = .007).

The Wilcoxon Signed Rank Test revealed that the Alphaback was rated significantly more difficult compared to WAIS-IV Coding ($z = -7.41$, $p < .001$, $r = .79$), WAIS-IV Symbol Search ($z = -7.97$, $p < .001$, $r = .84$), WASI-2 Vocabulary ($z = -3.00$, $p = .003$, $r = .32$), COWA ($z = -6.24$, $p < .001$, $r = .66$), CTOPP-2 Rapid Naming ($z = -8.17$, $p < .001$, $r = .86$), Beery VMI ($z = -4.26$, $p < .001$, $r = .45$), and WASI-2 Matrix Reasoning ($z = -2.73$, $p = .006$, $r = .29$). Overall, all cognitive tests were rated significantly less difficult compared to the Alphaback.

Discussion

The Relationship Between the Alphaback and Other Tests of Cognition

The results of the current study provide initial support that the Alphaback is a test that measures processing speed and may perform in a similar manner to other cognitive tests used to assess this cognitive domain. The Alphaback correlated significantly with WAIS-IV Coding and Symbol Search – two subtests that load on the processing speed factor in factor analytic studies (Wechsler, 2008). The Alphaback also significantly correlated with a test of verbal fluency, COWA, as well as a test of abstract non-verbal reasoning, WASI-2 Matrix Reasoning. The likability and difficulty ratings indicate that although the Alphaback is experienced as a moderately challenging test, it is viewed similarly to other cognitive tests that are commonly administered in many neuropsychological evaluations. Taken together, the Alphaback performed in this experiment like a test of processing speed and further research and development is warranted.

The hypothesis that proposed that a significant moderate-to-strong relationship would exist between the Alphaback and an established test of processing speed, WAIS-IV Coding, was supported. Total correct scores on the Alphaback had a mild-to-moderate correlation with WAIS-IV Coding ($r = .32$). WAIS-IV Coding is widely regarded and commonly used as a measure of processing speed, and the test loads strongly on a factor of processing speed ($r = .83$; Wechsler, 2008). The significant correlation between the Alphaback and WAIS-IV Coding strongly suggests that the Alphaback measures processing speed, establishing the construct and convergent validity of the test.

The hypothesis that proposed that a significant moderate-to-strong relationship would exist between the Alphaback and another established test of processing speed, WAIS-IV Symbol Search, was supported but with a less robust correlation than expected. Total correct scores on the Alphaback had a mild correlation with Symbol Search ($r = .21$). Like with WAIS-IV Coding, WAIS-IV Symbol Search loads strongly on a factor of processing speed ($r = .77$; Wechsler, 2008). The significant correlation between the Alphaback and WAIS-IV Symbol Search suggests that the Alphaback measures processing speed, further establishing the construct and convergent validity of the test.

The hypothesis that there would be a significant relationship between the Alphaback and a test of verbal fluency, COWA, was supported (r = .28). Researchers have previously shown that verbal fluency is mediated by processing speed (e.g., Elgamal, Roy, & Sharratt, 2011; Herbert, Brookes, Markus, & Morris, 2014; McDowd et al., 2011; Ojeda, Peña, Sánchez, Elizagárate, & Ezcurra, 2008). In another study, researchers demonstrated that COWA loaded significantly on a factor measuring processing speed (r = .44). COWA also shared more variance with the WAIS-III Digit Symbol Coding subtest (an earlier iteration of WAIS-IV Coding) than any other test, even executive functioning tests, included in the study (Boone, Pontón, Gorsuch, González, & Miller, 1998). The effect of processing speed on COWA performance led Boone et al. to caution that performance on COWA must always be interpreted in the context of processing speed, as impairments may be solely due to slowed speed as opposed to executive dysfunction. Other tests of processing speed, therefore, tend to show mild-to-moderate correlations with COWA, which is similar to how the Alphaback performed in this study. These findings also lend support of convergent validity that the Alphaback is a test that measures processing speed.

The hypothesis that there would be a significant relationship between the Alphaback and WASI-2 Matrix Reasoning was supported, as performance on WASI-2 Matrix Reasoning mildly correlated with total correct scores on the Alphaback (r = .21). Tests involving reasoning with visual matrices, like the WASI-2 Matrix Reasoning subtest, not only include components of non-verbal reasoning (i.e., fluid intelligence) and visuospatial processing, but also include several domains considered to be related to executive functioning. That is, in order to successfully solve each visual matrix, the examinee must use novel problem-solving strategies while holding a substantial amount of information in working memory (Carpenter, Just, & Shell, 1990). Researchers have previously shown that executive functioning tests, in general, have small correlations with established tests of both simple processing speed, such as reaction time tests, and complex processing speed such as the Symbol Digit Modalities Test (SDMT; e.g., Albinet, Boucard, Bouquet, & Audiffren, 2012). Given previous findings that processing speed is a component of two factors involved in WASI-2 Matrix Reasoning – executive functioning and fluid intelligence – it is reasonable to expect that the Alphaback would have at least a mild correlation with WASI-2 Matrix Reasoning, as we found in the current study.

The small correlation between the Alphaback and WASI-2 Matrix Reasoning may also be due to the specific characteristics of the Alphaback. The possibility exists that examinees visualize sequences of the alphabet when completing the test and engage visuospatial abilities in the process of visualization. Using functioning magnetic resonance imaging (fMRI), D'Esposito et al. (1997) demonstrated that generating common, concrete mental images (e.g., a tree) is a function of the visual association cortices in the brain. Examinees might also visualize concrete, common images (i.e., letters of the alphabet) when completing the Alphaback. If examinees are visualizing the alphabet when completing the Alphaback, this could lead to correlations between the Alphaback and tests with visuospatial components. Taken together, previous findings of the relationship between processing speed and performance on visual matrices tests, along with the possible visualization component of the Alphaback, suggest that the mild correlation between the Alphaback and WASI-2 Matrix Reasoning should be interpreted as convergent validity. Additionally, this finding suggests that the Alphaback may be a processing speed test with a visuospatial component that may make it unique from other processing speed tests.

Total correct scores on the Alphaback had no significant correlation with estimated overall IQ, WASI-2 FSIQ-2, a finding that did not support the hypothesis. Measures of processing speed have correlated with overall IQ in previous studies (e.g., Deary, 2001; Wechsler, 2008), and there are several potential reasons for the lack of correlation between the Alphaback and estimated overall IQ in the current study.

The WASI-2 FSIQ-2 is an *estimate* of overall IQ and is comprised of only two subtests: Vocabulary and Matrix Reasoning. Tests of vocabulary are generally resistant to neurological injury and normal aging (Lezak et al., 2012). In other words, scores on vocabulary tests remain stable even when performance on other cognitive tests is significantly affected in the context of neurological impairment, as in the case of significantly decreased scores on memory (and other) tests in Alzheimer's disease. Vocabulary tests are so resistant to neurological compromise that they are frequently used as components of algorithms to estimate premorbid cognitive functioning (e.g., Axelrod, Vanderploeg, & Schinka, 1999; Schoenberg, Duff, Scott, & Adams, 2003). Since half of WASI-2 FSIQ-2 is comprised of a test that is resistant to cognitive dysfunction, it is reasonable to expect a lack of relationship between WASI-2 FSIQ-2 and a test of processing speed, a measure that *is* sensitive to even subtle neurological dysfunction.

Another potential reason for the lack of relationship between WASI-2 FSIQ-2 and the Alphaback is the overlearned, crystalized nature of the alphabet. In most cases, people learn the alphabet early in life, and the alphabet is used consistently throughout the lifespan as the foundation for written language. The automatic nature of the alphabet may suggest that overall IQ is not a significant component of performance on the Alphaback. If this is the case, the Alphaback could be administered to patients across the spectrum of intellectual functioning and would not require as much of a correction for education and/or intelligence unlike other tests of processing speed. In this sample, WASI-FSIQ-2 operates as a measure of divergent validity.

Additionally, the relatively homogeneous characteristics of the current sample may have influenced the correlation between the Alphaback and WASI-2 FSIQ-2. That is, the mean estimated overall IQ for the sample was 103.64 with a standard deviation of 10.75, whereas the mean overall IQ for a nationally representative US sample is 100 with a standard deviation of 15 (Wechsler, 2008, 2011). This comparison shows that the current sample had average estimated overall intellectual functioning with less than typical variability. Perhaps the truncated variability in estimated overall IQ for the sample inadvertently created an insensitive measure for which to make comparisons with the Alphaback.

Contrary to the hypothesis, the Alphaback had no significant correlation with WASI-2 Vocabulary. Although most studies have found a significant correlation (r = .41 - .49) between tests of verbal reasoning and processing speed (Boone et al., 1998; Wechsler, 2008), other researchers have found a negligible correlation between a test of processing speed and vocabulary (r = .13; Facal, Juncos-Rabadán, Soledad Rodríguez, & Pereiro, 2012). The lack of correlation between verbal knowledge and reasoning and performance on the Alphaback demonstrates that well-developed verbal knowledge and reasoning abilities might not be a requirement for Alphaback performance. The lack of verbal ability required for the Alphaback indicates that the test may be appropriate for a wide range of intellectual functioning in adult populations or for children. Although WASI-2 Vocabulary is operating as a measure of divergent validity in this sample, more research is needed to clarify the nature of verbal knowledge and reasoning as it relates to performance on the Alphaback.

Performance on the Alphaback did not have a significant correlation with performance on CTOPP-2 Rapid Naming despite the similar nature of the tasks, which did not support the hypothesis. In contrast, the established tests of processing speed, WAIS-IV Coding and Symbol Search, had significant mild relationships with CTOPP-2 Rapid Naming ($r_s = .23$ and $r_s = .24$, respectively). This finding may infer that the Alphaback is measuring processing speed along with another cognitive domain, most likely working memory (the type of short-term memory storage that allows one to mentally manipulate information [Lezak et al., 2012]). That is, examinees must maintain sequences of the alphabet in memory as they simultaneously retrieve the preceding letter, inferring a working memory component is required to complete the Alphaback. CTOPP-2 Rapid Naming, on the other hand, likely does not require working memory abilities, as it is a test of automatic responding. The significant correlation between the established tests of processing speed and CTOPP-2 Rapid Naming might suggest that the former are tests of processing speed with less of a working memory component. In other words, the Alphaback, WAIS-IV Coding, and WAIS-Symbol Search may vary in the amount that they load with a working memory factor, leading to varied correlations with CTOPP-2 Rapid Naming.

Finally, no significant correlation existed between total correct scores on the Alphaback and Beery VMI, which did not support the hypothesis. Beery VMI has a relatively reduced processing speed component because it is an untimed test of visuospatial constructional ability, which is a related, but different, cognitive domain compared to visuospatial *reasoning* (as measured by WASI-2 Matrix Reasoning; Beery & Beery, 2010). Given the strong visuospatial constructional component of the Beery VMI, the lack of correlation between the Alphaback and Beery VMI demonstrates divergent validity.

The Experience of the Alphaback

Analysis of the likability and difficulty ratings revealed that the Alphaback was rated as the least likable (but equal to WASI-2 Vocabulary) and most difficult compared to the other cognitive tests in the study. Despite the comparatively lower likability rating, the Alphaback still received a mid-range "it was okay" average score. As mentioned, participants liked the Alphaback as much as WASI-2 Vocabulary, which is a widely administered test (Wechsler, 2008; 2011). Although the likability ratings between cognitive tests were statistically significant, the ratings were still within a relatively restricted range from five to seven (on a scale of one to 10). Additionally, the primary purpose of the study was to establish the validity of the Alphaback; thus, tests were chosen for the purposes of convergent and divergent validity. Had tests been chosen for the purpose of establishing the experience of taking the Alphaback, a different array of tests with a wide range of difficulty levels would have been included in the study. These results lend support that the Alphaback is a difficult test, but is clearly not experienced as aversive and would likely not damage rapport between the examinee and the examiner like other difficult tests such as the Paced Auditory Serial Addition Test (PASAT; Diehr et al., 2003; Mathias et al., 2004).

Limitations of the Current Study

The primary limitation of the current study involves the healthy, young, relatively high functioning characteristics of the sample. Participants between the ages of 18 and 24 with no previous medical, neurological, or psychiatric history were recruited for the study. This strict exclusion criteria was necessary to increase control of potential confounding factors on Alphaback performance given that this was the first experimental examination of the test. That said, this criteria led to a homogenous sample of participants with presumably intact processing speed and other cognitive functions, which does not necessarily reflect the characteristics and range of functioning seen in the general population.

Another limitation of the current study is the battery of cognitive tests in which the Alphaback was embedded. As previously mentioned, the relatively short (i.e., one hour) battery of cognitive tests was selected to establish the validity of the Alphaback, as well as to accommodate the reality of collecting empirical data on an undergraduate student population that received minimal incentives for study participation. Thus, this battery of cognitive tests does not necessarily reflect the length and wide array of cognitive tests that are typically included in a comprehensive neuropsychological assessment. The current battery, for example, did not include any tests of memory, which is a cognitive domain that should be assessed in virtually every neuropsychological evaluation in clinical and forensic settings (Larrabee, 2008). Future researchers can examine how the characteristics and perceptions of the Alphaback change when the test is a part of a more comprehensive battery of tests. Potential tests under consideration for a more comprehensive battery for future studies might include Trail Making Test (Reitan, 1955), California Verbal Learning Test – Second Edition (CVLT-II; Delis, Kramer, Kaplan, & Ober, 1994), Auditory Consonant Trigrams (Brown, 1958; Peterson & Peterson, 1959), and Rey-Osterrieth Complex Figure Task (Meyers & Meyers, 1995).

Future Directions for Examination of the Alphaback

Given that the current study was the first examination of the Alphaback and due to the limitations of the current sample, several future directions exist for examination of the characteristics and validity of the Alphaback. One starting point for future studies involves validating the Alphaback on healthy older adults to determine whether the test is sensitive to the decrements in processing speed associated with normal aging (Hedden & Gabrieli, 2004;

Wisdom et al., 2012). The Alphaback can also be validated on clinical populations with a range of mild to severe cognitive impairments (e.g., mild cognitive impairment, mild traumatic brain injury).

The difficulty rating of the Alphaback in the current study lends preliminary support that the test may be sensitive to subtle decreases in processing speed. The PASAT was considered a sensitive test to subtle impairment, but eventually fell out of favor due to the aversive experience of taking the test along with other problems (e.g., significant practice effects, highly loaded with IQ and mathematical ability, etc.; Crawford et al., 1998; Deary et al., 1991; Diehr et al., 2003; Gronwall, 1977; Mathias et al., 2004; Schächinger et al., 2003; Sherman et al., 1997; Tombaugh, 2006). There is potential that the Alphaback may be able to replicate the sensitivity of the PASAT without causing a negative experience for the examinee, which no other processing speed test has been able to accomplish to date.

Participants in the current study generally did not make many errors when completing the Alphaback (M = 4.32; SD = 3.89). This finding implies that when participants encountered a relatively more difficult letter of the alphabet, increased processing time to generate the correct preceding letter was more likely to occur rather than generating an incorrect letter. The low amount of total errors speaks to the overlearned nature of the alphabet, which subsequently created a floor effect and insignificant relationships between total errors on the Alphaback and performance on other tests of cognition. Although total errors on the Alphaback may not be a useful variable in the current study, it will be worthwhile to examine these variables in other samples. The generation of errors on the Alphaback may be more common in certain clinical populations, and total errors might be an indicator that assists with diagnostic clarification and/or differentiates between intact and impaired cognition.

Similarly, longest sequence of consecutive correct responses on the Alphaback was another variable with no significant correlations to performance on other cognitive tests. The longest sequence of consecutive correct responses was approximately half (*M* =16.84, *SD* = 9.10) of the amount of the total correct responses (*M* = 32.37, *SD* = 8.49) on the Alphaback. The relatively long sequences are likely related to the low amount of errors produced by the examinees in this sample. Longest sequence of consecutive correct may have diagnostic utility, however, in clinical populations with shorter sequences (and increased errors) possibly being related to impaired cognition.

As alluded to previously, researchers in future studies should evaluate whether the Alphaback correlates with more comprehensive measures of overall IQ such as WAIS-IV FSIQ in a variety of samples. Researchers will be able to determine whether performance on the Alphaback is actually related to IQ and that the current lack of correlation was due to the particular characteristics of the sample or the estimated WASI-2 FSIQ-2 used in the study. Conversely, researchers may be able to determine more conclusively that IQ is not a factor in Alphaback performance.

Researchers in future studies can also determine whether the mild correlation between the Alphaback and WASI-2 Matrix Reasoning was due to visuospatial processing secondary to visualization of the alphabet, to the executive functioning (i.e., working memory) component of visual matrices tasks in general (Carpenter et al., 1990), or to a combination of these aspects. Experimental designs using qualitative and imaging approaches, as well as studies including examinees with documented visuospatial deficits may help to clarify the relationship between the Alphaback and WASI-2 Matrix Reasoning.

As mentioned previously, the Alphaback may have a working memory component in addition to processing speed since examinees must maintain information in memory while completing the test. Factor analytic studies will aid in identifying the cognitive domains that are required to successfully perform on the Alphaback.

Finally, future researchers can compare the experience (i.e., likability and difficulty) of taking the Alphaback to a wider array of cognitive tests that an examinee may encounter in a typical neuropsychological assessment. The Alphaback may be viewed more positively and as less difficult if compared to more arduous tasks such as the PASAT (Gronwall & Sampson, 1974), Auditory Consonant Trigrams (Brown, 1958; Peterson & Peterson, 1959), or Selective Reminding Task (Buschke, 1973; Buschke & Fuld, 1974).

Conclusions

Slowed processing speed has been shown to be a sensitive indicator of neurological impairment. Despite the importance of assessing processing speed in the context of cognitive impairment and normal aging, few tests of processing speed are available to clinical neuropsychologists. The current study was the first undertaking of establishing the operating characteristics, as well as the convergent and divergent validity of a novel processing speed test, the Alphaback. The Alphaback significantly correlated with established tests of processing speed, WAIS-IV Coding and Symbol. Similar to other tests of processing speed, the test also had significant correlations with tests of verbal fluency (i.e., COWA) and non-verbal abstract reasoning (i.e., WASI-2 Matrix Reasoning). Taken together, the results of the current study strongly lend support: (a) to the construct validity of the Alphaback as a measure of processing speed and (b) that the Alphaback is operating in a similar fashion to other established tests of processing speed. With further validation, the Alphaback may be a new test of processing speed that clinical neuropsychologists can use to assess processing speed deficits in a wide variety of clinical populations given the lack of motor movement and potential reduced requirement for high IQ to complete the task.

References

Albinet, C. T., Boucard, G., Bouquet, C. A., & Audiffren, M. (2012). Processing speed and executive functions in cognitive aging: How to disentangle their mutual relationship? *Brain and Cognition*, *79*(1), 1–11. doi:10.1016/j.bandc.2012.02.001

Anderson, V. A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of executive functions through late childhood and adolescence in an Australian sample. *Developmental Neuropsychology*, *20*(1), 385-406. doi:10.1207/S15326942DN2001_5

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory, and physical factors enabling driving safety in older adults. *Clinical Psychology Review*, *25*(1), 45-65. doi:10.1016/j.cpr.2004.07.008

Archibald, C. J., & Fisk, F. D. (2000). Information processing efficiency in patients with multiple sclerosis. *Journal of Clinical and Experimental Neuropsychology*, *22*(5), 686-701. doi:10.1076/1380-3395(200010)22:5;1-9;ft686

Axelrod, B. N., Vanderploeg, R. D., & Schinka, J. A. (1999). Comparing methods for estimating premorbid intellectual functioning. *Archives of Clinical Neuropsychology*, *14*(4), 341–346. doi:10.1093/arclin/14.4.341

Barker-Collo, S. (2006). Quality of life in multiple sclerosis: Does information-processing speed have an independent effect? *Archives of Clinical Neuropsychology*, *21*(2), 167-174. doi:10.1016/j.acn.2005.08.008

Basso, M. R., Bornstein, R. A., & Lang, J. M. (1999). Practice effects of commonly used measures of executive function across twelve months. *The Clinical Neuropsychologist*, *13*(3), 283-292. doi:10.1076/clin.13.3.283.1743

Beery, K. B., & Beery, N. A. (2010). *Beery VMI administration, scoring, and teaching manual*. San Antonio, TX: Pearson.

Benton, A. I., & Hamsher, K. (1989). *Multilingual Aphasia Examination*. Iowa City, IA: AJA Associates.

Bezdicek, O., Stepankova, H., Novakova, L. M., & Kopecek, M. (2016). Toward the processing speed theory of activities of daily living in healthy aging: normative data of the Functional Activities Questionnaire. *Aging Clinical and Experimental Research*, *28*(2), 239-247. doi:10.1007/s40520-015-0413-5

Bleecker, M. L., Bolla-Wilson, K., Agnew, J., & Meyers, D. A. (1988). Age-related sex differences in verbal memory. *Journal of Clinical Psychology*, *44*(3), 403-411. doi:10. 1002/1097-4679(198805)44:3<403::aid-jclp2270440315>3.0.co;2-0

Boone, K. B., Pontón, M. O., Gorsuch, R. L., González, J. J., & Miller, B. L. (1998). Factor analysis of four measures of prefrontal lobe functioning. *Archives of Clinical Neuropsychology*, *13*(7), 585-595. doi:10.1016/s0887-6177(97)00074-7

Brittain, J. L., La Marche, J. A., Reeder, K. P., Roth, D. L., & Boll, T. J. (1991). The effects of age and IQ on Paced Auditory Serial Addition Task (PASAT) performance. *The Clinical Neuropsychologist*, *5*, 163-175. doi:10.1080/13854049108403300

Brown, J. (1958). Some tests of the decay of immediate memory. *Quarterly Journal of Experimental Psychology*, *10*, 12-21.

Buschke, H. (1973). Selective reminding for analysis of memory and learning. *Journal of Verbal Learning and Verbal Behavior*, *12*(5), 543-550. doi:10.1016/s0022-5371(73)80034-9

Buschke, H., & Fuld, P. A. (1974). Evaluating storage, retention, and retrieval in disordered memory and learning. *Neurology*, *24*(11), 1019-1025. Doi: 10.1212/01.wnl.0000398283.

10171.75

Carlozzi, N. E., Tulsky, D. S., Chiaravalloti, N. D., Beaumont, J. L., Weintraub, S., Conway, K., & Gershon, R. C. (2014). NIH Toolbox Cognitive Battery (NIHTB-CB): The NIHTB Pattern Comparison Processing Speed Test. *Journal of the International Neuropsychological Society, 20*(6), 630-641. doi:10.1017/s1355617714000319

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices test. *Psychological Review, 97*(3), 404-431. doi:10.1037/0033-295x.97.3.404

Cattell, J. McK., & Galton, F. (1890). Mental tests and measurements. *Mind, 15*(59), 373-381. doi:10.1093/mind/os-xv.59.373

Chiaravalloti, N. D., Christodoulou, C., Demaree, H. A., & DeLuca, J. (2003). Differentiating simple versus complex processing speed: Influence on new learning and memory performance. *Journal of Clinical and Experimental Neuropsychology, 25*(4), 489-501.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Coyle, T. R., Pillow, D. R., Snyder, A. C., & Kochunov, P. (2011). Processing speed mediates the development of general intelligence (*g*) in adolescence. *Psychological Science, 22*(10), 1265-1269. doi:10.1177/0956797611418243

Crawford, J. R., Obonsawin, M. C., & Allan, K. M. (1998). PASAT and components of WAIS-R performance: Convergent and discriminant validity. *Neuropsychological Rehabilitation, 8*(3), 255-272. doi:10.1080/713755575

Deary, I. J. (2001). Human intelligence differences: A recent history. *TRENDS in Cognitive Sciences, 5*(3), 127-130. doi:10.1016/s1364-6613(00)01621-1

Deary, I. J., & Der, G. (2005). Reaction time explains IQ's association with death. *Psychological Science, 16*(1), 64-69. doi:10.1111/j.0956-7976.2005.00781.x

Deary, I. J., Johnson, W., & Starr, J. M. (2010). Are processing speed tasks biomarkers of cognitive age? *Psychology and Aging, 25*(1), 219-228. doi:10.1037/a0017750

Deary, I. J., Langan, S. J., Hepburn, D. A., & Frier, B. M. (1991). Which abilities does the PASAT test? *Personality and Individual Differences, 12*(10), 983-987. doi:10.1016/0191-8869(91)90027-9

Delis, D. C., Kramer, J. H., Kaplan, E., & Ober, B. A. (1994). *California Verbal Learning Test – Second Edition, Adult Version.* San Antonio, TX: The Psychological Corporation.

DeLuca, J., Chelune, G. J., Tulsky, D. S., Lengenfelder, J., & Chiaravalloti, N. D. (2004). Is speed of processing or working memory the primary information processing deficit in multiple sclerosis? *Journal of Clinical and Experimental Neuropsychology, 26*(4), 550-562. doi:10.1080/13803390490496641

DeLuca, J., Christodoulou, C., Diamond, B. J., Rosenstein, E. D., Kramer, N., & Natelson, B. H. (2004). Working memory deficits in chronic fatigue syndrome: Differentiating between speed and accuracy of information processing. *Journal of the International Neuropsychological Society, 10*(1), 101-109. doi:10.1017/s1355617704101124

Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin, 89*(1), 63-100. doi:10.1037/0033-2909.89.1.63

D'Esposito, M., Detre, J. A., Aguirre, G. K., Stallcup, M., Alsop, D. C., Tippet, L. J., & Farah, M. J. (1997). A functional MRI study of mental image generation. *Neuropsychologia, 35*(5), 725-730. doi:10.1016/s0028-3932(96)00121-2

Diehr, M. C., Cherner, M., Wolfson, T. J., Miller, S. W., Grant, I., Heaton, R. K., & the HIV Neurobehavioral Research Center. (2003). The 50 and 100-item short forms of the Paced Auditory Serial Addition Task (PASAT): Demographically corrected norms and comparisons with the full PASAT in normal and clinical samples. *Journal of Clinical and Experimental Neuropsychology, 25*(4), 571-585. doi:10.1076/jcen.25.4.571.13876

Donders, J., Tulsky, D. S., & Zhu, J. (2001). Criterion validity of new WAIS–III subtest scores after traumatic brain injury. *Journal of the International Neuropsychological Society, 7*, 892-898.

Dyche, G. M., & Johnson, D. A. (1991). Development and evaluation of CHIPASAT, an attention test for children: II. Test-retest reliability and practice effect for a normal sample. *Perceptual and Motor Skills*, *72*(2), 563-572. doi:10.2466/pms.72.2.563-572

Elgamal, S. A., Roy, E. A., & Sharratt, M. T. (2011). Age and verbal fluency: The mediating effect of speed of processing. *Canadian Geriatrics Journal*, *14*(3), 66-72. doi:10.5770cgj.v14i3.17

Facal, D., Juncos-Rabadán, O., Soledad Rodríguez, M., & Pereiro, A. X. (2012). Tip-of-the-tongue in aging: Influence of vocabulary, working memory and processing speed. *Aging Clinical and Experimental Research*, *24*(6), 647–656. doi:10.3275/8586

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). Thousand Oaks, CA: SAGE Publications.

Gershon, R. C., Cella, D., Fox, N. A., Havlik, R. J., Hendrie, H. C., & Wagster, M. V. (2010). Assessment of neurological and behavioural function: The NIH Toolbox. *The Lancet Neurology*, *9*(2), 138-139. doi:10.1016/s1474-4422(09)70335-7

Gronwall, D. M. A. (1977). Paced Auditory Serial-Addition Task: A measure of recovery from concussion. *Perceptual and Motor Skills, 44*(2), 367-373. doi:10.2466/pms.1977.44.2.367

Gronwall, D. M. A., & Sampson, H. (1974). *The psychological effects of concussion*. Auckland, NZ: Oxford University Press.

Hawkins, K. A. (1998). Indicators of brain dysfunction derived from graphic representations of the WAIS-III/WMSIII technical manual clinical samples data: A preliminary approach to clinical utility. *The Clinical Neuropsychologist*, *12*(4), 535-551. doi:10.1076/clin.12.4.535.7236

Hedden, T., & Gabrieli, J. D. E. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5*(2), 87-96. doi:10.1038/nrn1323

Herbert, V., Brookes, R. L., Markus, H. S., & Morris, R. G. (2014). Verbal fluency in cerebral small vessel disease and Alzheimer's disease. *Journal of the International Neuropsychological Society, 20*, 413–421. doi:10.1017/S1355617714000101

Jensen, A. R. (1998). *The* g *factor: The science of mental ability*. Westport, CT: Praeger.

Kail, R. V. (2007). Longitudinal evidence that increases in processing speed and working memory enhance children's reasoning. *Psychological Science*, *18*(4), 312-313. doi:10.1111/j.1467-9280.2007.01895.x

Kolb, B., & Whishaw, I. Q. (2009). *Fundamentals of human neuropsychology* (6th ed.). New York, NY: Worth Publishers.

Larrabee, G. J. (2008). Flexible vs. fixed batteries in forensic neuropsychological assessment: Reply to Bigler and Hom. *Archives of Clinical Neuropsychology, 23*(7-8), 763–776. doi:10.1016/j.acn.2008.09.004

Lang, S., Cadeaux, M., Opoku-Darko, M., Gaxiola-Valdez, I., Partlo, L. A., Goodyear, B. G., . . . & Kelly, J. (2016). Assessment of cognitive, emotional, and motor domains in patients with diffuse gliomas using the National Institutes of Health Toolbox Battery. *World Neurosurgery, 99*, 448-456. doi:10.1016/j.wneu.2016.12.061

Lemke, U., & Zimprich, D. (2005). Longitudinal changes in memory performance and processing speed in old age. *Aging, Neuropsychology, and Cognition, 12*(1), 57–77. doi:10.1080/13825580590925116

Levin, H. S., Mattis, S., Ruff, R. M., Eisenberg, H. M., Marshall, L. F., Tabaddor, K., . . . & Frankowski, R. F. (1987). Neurobehavioral outcome following minor head injury: A three-center study. *Journal of Neurosurgery, 66*(2), 234-243. doi:10.3171/jns.1987.66.2. 0234

Lezak, M. D., Howieson, D. B., Bigler, E. D., & Tranel, D. (2012). *Neuropsychological assessment* (5th ed.). New York, NY: Oxford University Press.

Llorente, A. M., Miller, E. N., D'Elia, L. F., Selnes, O. A., Wesch, J., Becker, J. T., & Satz, P. (1998). Slowed information processing in HIV-1 disease. *Journal of Clinical and Experimental Neuropsychology, 20*(1), 60-72. doi:10.1076/jcen.20.4.60.1144

Loonstra, A. S., Tarlow, A. R., & Sellers, A. H. (2001). COWAT metanorms across age, education, and gender. *Applied Neuropsychology, 8*(3), 161-166. doi:10.1207/s153248 26an0803_5

Martin, T. A., Donders, J., & Thompson, E. (2000). Potential of and problems with new measures of psychometric intelligence after traumatic brain injury. *Rehabilitation Psychology, 45*(4), 402-408. doi:10.1037//0090-5550.45.4.402

Mathias, C. W., Stanford, M. S., & Houston, R. J. (2004). The physiological experience of the Paced Auditory Serial Addition Task (PASAT): Does the PASAT induce autonomic arousal? *Archives of Clinical Neuropsychology, 19*(4), 543-554. doi:10.1016/s0887-6177(03)00116-1

McDowd, J., Hoffman, L., Rozek, E., Lyons, K. E., Pahwa, R., Burns, J., & Kemper, S. (2011). Understanding verbal fluency in healthy aging, Alzheimer's disease, and Parkinson's disease. *Neuropsychology, 25*(2), 210–225. doi:10.1037/a0021531

McInerney, K., & Suhr, J. (2016). Neuropsychological correlates of hazard perception in older adults. *Journal of the International Neuropsychological Society, 22*(3), 332-340. doi:10. 1017/s1355617715001253

Meyers, J., & Meyers, K. (1995). *The Meyers scoring system for the Rey Complex Figure and the recognition trial: Professional manual*. Odessa, FL: Psychological Assessment Resources.

Naglieri, J. A., & Bardos, A. N. (1997). *General Ability Measure for Adults*. Minneapolis, MN: National Computer Systems.

Ojeda, N., Peña, J., Sánchez, P., Elizagárate, E., & Ezcurra, J. (2008). Processing speed mediates the relationship between verbal memory, verbal fluency, and functional outcome in chronic schizophrenia. *Schizophrenia Research, 101*, 225–233. doi:10.1016/j.schres. 2007.12.483

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*(2), 299-320. doi:10.1037//0882-7974.17.2.299

Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J. L., Frieske, D., Zwahr, M., & Gaines, C. L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging, 11*(4), 621-637. doi:10.1037//0882-7974.11.4.621

Parsons, O. A. (1996). Human immunodeficiency virus (HIV-1). In R. L. Adams, O. A. Parsons, J. L. Culbertson, & S. J. Nixon (Eds.), *Neuropsychology for clinical practice: Etiology, assessment, and treatment of common neurological disorders* (pp. 203-224). Washington, DC: American Psychological Association.

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, *58*(3), 193-198. doi:10.1037/h0049234

Reitan, R. M. (1955). The relation of the Trail Making Test to organic brain damage. *Journal of Consulting Psychology*, *19*(5), 393-394. doi:10.1037/h0044509

Reppermund, S., Sachdev, P. S., Crawford, J., Kochan, N. A., Slavin, M. J., Kang, K., . . . & Brodaty, H. (2010). The relationship of neuropsychological function to instrumental activities of daily living in mild cognitive impairment. *International Journal of Geriatric Psychiatry*, *26*(8), 843-852. doi:10.1002/gps.2612

Reynolds, M. K. (2016). The effect of terminology relating to mTBI on symptom and recovery expectations. Retrieved from Graduate Student Theses, Dissertations, & Professional Papers. (10803).

Ruff, R. M., Light, R. H., Parker, S. B., & Levin, H. S. (1996). Benton Controlled Oral Word Association test: Reliability and updated norms. *Archives of Clinical Neuropsychology, 11*(4), 329-338. doi:10.1016/0887-6177(95)00033-x

Salthouse, T. A. (1985). *A theory of cognitive aging.* Amsterdam, Netherlands: North-Holland.

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403-428. doi:10.1037//0033-295x.103.3.403

Sawamoto, N., Honda, M., Hanakawa, T., Fukuyama, H., & Shibasaki, H. (2002). Cognitive slowing in Parkinson's disease: A behavioral evaluation independent of motor slowing. *The Journal of Neuroscience, 22*(12), 5198-5203.

Schächinger, H., Cox, D., Linder, L., Brody, S., & Keller, U. (2003). Cognitive and psychomotor function in hypoglycemia: Response error patterns and retest reliability. *Pharmacology, Biochemistry, and Behavior, 75*(4), 915-920. doi:10.1016/s0091-3057(03)00167-9

Schmidt, F. L., & Hunter, J. E. (1998). The validity and utility of selection methods in personnel psychology: Practical and theoretical implications of 85 years of research findings. *Psychological Bulletin, 124*(2), 262-274. doi:10.1037//0033-2909.124.2.262

Schoenberg, M. R., Duff, K., Scott, J. G., & Adams, R. L. (2003). An evaluation of the clinical utility of the OPIE-3 as an estimate of premorbid WAIS-III FSIQ. *The Clinical Neuropsychologist, 17*(3), 308-321. doi:10.1076/clin.17.3.308.18088

Sherman, E. M. S., Strauss, E., & Spellacy, F. (1997). Validity of the Paced Auditory Serial Addition Test (PASAT) in adults referred for neuropsychological assessment after head injury. *The Clinical Neuropsychologist, 11*(1), 34-45. doi:10.1080/13854049708407027

Smith, A. (1982). *Symbol Digit Modalities Test manual – revised*. Los Angeles, CA: Western Psychological Services.

Smith, A. M., Walker, L. A. S., Freedman, M. S., Berrigan, L. I., St. Pierre, J., Hogan, M. J., & Cameron, I. (2012). Activation patterns in multiple sclerosis on the Computerized Tests of Information Processing. *Journal of the Neurological Sciences, 312*(1–2), 131-137. doi:10.1016/j.jns.2011.08.003

Spikman, J. M., Deelman, B. G., & van Zomeren, A. H. (2000). Executive functioning, attention and frontal lesions in patients with chronic CHI. *Journal of Clinical and Experimental Neuropsychology, 22,* 325-338. doi:10.1076/1380-3395(200006)22:3;1-v;ft325

Steinberg, B. A., Bieliauskas, L. A., Smith, G. E., & Ivnik, R. J. (2005). Mayo's older Americans normative studies: Age- and IQ-adjusted norms for the Trail Making Test, the Stroop Test, and MAE Controlled Oral Word Association test. *The Clinical Neuropsychologist, 19*(3-4), 329-377. doi:10.1080/13854040590945210

Strauss, E., Sherman, E., & Spreen, O. (2006). *Compendium of neuropsychological tests: Administration, norms, and commentary* (3rd ed.). New York, NY: Oxford University Press.

Thorndike, E. L., Bregman, E. O., Cobb, M. V., & Woodyard, E. (1927). *The measurement of intelligence.* New York, NY: Teachers College, Columbia University, Bureau of Publications.

Tombaugh, T. N. (1996). *Test of Memory Malingering (TOMM)*. Toronto, Ontario, Canada: Multi-Health Systems.

Tombaugh, T. N. (1999). *Administrative manual for The Adjusting-Paced Serial Addition Test (Adjusting-PSAT).* Ottawa, Ontario, Canada: Carleton University.

Tombaugh, T. N., Kozak, J., & Rees, L. (1999). Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. *Archives of Clinical Neuropsychology, 14*(2), 167-177. doi:10.1016/s0887-6177(97)00095-4

Tombaugh, T. N. (2006). A comprehensive review of the Paced Auditory Serial Addition Test (PASAT). *Archives of Clinical Neuropsychology, 21*(1), 53-76. doi:10.1016/j.acn.2005.07.006

Tombaugh, T. N., Berrigan, L. I., Walker, L. A. S., & Freedman, M. S. (2010). The Computerized Test of Information Processing (CTIP) offers an alternative to the PASAT for assessing cognitive processing speed in individuals with multiple sclerosis. *Cognitive and Behavioral Neurology, 23*(3), 192-198. doi:10.1097/WNN.0b013e3181cc8bd4

Tombaugh, T. N., & Rees, L. M. (2008). *Computerized Test of Information Processing*. Toronto, Ontario, Canada: Multi-Health Systems.

Tombaugh, T. N., Rees, L. M., Stormer, P., Harrison, A. G., & Smith, A. (2007). The effects of mild and severe traumatic brain injury on speed of information processing as measured by the computerized tests of information processing (CTIP). *Archives of Clinical Neuropsychology, 22*(1), 25-36. doi:10.1016/j.acn.2006.06.013

Vichinsky, E. P., Neumayr, L. D., Gold, J. I., Weiner, M. W., Rule, R. R., Truran, D., . . . & Armstrong, F. D. (2010). Neuropsychological dysfunction and neuroimaging abnormalities in neurologically intact adults with sickle cell anemia. *Journal of the American Medical Association, 303*(18), 1823-1831. doi:10.1001/jama.2010.562

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., & Pearson, N. A. (2013). *CTOPP-2 Comprehensive Test of Phonological Processing examiner's manual – second edition*. Austin, TX: PRO-ED.

Walker, L. A. S., Cheng, A., Berard, J., Berrigan, L. I., Rees, L. M., & Freedman, M. S. (2012). Tests of information processing speed: What do people with multiple sclerosis think about them? *International Journal of MS Care, 14*(2), 92-99. doi:10.7224/1537-2073-14.2.92

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale–revised*. New York, NY: The Psychological Corporation.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale–third edition*. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–fourth edition*. San Antonio, TX: Pearson.

Wechsler, D (2011). *Wechsler Abbreviated Scale of Intelligence – second edition.* Bloomington, MN: Pearson.

Willison, J., & Tombaugh, T. N. (2006). Detecting simulation of attention deficits using reaction time tests. *Archives of Clinical Neuropsychology, 21*(1), 41-52. doi:10.1016/j.acn.2005.07.005

Wisdom, N. M., Mignogna, J., & Collins, R. L. (2012). Variability in Wechsler Adult Intelligence Scale-IV subtest performance across age. *Archives of Clinical Neuropsychology*, *27*(4), 389-397. doi:10.1093/arclin/acs041

Zettel-Watson, L., Suen, M., Wehbe, L., Rutledge, D. N., & Cherry, B. J. (2017). Aging well: Processing speed inhibition and working memory related to balance and aerobic endurance. *Geriatrics & Gerontology International*, *17*, 108-115. doi:10.1111/ggi.12682

Zimprich, D., & Martin, M. (2002). Can longitudinal changes in processing speed explain longitudinal age changes in fluid intelligence? *Psychology and Aging*, *17*(4), 690-695. doi:10.1037//0882-7974.17.4.690

Appendix A

Screening Form

INSTRUCTIONS*: Please complete the following screening questionnaire by filling in the blanks or circling your answers.*

Date ____________ Age _______ Gender __________ Ethnicity ______________ GPA______

1. With which hand do you write? Right Left Both (ambidextrous)

2. Is English your first language? Yes No

   If NO, what was your first language? ____

   At what age did you learn English? ____

3. Were there any known difficulties with your birth? Yes No

   If YES, describe: ____

4. Do you have a vision problem that requires corrective lens wear (e.g., glasses)? Yes No

Education

5. Did you **ever** have to repeat any grades? Yes No

6. Were you **ever** placed in special education classes for learning difficulties? Yes No

7. Have you **ever** been diagnosed with a learning disability by a professional? Yes No

   If YES, describe: ____

8. Are you **currently** receiving services from Disability Services for Students (DSS) Yes No

   If YES, please indicate the reason you are receiving services: _________________________

   ____

9. What is the highest grade you have **completed**? (Please report years completed. For example, if you are a freshman you are in your 13th year of school, but you have completed 12 years of education. So, you would indicate 12.) ____

Medical and Health History

10. Have you **ever** been diagnosed with any serious illness/medical condition(s)? Yes No (e.g., diabetes, lupus, cancer, etc.)

If YES, please list: ____

If YES, are you **currently** experiencing the effects of the above condition(s)? Yes No

11. Have you **ever** been diagnosed with any neurological condition(s)? Yes No
(e.g., seizures, epilepsy, migraines, stroke, etc.)

If YES, please list: ____

12. Are you **currently** experiencing significant problems with your mood Yes No
(such as anxiety and/or depression) or any other psychiatric condition(s)?

If YES, please list: ____

13. Are you **currently** receiving treatment for your mood (such as anxiety or Yes No
depression or any other psychiatric condition(s)?

14. Have you **ever** felt you should cut down on your drinking/drug use? Yes No

15. Have you **ever** been annoyed by people who criticize your drinking/drug use? Yes No

16. Have you **ever** felt bad or guilty about your drinking or drug use? Yes No

17. Have you **ever** had a drink first thing in the morning to steady your nerves or Yes No
to get rid of a hangover?

Head Injury History

18. Have you **ever** been knocked unconscious **or** experienced a Yes No
concussion/brain injury?

--IF **NO**, STOP HERE--

19. Were you knocked unconscious? Yes No

If YES, how long were you unconscious? (circle one)

- Less than 1 minute
- 1 to 30 minutes
- More than 30 minutes

20. Do you remember the events before or after your head injury? Yes No

If NO, how long of a time period were you unable to remember? (circle one)

- A few seconds
- Less than 5 minutes
- Less than 30 minutes
- 30 to 60 minutes
- More than 60 minutes

21. Were you treated by a medical professional? Yes No

If YES, were you given a diagnosis? Yes No

If YES, please list: ____

Appendix B

Instructions for the Alphaback

This is a test of how well you know the alphabet. A letter will be presented on the screen and I want you to tell me the correct letter that *comes before* that letter as fast as you can. For example, if the letter 'B' is presented on the screen, you would say 'A.' Again, I want to see how *fast* you can come up with the correct answer. I'll take whatever answer you say first, even if it's wrong, and we will go on to the next letter. Any questions? Okay, let's do a practice of 5 letters to make sure you have the right idea. Ready?

[Practice is conducted with corrective feedback].

Good job. Now we will do the test. Remember, tell me the correct letter that *comes before* the letter presented on the screen as *fast* as you can. Ready?

Appendix C

Manipulation Check (MC)

Please answer the questions below. Your responses will not affect the amount of credit you receive for participation. Your honest responses are important!

1. Did you understand the instructions provided in this study?

Yes ___ No ___

2. Circle the number that best describes how hard you tried to follow the instructions you were given:

1	2	3	4	5	6	7	8	9	10

Didn't try at all — Tried moderately hard — Tried very hard

3. Circle the number that best describes how successful you think you were in producing the results asked of you in the instructions of the study:

1	2	3	4	5	6	7	8	9	10

Not at all successful — Moderately successful — Very successful

Appendix D

Test Acceptability Questionnaire (TAQ)

1. How difficult was that test?

1	2	3	4	5	6	7	8	9	10
Extremely easy	Easy			Neither easy nor difficult		Difficult			Extremely difficult

2. What did you think about that test?

1	2	3	4	5	6	7	8	9	10
Hated it		Disliked it		It was okay		Liked It			Loved it

Appendix E

Subject Information and Informed Consent

Study Title: The Alphaback: A Novel Processing Speed Test

Investigator(s):

Meredith Reynolds, M.A.
Clinical Psychology Graduate Student
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Dr. Stuart Hall, Ph.D.
Faculty Supervisor
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Special Instructions:

This consent form may contain words that are new to you. If you read any words that are not clear to you, please ask the person who gave you this form to explain them to you.

You must be between 18 and 24 years of age to participate. You can only participate in this study once.

Exclusion Criteria:

- Reported birth or learning difficulties
- Diagnosed learning disabilities
- Reported neurological impairments or current significant psychological symptoms
- Reported possible problems with drug or alcohol use
- Unable to understand the instructions of the study

Purpose:

You are being asked to take part in a research study that investigates a new processing speed test.

Procedures:

If you agree to take part in this research study, you will be asked to complete a demographic questionnaire. You will then complete several tests that assess your cognition. We will then ask you about your experience taking these tests. The entire study should take no longer than 1 hour.

Payment for Participation:

You will not receive monetary payment, but will earn three (3) research credits toward a class of your choice.

Risks/Discomforts:

There is no anticipated discomfort associated with participating in this study, so risk is minimal.

Benefits:

There is no promise that you will receive any benefit from taking part in this study. However, your participation in this study may contribute to your learning experience by providing you with first-hand experience of psychological research.

Confidentiality:

Your records will be kept confidential and will not be released without your consent except as required by law. Your identity will be kept private. If the results of this study are written in a scientific journal or presented at a scientific meeting, your name will not be used. The data will be stored in a locked file cabinet. Your signed consent form will be stored in a cabinet separate from the data.

Voluntary Participation/Withdrawal:

Your decision to take part in this research study is entirely voluntary. You may refuse to take part in or you may withdraw from the study at any time without penalty or loss of benefits to which you are normally entitled. If you decide to withdraw, your data will be destroyed.

Questions:

You may wish to discuss this with others before you agree to take part in this study.

If you have any questions about the research now or during the study, please contact: Meredith Reynolds (meredith.reynolds@umontana.edu).

If you have any questions regarding your rights as a research subject, you may contact the UM Institutional Review Board (IRB) at (406) 243-6672.

Statement of Your Consent:

I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that any future questions I may have will also be answered by a member of the research team. I voluntarily agree to take part in this study. I understand I will receive a copy of this consent form.

____

Printed Name of Subject

____ __________________________

Subject's Signature Date

Appendix F

Results of Tests of Parametric Assumptions for Males' and Females' Scores on Established Tests of Cognition

Cognitive Test	Levene's Test of Equal Variances	Kolmogorov-Smirnov Test of Normality	Skewness (*SE*)	Kurtosis (*SE*)
WAIS-IV Coding	$F(1, 88) = 2.27$	$D(90) = 0.06$	0.04 (0.26)	-0.50 (0.51)
Males		$D(19) = 0.14$	0.22 (0.52)	-0.41 (1.01)
Females		$D(71) = 0.08$	0.03 (0.29)	-0.63 (0.56)
WAIS-IV Symbol Search	$F(1, 89) = 0.44$	$D(91) = 0.09$	0.28 (0.26)	-0.15 (0.51)
Males		$D(20) = 0.10$	-0.03 (0.51)	-1.14 (0.99)
Females		$D(71) = 0.10$	0.35 (0.29)	0.09 (0.56)
WASI-2 FSIQ-2	$F(1, 86) = 3.34$	$D(88) = 0.07$	-0.07 (0.26)	0.35 (0.51)
Males		$D(18) = 0.13$	0.06 (0.54)	-0.13 (1.04)
Females		$D(70) = 0.06$	-0.17 (0.29)	0.14 (0.57)
WASI-2 Vocabulary	**$F(1, 89) = 6.71$***	**$D(91) = 0.11$****	**-1.06 (0.26)*****	**3.62 (0.51)*****
Males		**$D(20) = 0.20$***	-0.17 (0.51)	-0.77 (0.99)
Females		$D(71) = 0.10$	**-0.95 (0.29)****	**2.65 (0.56)*****

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

Appendix F (Continued)

Results of Tests of Parametric Assumptions for Males' and Females' Scores on Established Tests of Cognition (Continued)

Cognitive Test	Levene's Test of Equal Variances	Kolmogorov-Smirnov Test of Normality	Skewness (*SE*)	Kurtosis (*SE*)
COWA	*F*(1, 88) = 1.14	*D*(90) = 0.08	-0.23 (0.26)	-0.63 (0.51)
Males		*D*(20) = 0.15	-0.15 (0.51)	-0.14 (0.99)
Females		*D*(70) = 0.06	0.01 (0.29)	-0.51 (0.57)
CTOPP-2 Rapid Naming	*F*(1, 89) = 0.78	***D*(91) = 0.11****	**-0.71 (0.26)****	0.22 (0.51)
Males		***D*(20) = 0.21***	**1.32 (0.51)****	1.32 (0.99)
Females		*D*(71) = 0.09	**-0.62 (0.29)***	0.30 (0.56)
Beery VMI	*F*(1, 89) = 0.03	***D*(91) = 0.15*****	**-0.69 (0.26)****	0.46 (0.51)
Males		*D*(20) = 0.16	-0.27 (0.51)	-1.05 (0.99)
Females		***D*(71) = 0.14****	**-0.74 (0.29)***	0.65 (0.56)
WASI-2 Matrix Reasoning	*F*(1, 86) = 0.23	***D*(88) = 0.12****	**-0.51 (0.26)***	-0.19 (0.51)
Males		*D*(18) = 0.14	-0.16 (0.54)	-0.98 (1.04)
Females		***D*(70) = 0.11***	**-0.63 (0.29)***	0.17 (0.57)

Note. **p* < .05. ***p* < .01. ****p* < .001.

Appendix G

Descriptive Statistics for Pooled Variables of Tests of Cognition

Cognitive Test	*N*	Raw Score *M* (*SD*)	95% CI	Standardized Score *M* (*SD*)	95% CI
Alphaback Total Correct	91	32.37 (8.49)	[30.56, 34.18]	N/A	N/A
Alphaback Total Errors	91	4.32 (3.89)	[3.49, 5.15]	N/A	N/A
Alphaback Longest Sequence	91	16.84 (9.10)	[14.90, 18.78]	N/A	N/A
WAIS-IV Coding	90	80.41 (11.57)	[77.95, 82.88]	11.45 (2.28)[a]	[10.96, 11.93]
WAIS-IV Symbol Search	91	35.09 (6.88)	[33.63, 36.56]	10.56 (2.55)[a]	[10.02, 11.11]
WASI-2 FSIQ-2	88	N/A	N/A	103.64 (10.75)[b]	[101.35, 105.94]
WASI-2 Vocabulary	91	39.12 (4.67)	[38.13, 40.12]	53.92 (8.38)[c]	[52.13, 55.71]
COWA	90	38.46 (8.22)	[36.71, 40.21]	48.96 (9.03)[c]	[47.03, 50.89]
CTOPP-2	91	N/A	N/A	94.15 (14.05)[b]	[91.16, 97.14]
Beery VMI	91	27.87 (1.63)	[27.53, 28.22]	97.03 (7.59)[b]	[95.42, 98.65]
WASI-2 Matrix Reasoning	89	20.67 (3.24)	[19.98, 21.36]	50.40 (7.75)[c]	[48.75, 52.05]

Note. [a]Scaled score. [b]Standard score. [c]T-score.

Appendix H

Correlations Between the Alphaback and Established Tests of Cognition

	Alphaback Total Errors	Alphaback Longest Sequence	WAIS-IV Coding	WAIS-IV Symbol Search	WASI-2 FSIQ-2	WASI-2 Vocabulary	COWA	CTOPP-2 Rapid Naming	Beery VMI	WASI-2 Matrix Reasoning
Alphaback Total Correct	**-.29**[a]**	**.26**[b]**	**.32**[c]**	**.21*[c]**	.11[c]	.05[a]	**.28**[c]**	.07[c]	.17[a]	**.21*[a]**
Alphaback Total Errors		**-.77**[a]**	.12[a]	.13[a]	-.02[a]	.02[a]	-.03[a]	-.08[a]	-.02[a]	-.11[a]
Alphaback Longest Sequence			.09[a]	.02[a]	.07[a]	-.02[a]	.06[a]	-.09[a]	.10[a]	.13[a]
WAIS-IV Coding				**.50**[c]**	-.05[c]	-.11[a]	.20[c]	**.23*[a]**	.15[a]	.11[a]
WAIS-IV Symbol Search					-.10[c]	-.17[a]	**.25*[c]**	**.24*[a]**	.20[a]	.02[a]
WASI-2 FSIQ-2						**.72**[a]**	.20[c]	.05[a]	.13[a]	**.75**[a]**
WASI-2 Vocabulary							.16[a]	.05[a]	.08[a]	.17[a]
COWA								.19[a]	-.03[a]	.07[a]
CTOPP-2 Rapid Naming									.02[a]	.02[a]
Beery VMI										.09[a]

Note. [a]Spearman's rho. [b]Intraclass correlation (two-way mixed effects model, absolute agreement, single measures). [c]Pearson's correlation. $*p < .05$. $**p < .01$.

Appendix I

Scatterplots of Alphaback Total Correct Scores and Established Tests of Cognition

Figure I1

Scatterplot of Alphaback Total Correct Scores and WAIS-IV Coding Total Scores

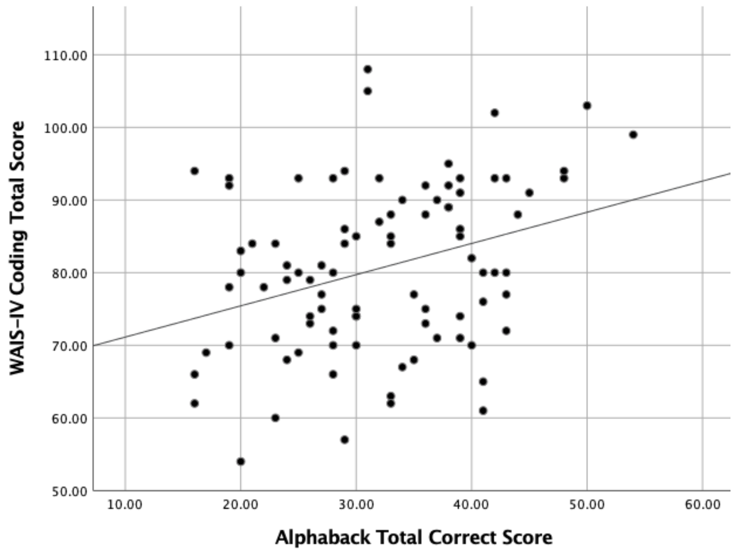


Figure I2

Scatterplot of Alphaback Total Correct Scores and WAIS-IV Symbol Search Total Scores

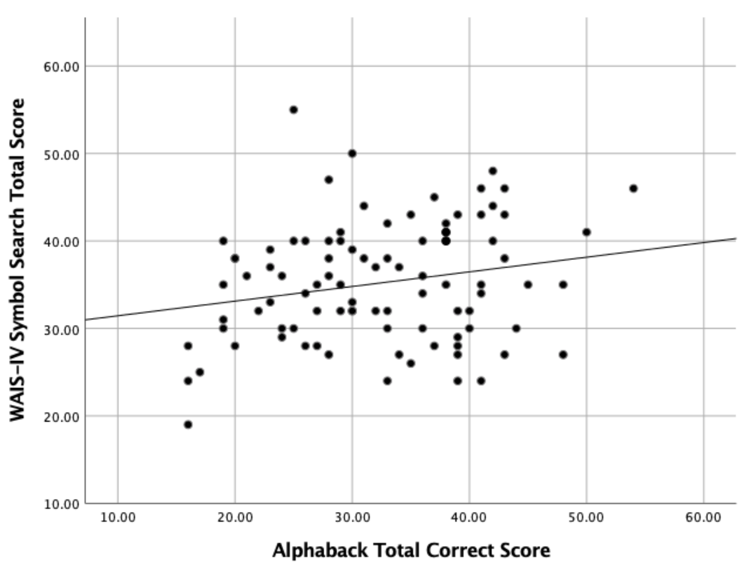


Figure I3

Scatterplot of Alphaback Total Correct Scores and WASI-2 FSIQ-2 Standard Scores

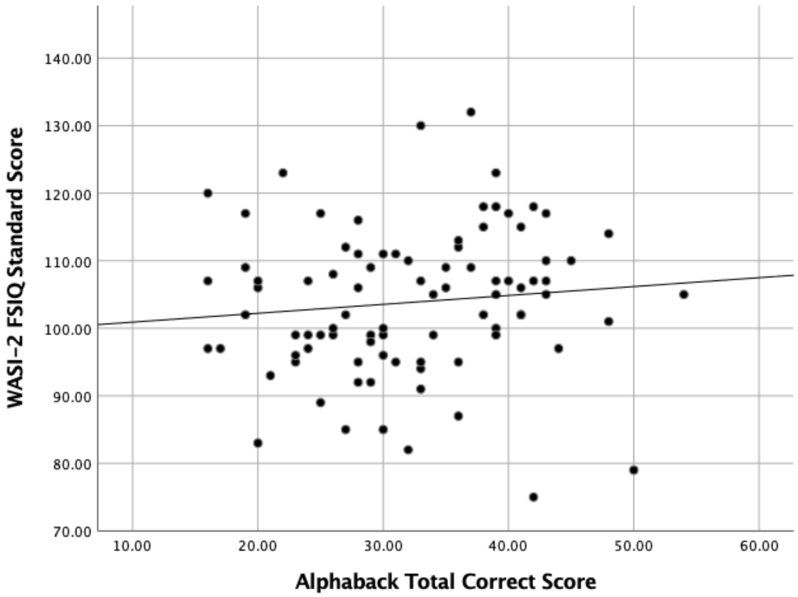


Figure I4

Scatterplot of Alphaback Total Correct Scores and WASI-2 Vocabulary Total Scores

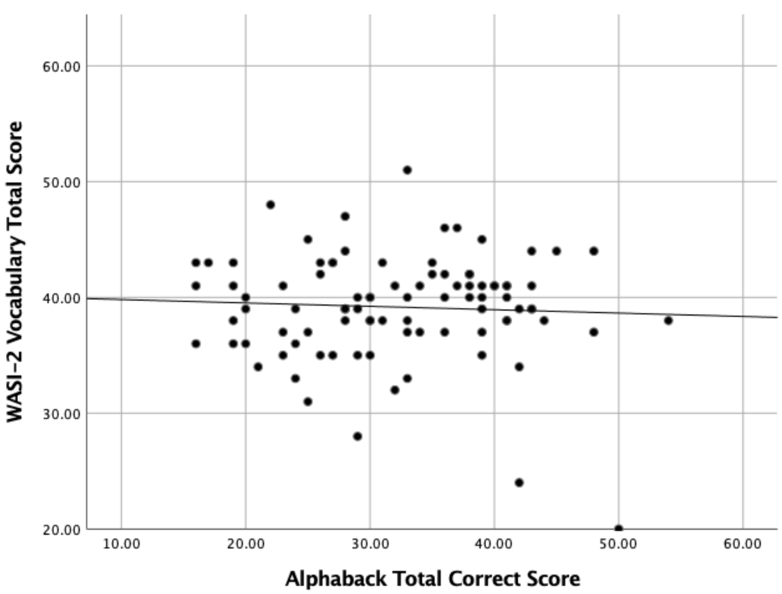


Figure I5

Scatterplot of Alphaback Total Correct Scores and COWA Corrected Total Scores

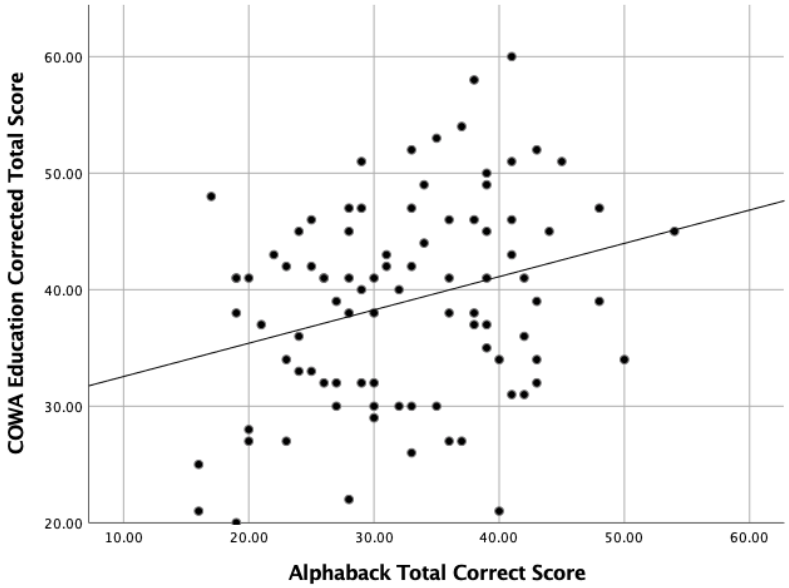


Figure I6

Scatterplot of Alphaback Total Correct Scores and CTOPP-2 Rapid Naming Standard Scores

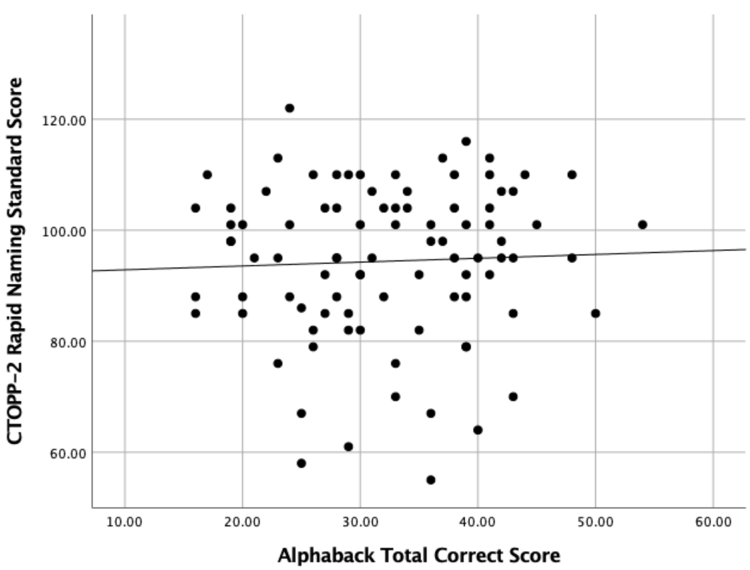


Figure I7

Scatterplot of Alphaback Total Correct Scores and Beery VMI Total Scores

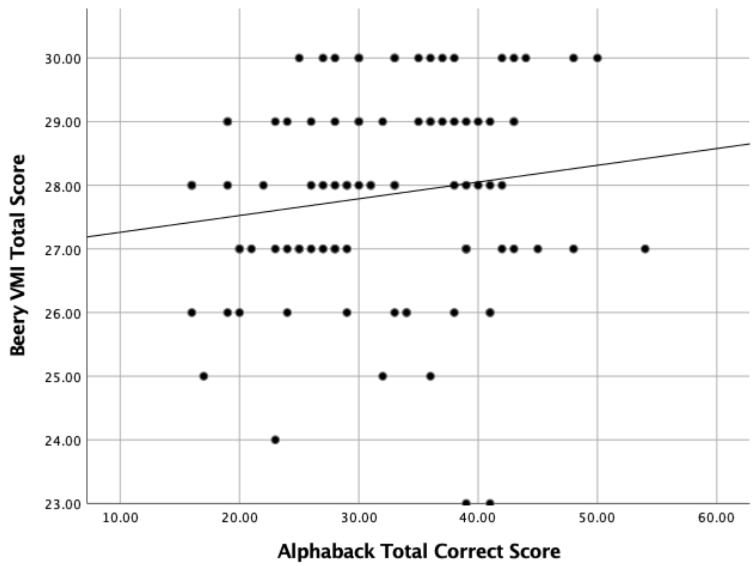
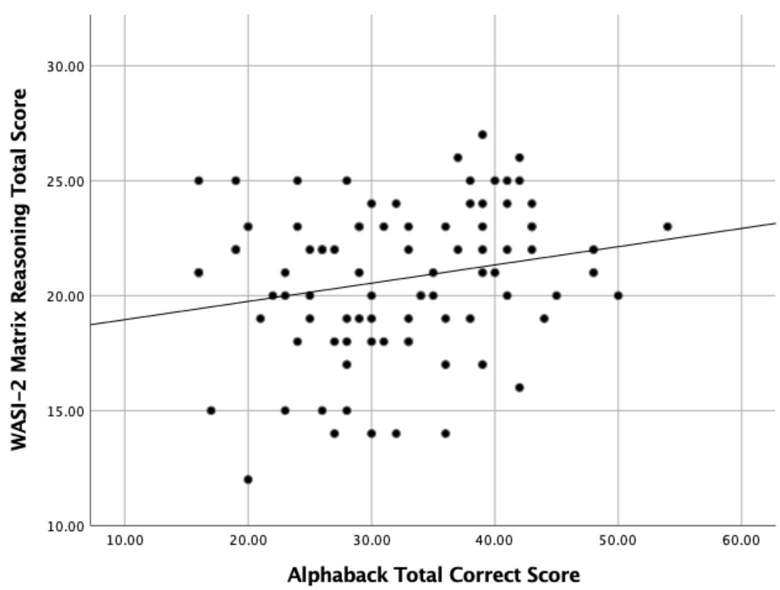


Figure I8

Scatterplot of Alphaback Total Correct Scores and WASI-2 Matrix Reasoning Total Scores



Appendix J

Scatterplots of Alphaback Total Errors and Established Tests of Cognition

Figure J1

Scatterplot of Alphaback Total Errors and WAIS-IV Coding Total Scores

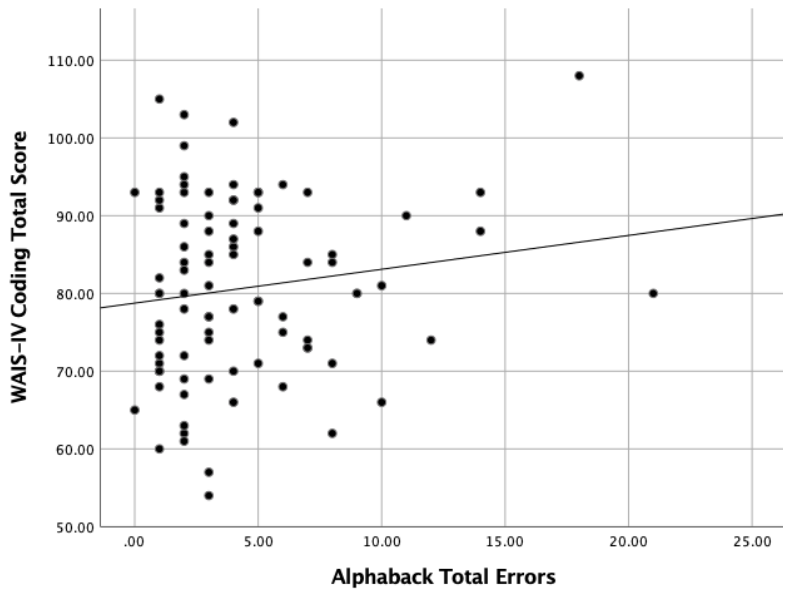


Figure J2

Scatterplot of Alphaback Total Errors and WAIS-IV Symbol Search Total Scores

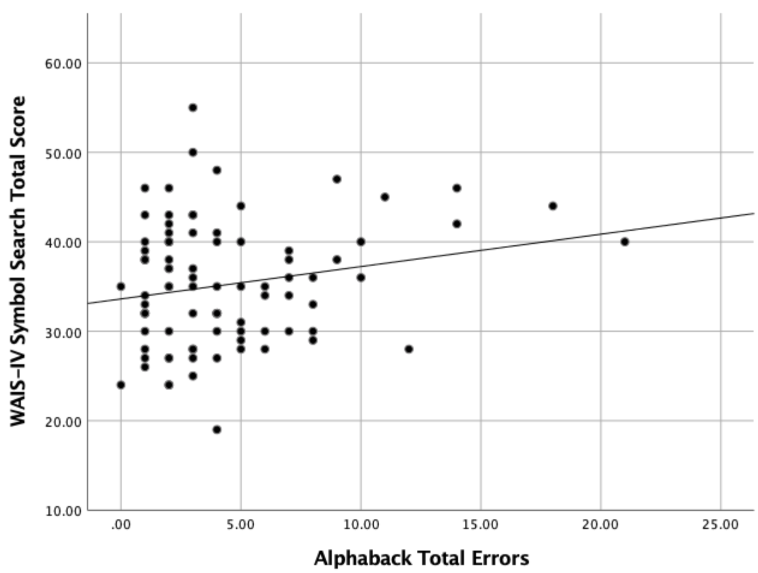


Figure J3

Scatterplot of Alphaback Total Errors and WASI-2 FSIQ-2 Standard Scores

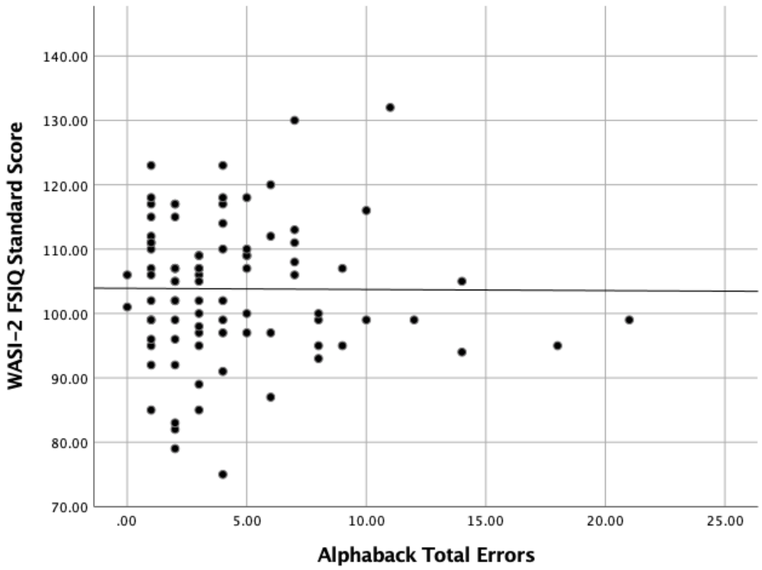


Figure J4

Scatterplot of Alphaback Total Errors and WASI-2 Vocabulary Total Scores

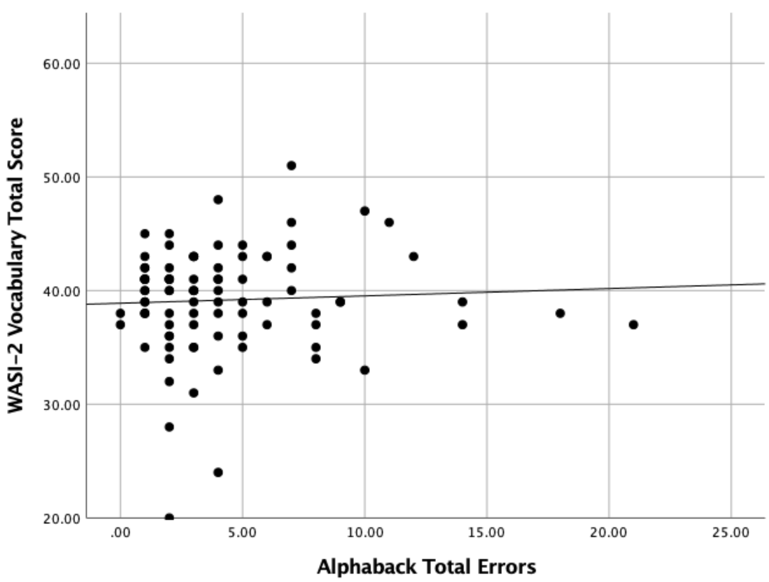


Figure J5

Scatterplot of Alphaback Total Errors and COWA Corrected Total Scores

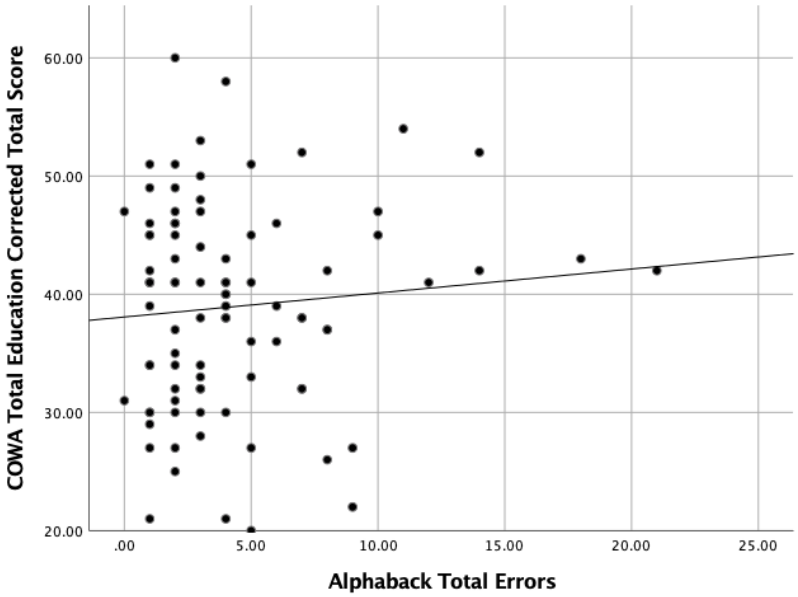


Figure J6

Scatterplot of Alphaback Total Errors and CTOPP-2 Rapid Naming Standard Scores

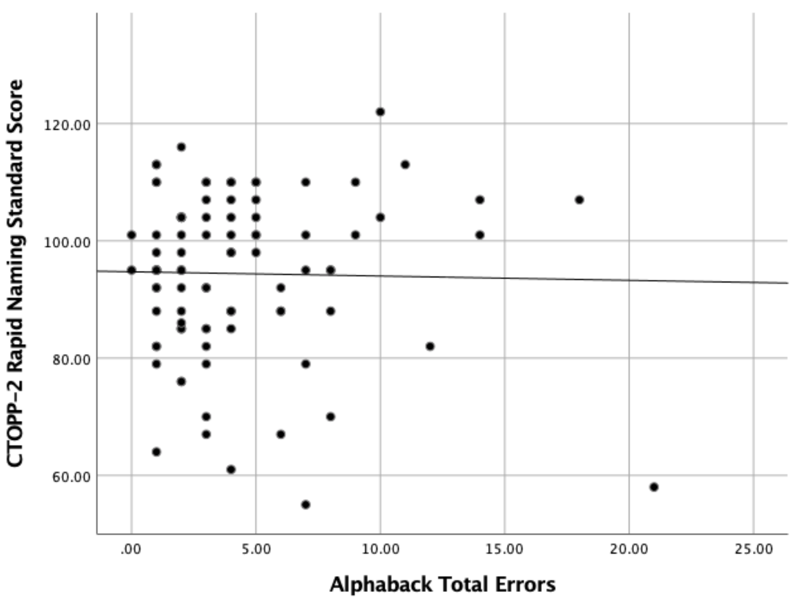


Figure J7

Scatterplot of Alphaback Total Errors and Beery VMI Total Scores

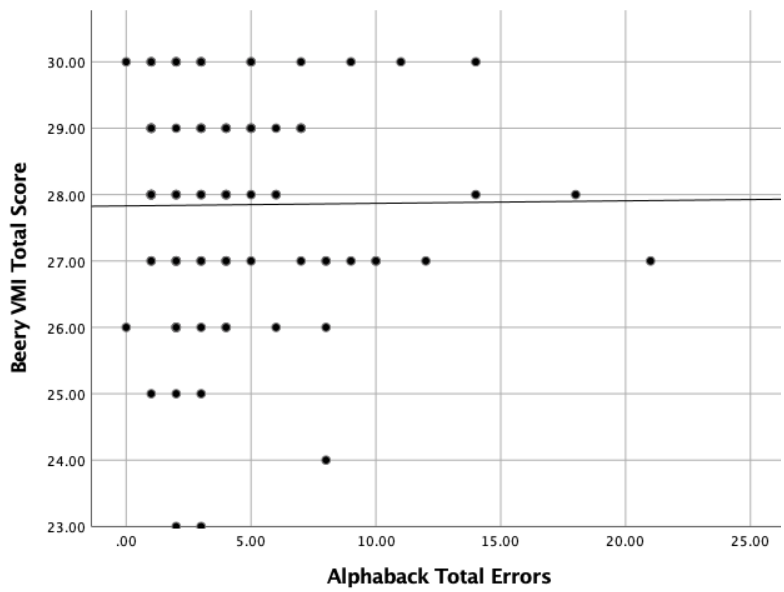
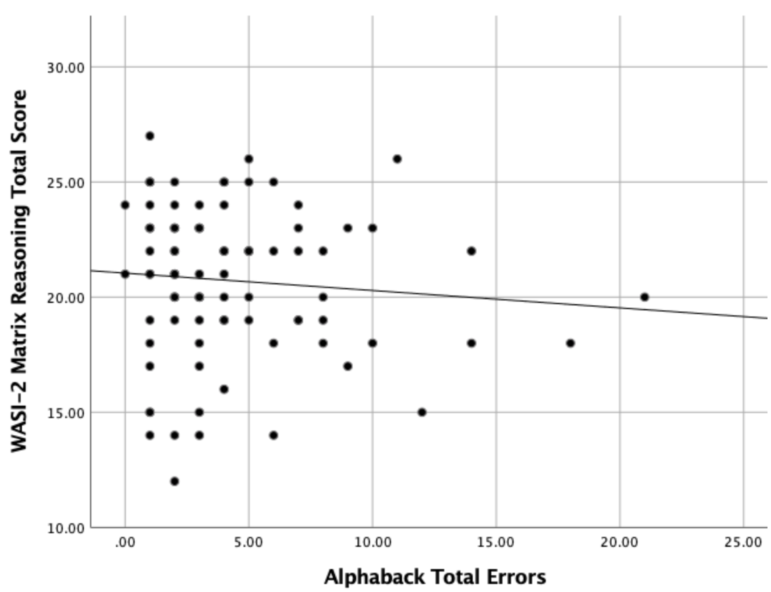


Figure J8

Scatterplot of Alphaback Total Errors and WASI-2 Matrix Reasoning Total Scores



Appendix K

Scatterplots of Alphaback Longest Sequence of Consecutive Correct Responses and Established Tests of Cognition

Figure K1

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and WAIS-IV Coding Total Scores

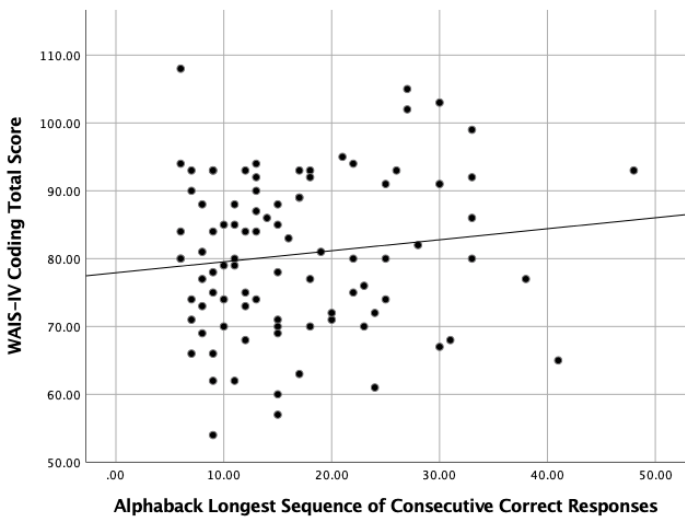


Figure K2

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and WAIS-IV Symbol Search Total Scores

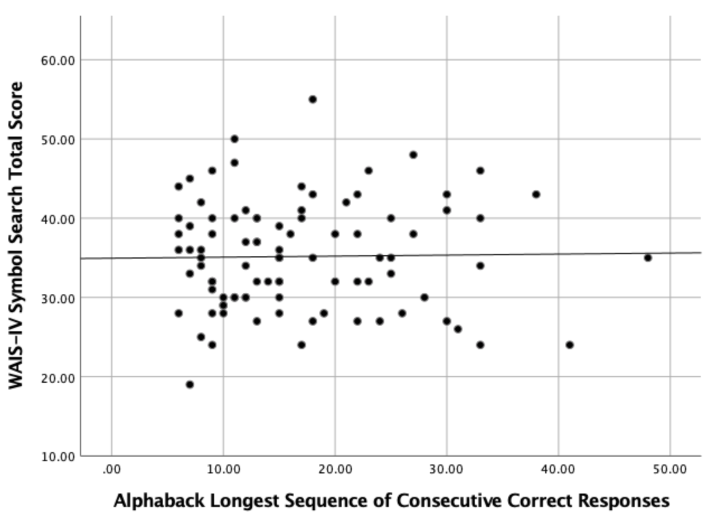


Figure K3

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and WASI-2 FSIQ-2 Standard Scores

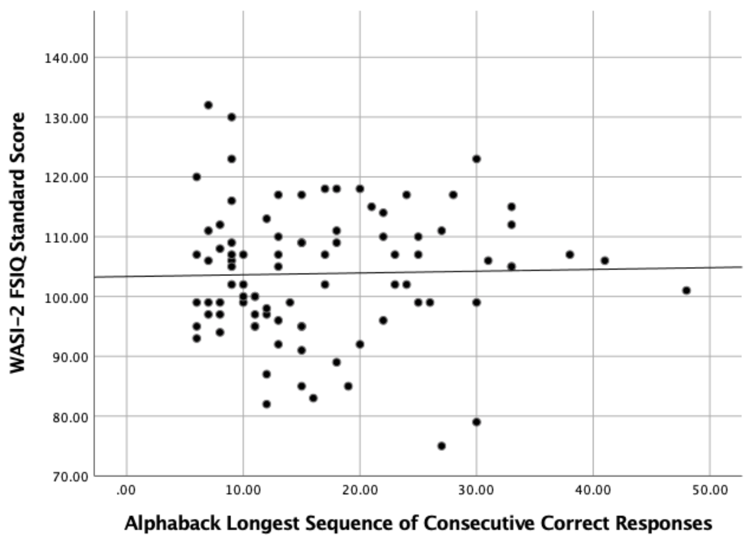


Figure K4

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and WASI-2 Vocabulary Total Scores

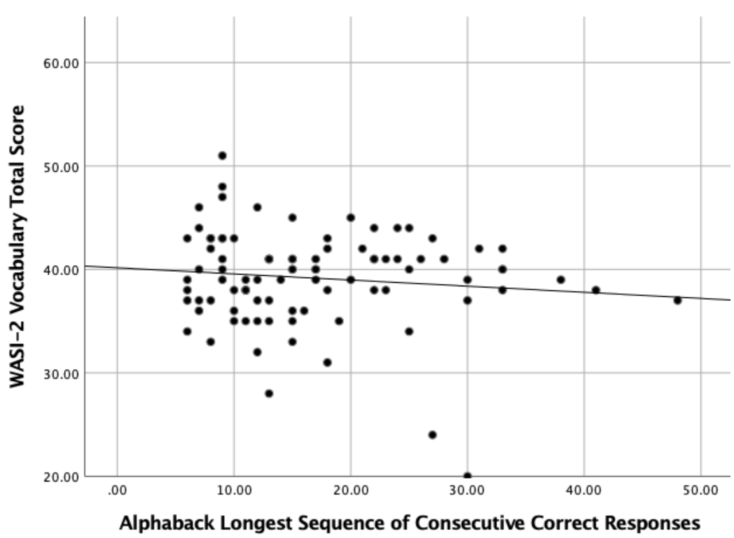


Figure K5

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and COWA Corrected Total Scores

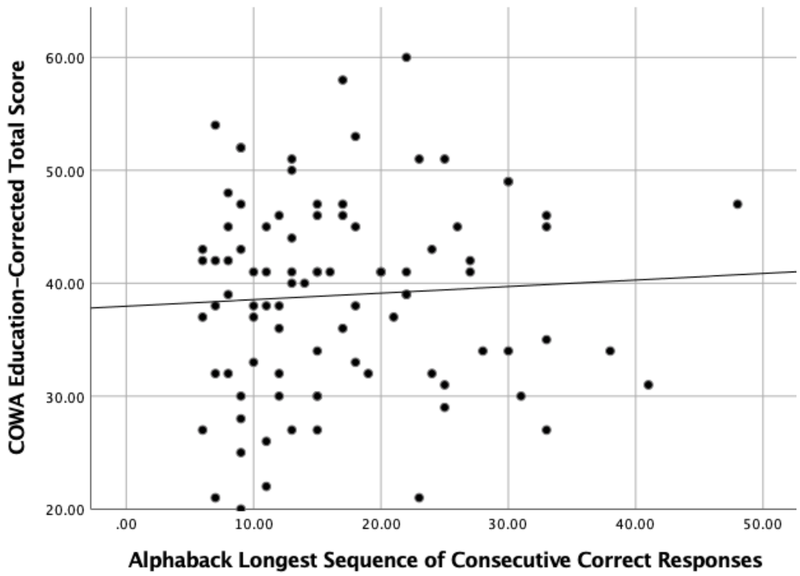


Figure K6

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and CTOPP-2 Rapid Naming Standard Scores

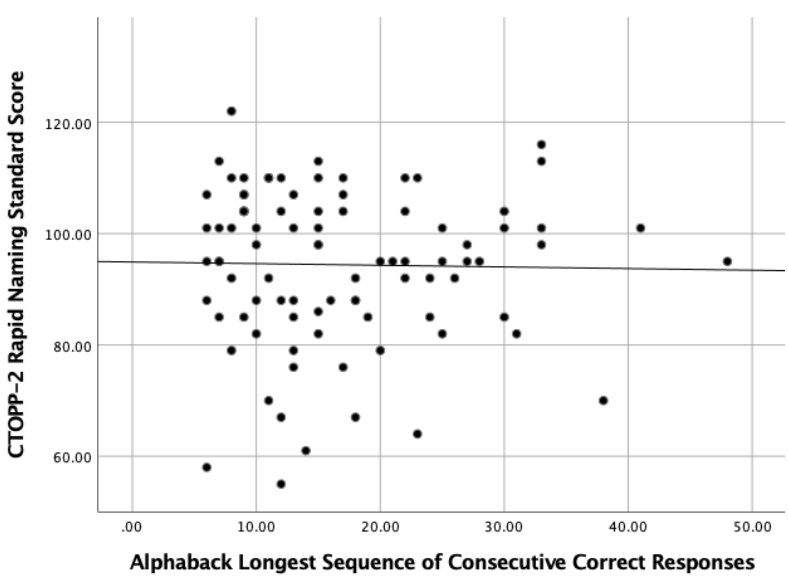


Figure K7

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and Beery VMI Total Scores

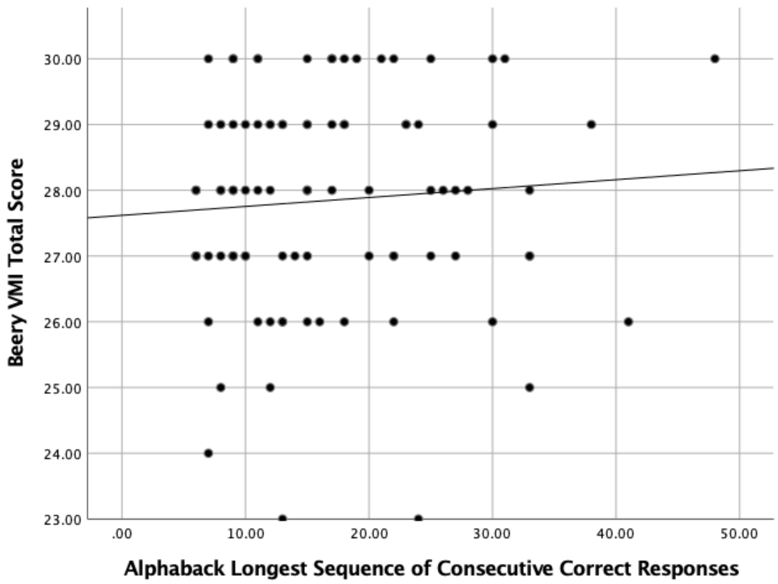
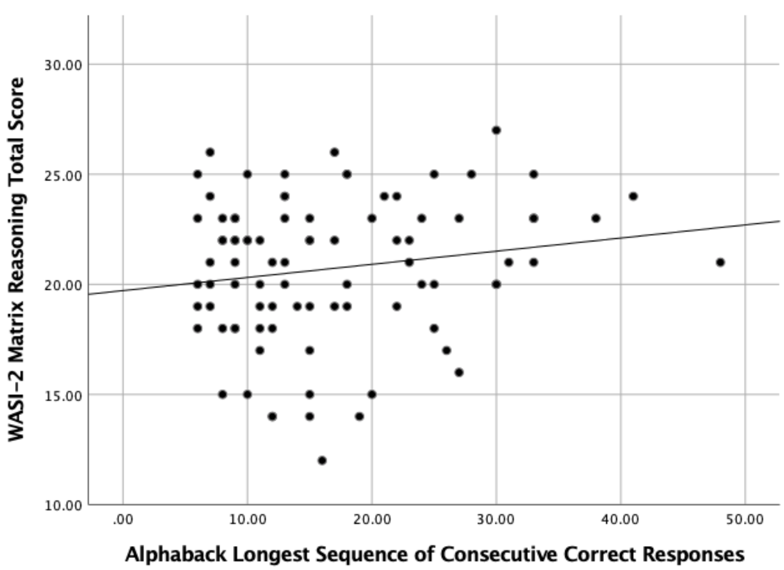


Figure K8

Scatterplot of Alphaback Longest Sequences of Consecutive Correct Responses and WASI-2 Matrix Reasoning Total Scores



Appendix L

Results of Tests of Parametric Assumptions for Likability and Difficulty Ratings on Tests of Cognition

Cognitive Test	Levene's Test of Equal Variances	Kolmogorov-Smirnov Test of Normality	Skewness (*SE*)	Kurtosis (*SE*)
Alphaback				
Likability	**$F(1, 88) = 6.61$***	**$D(90) = 0.17$*****	0.20 (0.25)	-0.71 (0.50)
Difficulty	$F(1, 88) = 0.27$	**$D(90) = 0.24$*****	**-1.27 (0.25)*****	**2.40 (0.50)*****
WAIS-IV Coding				
Likability	$F(1, 88) = 0.02$	**$D(90) = 0.18$*****	0.13 (0.25)	-0.88 (0.50)
Difficulty	$F(1, 88) = 1.26$	**$D(90) = 0.15$*****	-0.24 (0.25)	-0.88 (0.50)
WAIS-IV Symbol Search				
Likability	$F(1, 89) = 0.00$	**$D(91) = 0.22$*****	-0.19 (0.25)	**-0.67 (0.25)****
Difficulty	$F(1, 89) = 0.12$	**$D(91) = 0.20$*****	**0.94 (0.25)*****	0.52 (0.50)
WASI-2 Vocabulary				
Likability	$F(1, 89) = 0.16$	**$D(91) = 0.12$****	-0.18 (0.25)	-0.59 (0.50)
Difficulty	$F(1, 89) = 0.07$	**$D(91) = 0.13$*****	-0.27 (0.25)	-0.06 (0.50)
COWA				
Likability	$F(1, 88) = 0.42$	**$D(90) = 0.19$*****	-0.03 (0.25)	-0.97 (0.50)
Difficulty	$F(1, 88) = 0.60$	**$D(90) = 0.12$****	-0.30 (0.25)	-0.10 (0.50)
CTOPP-2 Rapid Naming				
Likability	$F(1, 89) = 0.61$	**$D(91) = 0.22$*****	-0.28 (0.25)	-0.81 (0.50)
Difficulty	$F(1, 89) = 0.80$	**$D(71) = 0.32$*****	**2.03 (0.25)*****	**4.90 (0.50)*****
Beery VMI				
Likability	$F(1, 89) = 0.03$	**$D(91) = 0.18$*****	0.15 (0.25)	-0.75 (0.50)
Difficulty	$F(1, 89) = 0.81$	**$D(91) = 0.18$*****	**-0.77 (0.25)****	0.31 (0.50)
WASI-2 Matrix Reasoning				
Likability	$F(1, 86) = 0.01$	**$D(88) = 0.14$*****	-0.31 (0.26)	0.25 (0.51)
Difficulty	$F(1, 86) = 0.17$	**$D(88) = 0.15$*****	-0.39 (0.26)	-0.26 (0.51)

Note. *$p < .05$. **$p < .01$. ***$p < .001$.