# Working Memory after Acquired Brain Injury: Listening Span Recall

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## Dedication

This thesis is dedicated to my parents, Tim and Jean Johnson.

**Abstract**

Twenty-three mildly impaired adults with acquired brain injury (ABI) and eighteen carefully matched healthy controls performed three commonly used working memory tasks (WM): the digit span, n-back task, and listening span task (Tompkins, Bloise, Timko, & Baumgaertner,1994). In a preliminary study, Baumgarten (2009) administered these to a small group of mildly impaired adults with ABI and controls and found that participants with ABI made more errors on the listening span task, but did not perform worse on the n-back or digit span tasks compared to controls.

The present study followed the same methods and procedures used in Baumgarten (2009) with the addition of error analysis by type for recall errors made on the listening span task. Recall errors were coded as either intrusions or omissions. Intrusion errors were broken down into within-task intrusions, categorical intrusions, non-categorical intrusions and phonemic intrusions. Analysis of variance (ANOVA) was used when there were both between- and within-group comparisons, and simple group comparisons were done in the absence of within-group variables. Adults with ABI made more total errors and more omission errors than controls on the listening span task, however groups did not differ in total intrusion errors or in specific intrusion error types. All participants made more omission than intrusion errors on the listening span task. Performance on the digit span task and the n-back task were similar between groups. The listening span task appears to capture WM that has a linguistic base, including pre-injury vocabulary and post-injury word fluency. The clinical significance of this is discussed.

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# Introduction

Working memory (WM) is the functional system within the brain which temporarily processes and stores information. WM is often impaired after traumatic brain injury (TBI) (Vakil, 2005) and many high-level cognitive skills are known to be affected by WM ability (Baddeley, 1992; Baddeley 2003; Levin, Benton, & Grossman, 1982; Vakil, 2005). The present study examines WM ability in adults with TBI with three often used assessments: the Digit Span task from the Weschler Memory Scale – 3rd Edition (Wechsler, 1997), the auditory n-back task, and the listening span task (Tompkins, Bloise, Timko,& Baumgaertner, 1994).

The concept of WM and its effects on language and other cognitive processes are discussed through a review of the literature. Then the three WM tasks and the California Verbal Learning Test – 2nd Edition (Delis, Kramer, Kaplan and Ober, 2000) which is a test of verbal learning and memory, are described according to their relevance in assessment of WM in the TBI population.

## *Working Memory*

Memory has previously been conceptualized as two components, short term memory (STM) and long term memory (LTM). The definition of these two types of memory emerged as research by Brown (1958) and Peterson and Peterson (1959) demonstrated that information is rapidly lost from memory if rehearsal is prevented. Atkinson and Shiffrin's (1968) two-component model of memory described STM as the space where perceived information is stored temporarily prior to removal or entry in

LTM. The concept of WM was proposed in 1974, by Baddeley and Hitch, as a new way to conceptualize memory. Baddeley and Hitch defined WM as being comprised of three components: the central executive, the visuo-spatial sketch pad, and the phonological loop. The central executive initiates and controls decision making, reasoning, and language comprehension and transfers information to LTM through rehearsal. The visuo-spatial sketchpad deals primarily with visual imagery tasks, and the phonological loop deals with temporary storage for articulatory rehearsal processes.

In 2000, Baddeley added a fourth component called the episodic buffer. The episodic buffer is a system that integrates and holds phonological, visual, and spatial information as one unit. Since Baddeley's original theory in 1974 and revision in 2000, additional models have been proposed to explain WM (Baddeley, 2003; Miyake & Shah, 1999). Still, WM is an agreed upon concept which best illustrates the dual function of the system within the brain that operates to process and store temporary information simultaneously. Thus, WM is a temporary storage system which supports one's overall capacity for thinking. As such, WM has been shown to be an important underlying ability for many higher cognitive functions, including language processing and language comprehension (Baddeley, 1992; Baddeley 2003).

Daneman and Merikle (1996) completed a meta-analysis of data from 6197 participants in 77 studies to examine the association between WM capacity and the ability to comprehend language. They concluded that this research supported the significant role of WM in language comprehension. Reading comprehension has also been found to be crucially impacted by WM ability. Research has demonstrated that individual differences in reading comprehension are related to differences in WM capacity (Daneman & Carpenter, 1980; Baddeley & Hitch, 1974). Furthermore, WM capacity has also been shown to have a role in the acquisition of vocabulary (Gathercole & Baddeley, 1993) and verbal reasoning (Baddley & Hitch 1974).

In a study done by Raulerson, Donovan, Whiteford and Kellogg (2010), two groups of typical college students were compared to determine the contribution of verbal, visual, and spatial WM in written language production. Groups composed written definitions for nouns while concurrently performing a verbal, visual, or spatial WM task. As shown by interference on the verbal WM task during the written composition of noun definitions, they found that the written composition component placed the largest demand on verbal WM for both low and high frequency nouns.

Performance on WM span tasks, often used in WM assessment, has been found to predict performance in reasoning, language comprehension, and problem solving tasks (Daneman & Carpenter, 1980; Just & Carpenter, 1999). Turksra, Evans & Ellis Weismer (2009) used a modified version of the Daneman and Carpenter's (1980) listening span task, the Competing Language Processing Test (CLPT) published by Gaulin and Campbell (1994) to assess WM ability in typically developing adolescents and adolescents with Specific Language Impairment (SLI). They found the CLPT to significantly differentiate the SLI group from their typical peers, suggesting that WM may be one underlying determinant of language ability.

*Traumatic Brain Injury and Working Memory*

Traumatic brain injury (TBI) is the result of open or closed head trauma, which causes brain damage or dysfunction. TBI frequently causes diffuse axonal injury (Ommaya & Gennarelli, 1974) and other lesions such as contusions, cerebral edema, ischemia, and hemorrhage (Bigler, 1990). The frontal and temporal lobes are particularly vulnerable to TBI (Adams, 1975). The severity of injury can range from "mild" to "severe" and the severity of impairments that result from TBI also vary. The severity of deficits after TBI correlate with the severity of the injury and other complications related to the injury (e.g. cell death and diffuse axonal injury, brain swelling, and anoxia) (Constantinidou, Thomas & Best, 2004). Commonly occurring, persistent neurocognitive impairments after TBI include deficits of memory, attention, speed of processing, and executive functions (Levin, Benton & Grossman, 1982; Vakil, 2005).

Impairment of memory, in particular WM, is one of the most common and enduring deficits after TBI that recovers slower than other cognitive functions (Lezak, 1979). In a review of literature on memory impairment, Vakil (2005) concluded that memory impairment after TBI can vary widely, but resembles memory impairment following frontal lobe injury. The frontal lobe has a significant role in executive functions which include high level neurocognitive abilities such as planning, decision-making, judgment, self-perception and self-monitoring (Tranel, Anderson & Benton, 1994). As such, damage to the frontal lobes, common in TBI, can impede the ability to use strategies, such as organization or rehearsal while encoding or retrieving memory (Vakil, 2005), which is important for the successful use of WM. Vakil (2005) concluded that "tasks that require manipulation of stimuli, and as such probably tap the central executive component of working memory (e.g., digit backward), are more sensitive to the effects of TBI than tasks that probably tap the phonological loop (e.g., digit forward , the recency effect) (pg. 982)."

Survivors of TBI have been found to have deficits in the coordinative function of the central executive, and reduced visuo-spatial and verbal WM ability (Anderson & Knight, 2010; McDowell et al., 1997). Age, mental fatigue, injury type and injury severity can all affect cognitive tasks that are linked to WM ability after TBI (Senathi-Raja & Ponsford, 2010; Johansson, Berglund & Ronnback, 2009; Moran & Gillon, 2004). A study by Moran and Gillon in 2004 examined the language comprehension profiles of adolescents who suffered moderate to severe TBI in childhood. They assessed a group of adolescents with TBI with a standardized test battery including a test of comprehension of figurative language. They found that half of the participants with TBI performed below average in understanding figurative language while the other half performed at age-appropriate levels. They suggested that differences in WM ability may explain this inconsistency. To examine this further, Moran, Nippold and Gillon (2006) conducted a study to examine the relationship between WM and comprehension of figurative language in adolescents with TBI. They used the Proverb Comprehension Task which consisted of 20 short-stories each containing a low-familiarity proverb in which the participants had to infer the meaning given an associated short story. To assess WM, the Tompkins et al. (1994) listening span task was used. A significant difference was found between the two groups (TBI and controls) in their overall understanding of low-familiarity proverbs, in which the TBI group comprehended fewer low-familiarity proverbs. It was also found that performance on the listening span WM task was correlated to performance on the Proverb Comprehension Task for both the TBI and control groups. They concluded that a reduced WM capacity may constrain comprehension of figurative language due to the significant demand on WM required to comprehend and simultaneously analyze the component parts and contextual cues in determining the meaning of the proverb.

Adequate assessment of WM after TBI is important for accurate identification of deficits and determining appropriate goals and treatment plans. An appropriate assessment of WM will yield information regarding the core deficits that may be contributing to an individual's speech, language or cognitive impairments. Three tasks commonly used to assess WM are the digit span (forwards, backwards), n-back task, and listening span task.

The digit span task is frequently used to evaluate WM in the TBI population. In this task, the participant is asked to remember and verbally recall increasingly longer strings of numbers. This task was designed to tax the processing and storage of WM. More recently, the digit span task has used both a digit forward and a digit backward component: in digits forward participants store and verbally recall the string of numbers in the same order as they were read, and in digits backward participants recall the string of numbers in reverse order. The current study used the Digit Span subtest of the Wechsler Memory Scale (WMS) – III (Wechsler, 1997), which includes both digits forward and digits backward. When used to assess the TBI population, it has been found that digit span backward may be impaired yet the digit span forward may be intact (Brooks 1976; Haut, Petros, Frank & Lamberty, 1990).

The n-back task has been used frequently in studies of WM in the TBI population (Sanchez-Carrion et al., 2008; Scheibel et al., 2003; McAllister et al., 2001). The n-back task requires participants to monitor a given element throughout a series of stimuli and then indicate when that element is present in the series. The current study uses an auditory n-back task, in which participants listen to a series of letters and indicate throughout the series whether they have heard the pre-specified letter they were asked to identify within this series. The auditory n-back task was modeled after a task by McAllister et al. (1999), which also presents letters auditorily.

Daneman & Carpenter (1980) originally designed a listening span task to measure WM capacity in reading. Not unlike the traditional digit span and word span tasks, this task had participants read one or more sentences grouped in increasingly larger sets while also remembering the final word of each sentence for verbal recall upon completion of the set. In 1994, Tompkins et al. adapted this task by adding a truth value judgment component to verify comprehension. The participant had to determine whether the sentence was true or false while simultaneously remembering the last word of each sentence in the set upon completion of the set. This was designed to increase the demand on WM by taxing temporary storage and processing. Tompkins et al. (1994) investigated WM ability and auditory comprehension, implementing the listening span task in adults with right hemisphere damage, adults with left hemisphere damage, and controls without brain damage. They found a correlation between word recall errors made on the WM task and severity of auditory comprehension deficit.

In 2009 Baumgarten used the Tompkins et al. (1994) listening span task to assess WM ability in a group of adults with acquired brain injury (ABI). This is the only study to date known to use this task with a group of mostly adults with TBI. Baumgarten (2009) found that the listening span task significantly differentiated the control group from the group of adults with ABI, whereas the digit span and auditory n-back tasks did not. This suggested that the listening span task was more sensitive in identifying impairment of WM than the digit span or n-back task; however the sample size was very small and given the variability in the ABI population, these results needed to be verified with a larger sample.

*Working Memory and Proactive Interference*

Tompkins et al. (1994) listening span task allows for analysis of WM ability according to the total number of errors made during the task. The specific types of errors may potentially illustrate a similar and related concept to WM, called proactive interference. Proactive interference (PI) is the decremental effect of prior learning on retention of subsequently learned material (Postman, 1971). For example if a person first learned about topic A then learned about topic B, and was then unable to recall the information about topic B due to the interference of the prior learning about topic A then PI impeded the retention and learning of topic B. This high level cognitive skill is closely related to WM ability. Whitney, Arnett, Driver and Budd (2001) found that PI is a strong predictor of WM performance. In a literature review, Jonides and Nee (2006) examined the brain mechanisms of WM and PI. They found many studies demonstrating WM span tasks to be good predictors of PI resolution ability (e.g. Conway & Engle, 1994). Jonides and Nee (2006) also concluded that the suspected site in the brain involved in interference resolution is thought to be the left inferior frontal gyrus. Other areas activated during interference resolution included the intraparietal sulcus, fronto polar cortex and middle frontal gyrus in the right hemisphere. However these other areas are suspected to be involved in other cognitive processes (e.g. regulating attention, evaluation of goals) during the task, rather than resolving interference. Anderson and Neely (1996) proposed that reduced WM capacity is a result of reduced ability to resolve PI thus making accurate retrieval more difficult. It is hypothesized in the current study that through analysis of the types of recall errors made on the listening span task that the degree of proactive interference would also be evident and related to WM ability.

As shown by this research, PI and WM are closely related and evidence of impaired PI can suggest impaired WM and vice versa. As such, persons with TBI who have WM impairments are likely to have reduced ability to resolve PI. The California Verbal Learning Test - Second Edition (CVLT-II) (Delis, Kramer, Kaplan & Ober, 2000) is a measure of verbal memory that is commonly used to assess both learning and memory in adults with TBI. The test requires the participant to recall and recognize two lists of 16 words; the first presented five times (list A) and the second presented only once (list B). There are inserted time delays, both long and short, to allow for different measures of recall. The ability to recall list items is measured with and without the use of categorical cues, and the number of repetitions (same word repeated twice) and intrusions (word recalled that was not on the target list) made during the test are scored. The CVLT-II purports to measure PI along with several characteristics including semantic and serial learning strategies, serial position effects, learning characteristics, recall consistency, and others. The degree of PI is calculated on the CVLT-II by using a contrast measure. Contrast measures are defined as the difference between the subject's scores on two areas of the CVLT-II. The contrast measure proposed to measure PI is the difference between the raw scores from the first of list A and the single trail of list B.

Vanderploeg et al. (2001) used the California Verbal Learning Test (CVLT) to determine the nature of memory problems that are prevalent after TBI. They examined the possibility of either an encoding deficit, consolidation deficit or retrieval deficit. They hypothesized that inability to resolve PI was an indicator of a consolidation deficit. Thus ongoing consolidation of new information (a process by which learned information is maintained, elaborated on, and stored in long term memory) would be affected by prior learning of old information and that interference would be the primary source of the memory deficit. This study analyzed consolidation using the following CVLT 'contrast' measures: rate of forgetting (trial 5 of list A compared to both short delay free recall and long delay free recall) and trial 1 of list A compared to list B. Their results indicated that retrieval and encoding deficits were not likely to be the primary cause of memory problems, supporting consolidation as the primary deficit underlying poor verbal learning and memory for most individuals with TBI.

Donders (2006) examined six contrast measures of the CVLT-II in the standardization sample of the CVLT-II and found that about one third had at least one contrast that was considered to be in the "unusual" range. Jacobs and Donders (2007) gave the CVLT-II to a group of adults who had TBI within one year post-injury. They examined six contrast measures: PI, retroactive interference, two contrasts addressing rapid forgetting, and two contrasts addressing retrieval problems. Their results demonstrated that although the TBI group scored .3 to .75 SDs below the normative mean on the CVLT-II, only one of the rapid forgetting contrasts was statistically significant. Importantly, there was no evidence of elevated PI or retroactive interference, and no performance discrepancies that were unique to the TBI population. They concluded that an individual's CVLT-II result(s) may be considered "unusual" but are not necessarily unique or attributable to TBI.

The CVLT-II has adequate construct validity both in the standardization sample and in clinical population of individuals with TBI (Donder, 2008a; DeJong & Donders (2009). In research of the CVLT-II in a clinical population of individuals with TBI, Donders and Neinhues (2007), and Jacobs and Donders (2007) found that individuals with TBI recalled fewer correct words and made more recall errors than their demographically matched controls. Dejong and Donders (2010) found there was no profile of performance unique to the TBI population on the CVLT-II and that the TBI population showed similar patterns of learning and memory as compared to healthy controls. They concluded that although injury severity was directly related to lower performance, "detailed interpretation of an individual's pattern of performance [on the CVLT-II] following TBI…may not be advisable" (pg. 959).

Use of the CVLT-II as an appropriate and sensitive instrument in identifying impaired WM and ability to resolve PI has been questioned. Research has shown that individuals with TBI were not sensitive to PI as measured by the CVLT-II (Jacobs & Donders, 2007). Some research has found that frontal dysfunction is linked to increased susceptibility to PI (Gershberg & Shimamura, 1995; McDonald, Bauer, Grande, Gilmore & Roper, 2001) while others have found no clearly elevated levels of PI on the CVLT-II in patients with focal frontal lesions (Baldo, Delis, Kramer & Shimamura, 2002).

Based on results from the CVLT-II, the TBI population may not show a clinically unique pattern of discrepancies nor evidence of elevated PI. This lack of identification of PI on the CVLT-II is contrary to research that finds performance on WM span tasks to be poorer for individuals with TBI and WM performance and susceptibility to PI to be closely related.

*The Present Study*

In a preliminary study, Baumgarten (2009) administered the digit span (forwards, backwards), the n-back task, and the listening span task (Tompkins et al., 1994) to a small group of mildly impaired adults with ABI and carefully matched controls. Adults with ABI made more errors on the listening span task than controls, but performed similarly to controls on the n-back and digits span tasks. Positive correlations were found between performance on the listening span task, estimated verbal IQ and verbal fluency, suggesting that these three tasks share underlying processes that involve language and WM.

The purpose of the present study was to expand on the findings of Baumgarten

(2009) to determine if these results would be found by increasing the sample size, and to investigate the types of errors made on the listening span task. The research questions were:

1. Which WM measure differentiates mildly impaired adults with ABI from carefully matched controls? Are those measures associated with each other?

2. What types of errors do adults with ABI make on the listening span task compared to controls?

3. Are errors made on the listening span task and the CVLT-II associated with each other?

Three hypotheses were proposed:

1. Listening span measures will be the only WM measures to differentiate mildly impaired adults with ABI from controls. Listening span measures will not be related to the other experimental WM measures, i.e., digits span and n-back.

2. Adults with ABI will demonstrate more interference than controls on the listening span task demonstrated by more intrusion errors, specifically more within-task intrusion errors.

3. Recall errors made on the listening span task will not be associated with recall errors made on the CVLT-II.

# Methods

*General Procedures*

All procedures in this study were approved by the University of Minnesota Institutional Review Board (IRB) and all participants provided informed consent prior to participation. The current study followed the same methods and procedures as Baumgarten (2009), with the addition of eighteen participants, ten with ABI and eight healthy controls. The addition of these participants allowed for an increase in the sample size. The description of the participants below includes the entire data set, not just those added most recently.

*Participants*

Forty-one adults participated in this study. Twenty-three had a brain injury (mostly TBI) and 18 were healthy controls. Groups were matched by age, education and estimated verbal IQ. Participants with brain injury were recruited from a list indicating their participation in previous studies at the University of Minnesota and their willingness to be contacted for further studies. Participants were also recruited via an announcement in the Brain Injury Association-Minnesota newsletter, which reaches many individuals with ABI and various brain injury support groups.

All participants with ABI met the following criteria: ABI documented by medical records; a minimum of 10 years of formal full-time education; and English as a first and primary language. Participants were excluded based on the following criteria: neurological injury of illness other that the primary documented ABI; documented learning disability, visual or reading impairment, or giftedness; history of alcohol or drug abuse; severe amnesia, aphasia, or apraxia of speech; less than six months post-injury; or current enrollment in rehabilitative therapy. Control participants were recruited in the same manner and were required to meet the same biographical inclusion and exclusion criteria as the participants with brain injury. In addition, control participants were excluded if there was indication of previous or current neurological illness, injury or chronic substance abuse. See Appendix A for the detailed intake protocol.

Clinical data and group demographic information are available in Table 1. The experimental and control groups were matched for age, years of formal education, gender ratio, and predicted verbal IQ (National Adult Reading Test – 2nd Edition, Nelson & Willison, 1991). No participants had aphasia, hearing loss, or a history of neurological disease or substance dependency. All participants were native speakers of English. No significant differences were found to exist between groups in age, education, or estimated verbal IQ.

Adults with ABI averaged 47.36 years of age and 14.75 years of education whereas controls averaged 43.73 years of age and 15.44 years of education. Groups were not significantly different on these variables or on estimates of verbal IQ. Average years since brain injury was 12.36 (SD = 11.84). A total of nine participants were excluded from the study due to history of neurological disease or incident (six), mental illness (two) and non-native English language (one).

Neurological information for participants is available in Table 2. The severity of injury for participants with brain injury included 14 severe, 2 moderate and 6 mild

(Lezak, 1995). Based on medical records, seven Glasgow Coma Scale (GCS) scores (mean = 6, SD = 1.91) and fifteen losses of consciousness (ranging from at accident site to four months) were documented. Loss of consciousness (LOC) and GCS scores were unavailable for six participants, though medical documentation of past brain injury was obtained. Mean years post-injury for the brain injury group was 12.36 (SD = 11.84). Medical records were unavailable for two participants, in which case information regarding injury severity and years post-onset of TBI was reported by the participants.

After examination of medical records, two participants had not sustained a TBI. One of these participant's medical records indicated identification and removal of a right frontal tumor around the time of the reported brain injury. The second participant's medical records indicated a ruptured brain aneurysm. A third participant had a sustained a TBI but also had a documented old lacunar infarct in the right medial temporal lobe in addition to the TBI. Their data was not deleted from the experimental set because no differences were found between these participants' standardized and experimental task performance as compared to the rest of the TBI group, and because they reported cognitive impairments. Thus, since the TBI group includes individuals with a differing form of acquired brain injury (ABI), the TBI group will be referred to as the ABI group from this point forward.

*Standardized Tests*

To describe the population sample, a battery of standardized tests were administered to all participants including the Delis-Kaplan Executive Function System

(DKEFS, Delis et al., 2001), the California Verbal Learning Test – 2nd Edition (CVLT-II) (Delis, Kramer, Kaplan & Ober, 2000), the Western Aphasia Battery (Kertesz, 1982), the National Adult Reading Test - 2nd Edition (NART-2, Nelson & Willison, 1991) and Digit Span from the Weschler Memory Scale – III (Weschler, 1997). The DKEFS examines many high-level cognitive functions with a variety of subtests; the verbal fluency, design fluency and trail-making task subtests were used in this study. The CVLT-II is a standardized test that examines verbal learning and memory for two lists of words. The Western Aphasia Battery is a test designed to identify receptive and expressive aphasia, and was given to rule out the presence of aphasia. The NART-2 is test of vocabulary which provides a score of predicted verbal intelligence quotient. The Digit Span task is designed to examine WM through increasing spans of numbers which must be recalled. The complete list of standardized tests administered is located in Appendix B. Means and standard deviations of performance are reported in Table 3.

Independent sample t-tests were used with $p > .05$. When compared to the control group, the ABI group was found to display multiple significantly lower scores on the verbal fluency (VF) subtest of the D-KEFS including: letter fluency total correct, category fluency total correct, category switching total correct responses, category switching total switching accuracy, interval two total correct, interval three total correct and interval four total correct. Significant differences were also seen on the trail-making subtest of the DKEFS including letter sequencing, number-letter switching and motor speed.

Standardized tests were presented in the same order across participants to allow for insertion of required delay times and to minimize the length of the testing session. Participants were permitted to take breaks as needed between tests or subtests provided that a break would not interfere with the standardized test administration protocol.

*Experimental Working Memory Tasks*

Three experimental auditory WM tasks were administered, as was done in Baumgarten (2009): the digit span (forwards, backwards), the auditory n-back task (McAllister et al., 1999), and the listening span task (Tompkins et al., 1994). The digit span task was administered as a part of the standardized assessment battery. The auditory n-back and listening span were administered either before or after the standardized assessment battery. The order of administration of the standardized test battery and experimental tasks were alternated to control for possible effect of mental fatigue on performance. The experimental tasks were presented via computer, using E-prime software.

Auditory N-back Task: This WM task, modeled after the auditory n-back task in McAllister et al. (1999), required participants to listen to a series of letters and decide whether the most recent letter matched a single target letter presented n-places back in the task. The number n was specified prior to each series in the instructions of the task. Three conditions were presented: 0-back, 1-back and 2-back. The 0-back condition was considered to be a control condition, requiring minimal WM ability to match the letter immediately prior to the most recent letter. The 1-back and 2-back were considered to be the experimental conditions, as they placed increasing demand on WM. The 1-back and

2-back conditions were each presented 3 times. The 0-back condition was presented 6 times and alternated with the two experimental conditions. Within each series, there were a total of 15 items comprised of 5 matches and 10 foils, which were balanced within and across conditions. Stimuli consisted of 12 sets of 15 randomly selected consonant letters (e.g. L, O, and R), which were presented auditorily. Participants provided responses by hitting the space bar on the computer.

Participants first engaged in 1 session of a practice task, which provided detailed explanation of the types of instructions to be given during the actual n-back experimental task, as well as a practice series of 10 items for each of the three conditions. The participant navigated through the experiment via the space bar on the computer, and a blinder was placed over the rest of the keys to avoid use of the letters as cues. An infinite amount of time was programmed between each series to allow for questions or breaks if necessarily. None of the participants requested a break during this task. See Appendix C for the full instructions given in this task.

Participants correct and incorrect responses from the n-back task were recorded by the computer, analyzed, and an adjusted accuracy score was calculated in order to account for false positive (FP) responses. The following formula was used for this score: (Correct responses – [0.5 x FP]).

Listening Span Task: This WM task, created by Tompkins et al. (1994), required participants to listen to a series of sentences, retaining the final word of each sentence for spoken recall at the end of the series, while simultaneously judging each sentence as true or false. Stimuli consisted of 46 simple active declarative sentences (including 4 sentences used for practice) that were based upon common knowledge (e.g. "the sky is blue"). Sentences were organized into 5 levels increasing in difficulty as the number of sentences in each level increased. Level 1 contained two sets of two sentences for practice. Levels two to five contained three sets of sentences each, and the number of sentences in each level increased from two to five sentences to increase difficulty. The number of true and false sentences was balanced within each level and truth value was not made obvious in the sentence until the final word. All stimuli were prerecorded and presented auditorily via computer speakers. See Appendix C for the full instructions given in this task.

Researchers gave detailed instructions to participants according to the original protocol created by Tompkins and her colleagues (1994). When participants demonstrated understanding, the experiment began with two sets of practice sentences and continued on to the task as long as participants demonstrated full understanding. Participants' true/false responses were recorded manually by the researcher in the computer and recall responses were recorded by hand by the researcher on the response form. Words recalled in error were written exactly as they were recalled and in the order of recall. For further detail on the creation and implementation of this task, see Baumgarten (2009).

Upon completion of the listening span task, recall errors made were analyzed and coded according to the type of error made. Tompkins et al. (1994) categorized recall errors according to error type (e.g. related to target word, repetition, intrusion from a previous set, non-target word from same set), however errors were not analyzed in the

Tompkins et al. (1994) study due to the infrequency of the occurrence of any error category found. Thus, Baumgarten (2009) did not examine recall errors according to specific type, only the total number of correct responses and error locations were recorded. In the present study, a coding system similar to Tompkins et al. (1994) was established to examine the types of recall errors made in brain injured population. Words recalled were coded as correct if they were recalled exactly or with only a slight difference in form that did not significantly change the meaning of the target word. For example recalling “house” when the target word was “houses” was scored as correct.

Words recalled in error on the listening span task were coded as either omission or intrusion errors. Omission errors occurred when a participant did not recall the target word at all. Intrusion errors were defined using similar definitions to those found in the CVLT-II (Delis et al., 2000). Four types of intrusion errors were defined: categorical errors, within-task errors, phonemic errors and non-categorical errors. Categorical intrusion errors occurred when the target word and the word recalled in error were members of the same semantic category. For example, recalling the word “tiger” for the target “lion” was a categorical error because both are animals. Within-task intrusion errors occurred when the word recalled in error could be found in any of the previous sentences prior in the task. For example recalling the word “books” from sentence 20 for the target “dance” in sentence 31 was a within-task intrusion error since the word “books” was a part of a previous sentence earlier in the task. Phonemic intrusion errors occurred when the word recalled in error was phonemically similar to the target word. For example, recalling the word “fast” for the target “fly”, or “lime” for the target “time”, were both phonemic intrusion errors as each pair is phonemically similar to each other. Errors were non-categorical when the recalled word was semantically and phonemically unrelated to the target word and was not used in any of the previous sentences in the task. For example recalling the word “ice” for the target “Ohio” is a non-categorical intrusion error because the two words are neither semantically nor phonemically related, and the word “ice” was not found in any sentences prior in the task.

An error was coded more than once if it fit the definition for more than one intrusion type. For example if a participant recalled “fast” for “fly” it was both a phonemic intrusion error and a within-task intrusion error since the two words are phonemically similar and since fast was used in a previous sentence in the task. Errors made within the two practice sets were not counted as errors; however later within-task intrusion errors could include words recalled in error that were within the practice sentences. Using this coding system, an independent rater coded 25% of the data reaching 90% agreement with the primary rater.

## Results

*Data Analysis*

Analysis of variance (ANOVA) with between- and within-group comparisons, and simple group comparisons were made with the p value set at .05. Analysis involved between group and within group comparisons of difficulty level for the listening span task, n-back task, and digit span task. The dependent variables from the listening span task consisted of total recall errors, total omission errors, total intrusion errors, within-task intrusion errors, and T/F errors. Phonemic, categorical and non-categorical intrusion errors were not analyzed due to their low occurrence in both the ABI and control groups. The dependent variables from the n-back task included adjusted accuracy, omissions, and false positives. The dependent variables from the digit span task included number of digits recalled forward and backward. In addition, standardized test scores were analyzed to determine whether correlations existed between these scores and the WM measures from the experimental tasks. Means and standard deviations from the three WM tasks are presented in Table 4.

*Listening Span Task*

A simple between group comparison was made for T/F errors. The ABI group tended to make more T/F errors than the control group although this was not statistically significant [$F(1,39) = 2.82$, $p = .10$, $d = .61$].

To examine the number of total recall errors (omissions and intrusions) made across listening span levels, a Group (ABI, control) x Level (2, 3, 4, and 5 sentence levels)

ANOVA was conducted. There was a significant main effect for group [F (1,39)=13.93, p=.001, $\eta p^2$ =.26] indicating that the ABI group made more total recall errors than controls. There was also a significant main effect for level [F (1,39)=157.61, p=.000, $\eta p^2$ =.80] in that all participants had more errors as the level increased. There was also a significant interaction effect across the four levels [F (1,39)=11.50, p=.002, $\eta p^2$ =.23]. A significant linear interaction effect for group x level was found [F (1,39)=5.35, p=.03, $\eta p^2$ =.12] as well as a quadratic effect [F (1,39)=7.54, p=.01, $\eta p^2$ =.16]. These interactions, visible in Figure 1, were significant but had small effect sizes. Thus the listening span task did differentiate the ABI group from the controls in that they made more total errors and the error pattern differed by level.

A mixed ANOVA of Group x Errors (omission and intrusions) was calculated. A significant main effect for group was found in that ABI participants made more errors than controls [F (1,39) = 13.99, p = .001, $\eta p^2$ = .26]. More omission errors than intrusion errors were made by both groups [F (1,39)=56.64, p=.00, $\eta p^2$ =.59] indicated by a main effect for errors. Furthermore, the interaction effect was significant [F (1,39) = 7.38, p = 01, $\eta p^2$ = .16]. Figure 2 shows that the ABI participants made many more omission errors than intrusion errors, whereas there was less of a difference between these kinds of errors made by controls.

A simple between groups comparison was conducted to analyze listening span intrusion errors. ABI participants tended to make more total within-task errors than controls [F (1,39) = 2.97, p = .09, d = .60]. Only two ABI and two control participants made one phonemic error each, and only two ABI participants made one categorical error each, and no participants in the control group made categorical errors. Only one participant, in the control group, made a non-categorical error. The low occurrence of intrusion errors precluded further analysis. Thus the specific types of errors did not differentiate the ABI group from the controls.

*Auditory n-back Task*

A simple between group comparison of adjusted accuracy (AA) scores revealed no significant group differences [$F(1,39) = 2.94$, $p = .10$, $d = -1.49$]. For omissions, a Group (ABI, control) x Level (0-, 1-, and 2-back) ANOVA was conducted. Participants with ABI tended to have more omission errors than control participants but these were non-significant [$F(1,39) = 2.70$, $p = .11$, $\eta p^2 = .07$]. There was a highly significant linear effect for omission errors for level [$F(1,39) = 29.81$, $p = .000$, $\eta p^2 = .43$] and a significant quadratic effect for level [$F(1,39) = 13.16$, $p = .00$, $\eta p^2 = .25$]. There was a nearly significant Group x Level linear interaction effect [$F(1,39) = 3.93$, $p = .055$, $\eta p^2 = .09$], as well as a trend towards a quadratic interaction effect [$F(1,39) = 2.81$, $p = .10$, $\eta p^2 = .07$]. Figure 3 depicts the nature of the interaction effect by level for omission errors. Both groups tended to have more omissions in the 0-back and 2-back conditions, than in the 1-back condition, but differences between groups were not significant.

A Group (ABI, control) x Level (0-, 1-, and 2-back) ANOVA for false positives demonstrated a non-significant main effect for group [$F(1,39) = 1.89$, $p = .18$, $\eta p^2 = .05$]. All participants had more false positives as the task became more challenging in a linear main effect for level [$F(1, 39) = 5.53$, $p = .02$, $\eta p^2 = .12$]. However, there were differences across levels indicated by a significant quadratic main effect [F (1,39) = 6.44, p = .02, $\eta p^2$ = .14]. Neither interaction effects of Group x Level were significant {linear = [F (1,39) = .44, p = .51, $\eta p^2$ = .01]; quadratic = [F (1,39) = .07, p = .80, $\eta p^2$ = .00]}. Thus in agreement with the hypothesis the n-back task did not significantly differentiate the ABI group from the control group.

*Digit Span Task*

A Group x Order ANOVA was performed in which group (ABI or control) was a between factor and order (forward, backward) was a within factor. The two groups recall did not differ in a non-significant main effect [F (1,39) = 1.11, p = .30, $\eta p^2$ = .03]. There was a highly significant main effect for order, in that all participants recalled more digits forwards than backward [F (1,39) = 126.64, p = .000, $\eta p^2$ = .77]. The interaction effect was not statistically significant [F (1,39) = .92, p = .76, $\eta p^2$ = .00]. Thus, in agreement with the hypothesis, ABI participants performed similarly to controls in their recall of digits both forward and backward.

*Correlations among Measures*

Error measures for the experimental tasks were correlated using Pearson product moment correlations. These measures were calculated between the following scores: listening span total recall errors (RE), omission errors (OE), intrusion errors (IE), and within task intrusion errors (WE); n-back adjusted accuracy (AA), omissions (O), and false positives (FP); digit span (DS) forward and backward, and predicted verbal IQ

(PVIQ). Participants' scores from the CVLT-II measures were also used in this analysis. Correlation data for ABI and control groups may be found in Table 5 (ABI) and Table 6 (Controls). Correlation data for the CVLT-II measures and the listening span and digit span tasks can be found in Table 7 (ABI) and Table 8 (Controls).

In both groups, listening span RE was correlated with listening span OE (rABI = .89; rControl = .96), and listening span WE were correlated with listening span IE (rABI = .99; rControl = .95). Thus those in both groups, those who made more RE also made more OE and those who made more IE also made more WE. This is expected as the listening span RE is the sum of listening span OE and IE, and listening span WE were used to calculate IE. For the ABI group, listening span RE were also positively correlated with listening span IE (r = .67) and listening span WE (r = .68), meaning that the more total RE, the more IE and WE made. In the control group, listening span RE did not correlate with listening span IE or WE.

For the ABI group, none of the listening span measures were correlated with any of the CVLT-II measures (Table 7). For the control group, CVLT-II total intrusions were found to be correlated with listening span T/F errors (r = -.56), meaning that those with more CVLT-II total intrusions, had fewer T/F errors on the listening span task. Also in the control group, the CVLT-II long delay cued recall was negatively correlated with listening span RE (r = -.49) and listening span OE (r = -0.53), meaning that controls who had higher CVLT-II long delay cued recall scores made fewer listening span RE and OE (Table 8). CVLT-II total intrusions were not correlated with listening span IE for the ABI or control group.

Both the ABI and control groups had highly significant (<0.01 level) negative correlations between n-back AA and O (rABI = -0.99; rControl = -0.95), as well as n-back AA and FP (rABI = -0.69; rControl = -0.80) (Tables 5 & 6). This was expected, as AA scores are determined based on a formula using FP and O scores. A higher AA score meant fewer false positive and omission errors were made. Both ABI and control groups' O and FP scores were found to be positively correlated (rABI = .61; rControl = .71). The more O errors made the more FP errors made.

For the ABI group, n-back FP was found to have a significant negative correlation with the DS forward presentation (r = -.44), in that the more digits forward recalled, the fewer FP errors made on the n-back task (Table 5). No other correlations between the n-back scores were found for the ABI group.

For the control group, n-back AA and n-back O were significantly correlated with the DS forward (rAA = .51) and (rO = -.47) but in opposite directions. The more digits forward recalled, the higher the AA and the fewer O errors made. Also within the control group, the n-back AA and O were also correlated with listening span WE (rAA = -.50) and (rO = .60), in that the lower the AA score, the more O errors made on the n-back task and the more WE made on the listening span task (Table 6). The n-back O was also correlated with listening span IE (r = .56) meaning that the more O errors made on the n-back, the more IE made on the listening span task.

The DS forward and backward were positively correlated for both the ABI and control groups (rABI = .73; rControl = .56). The DS forward was negatively correlated with listening span RE and listening span OE in the ABI group (rRE = -.55; rOE = -.53), meaning that those who recalled more digits forwards made fewer total recall and omission errors. In the control groups these relationships were also significant and the direction was similar (rRE = -.52; rOE = -.48). DS backward was negatively correlated with listening span RE and listening span OE in the ABI group (rRE = -.76; rOE = -.72) and in the control group (rRE = -.57; rOE = -.52). Thus, in both the ABI and control groups, those who recalled more digits backward made fewer RE and OE on the listening span task. For the ABI group, DS backward was also found to be negatively correlated with both listening span IE (r = -.45) and listening span WE (r = -.49), in that ABI participants who recalled more digits backward had fewer listening span IE and WE.

Within the ABI group, PVIQ was positively correlated with DS forward (r = .48) and DS backward (r = .58), but negatively correlated with listening span RE (r = -.67), listening span OE (r = -.58), listening span IE (r = -.50), and listening span WE (r = -.45). This meant that the higher the PVIQ score, more digits were recalled (both forward and backward) and the fewer number of RE, OE, IE and WE made on the listening span task. In the ABI group, PVIQ was not correlated with any of the n-back measures. For the control group PVIQ was not correlated with any of the experimental measures.

## Discussion

The intent of the current study was to expand on the findings of the study done by Baumgarten (2009) to determine if the same results could be found by increasing the sample size. Baumgarten had compared WM performance on an auditory n-back task, digit span task, and listening span task in adults with and without ABI. She found that the listening span task was the only task to differentiate the two groups, and that groups performed similarly on the auditory n-back and digit span tasks. A second purpose of the current study was to further analyze errors made on the listening span task to investigate the different types of recall errors made. Each of the research questions are revisited here, along with probable explanations for the present findings.

*Which WM measure differentiates mildly impaired adults with brain injury (BI) from carefully matched controls? Are those measures associated with each other?*

It was hypothesized that the listening span task (Tompkins et al., 1994) would be the only WM task to differentiate these mildly impaired adults with ABI from controls. This hypothesis was formulated based on the preliminary results of Baumgarten (2009) who found that the total number of recall errors was the only WM measure of the three tasks (including the auditory n-back and digit span task) to differentiate the ABI group from the control group.

Findings from the current study further support this hypothesis and findings in Baumgarten (2009) as the total number of recall errors significantly differentiated the mildly impaired ABI group from the control group. Additionally, the number of omission errors was significantly different between the ABI and control group. This was expected as total recall errors is the sum of total omission errors and total intrusion errors. The total number of intrusion errors did not significantly differ between the two groups. Neither measures from the digit span nor the auditory n-back task scores were found to be significantly different between the ABI group and control group, which also supports the hypothesis and the preliminary findings of Baumgarten (2009).

In a study done by McAllister et al. (2001), similar findings were discovered when a group of 17 participants with mild TBI and 12 without brain injury performed similarly on a task similar to the n-back task. The low level of impairment of participants in the McAllister et al. (2001) study and in the present study may be part of the reason the n-back task did not differentiate these individuals with ABI from healthy controls. The n-back task may be more sensitive to a population of more moderate to severely impaired individuals with brain injury.

In regards to the n-back task, while performance on this task did not differentiate the groups, there was a significant group x level interaction effect for both omission errors and false positive errors. The ABI group showed the same interaction pattern for false positives and omissions errors, meaning more errors were made in the 0-back and 2-back conditions, than in the 1-back condition. The controls had a similar pattern to the ABI group for omission errors however not for false positives. In the control group the same average number of false positive errors was made in 0-back and 1-back with an increase in false positives in the 2-back condition. This interaction effect may have been the result of reduced attention ability and/or task comprehension for the ABI and control groups. However for these interaction effects, for both the ABI and control groups, power was low.

The correlation relationships found in this study between the experimental WM tasks differed from the results of the preliminary study by Baumgarten (2009). There were no significant correlations in the ABI group between the n-back task and digit span backwards that were found in Baumgarten (2009). With this larger data set, only one significant negative correlation was found, between digit span forward and n-back false positives. Also, in the smaller study, Baumgarten (2009) found listening span recall errors to only be correlated with the digit span backward. The findings from the present study also found correlation between the listening span task scores and the digit span backward task but for both groups. In addition, correlations between the listening span task and digit span forward and backward were also found for both the ABI and control groups. It was also found that the n-back adjusted accuracy and omissions scores were correlated with the digit span backward task for the ABI group.

Baumgarten had (2009) found that recall of digit span backward was correlated with total recall errors on the listening span task, with no other correlations were found between the experimental measures for the ABI group. Also, Baumgarten (2009), had found that there were no correlations between the listening span task, digit span task or n-back task in the control group

Findings from the current study indicated that for the ABI group the digit span backwards condition was correlated with all measures from the listening span task (total recall errors, omission errors, intrusion errors and within-task errors) and the digit span forwards condition was correlated with two listening span measures (total recall and omission errors). These correlations were in contrast to the hypothesis, demonstrating that the digits span forwards and backwards are associated with performance on the listening span task when a larger sample size was included, thus providing more statistical power. This suggests that the digits span and listening span tasks both tax WM, and that this process of temporarily storing and manipulating learned information appears to be similar for numeric and linguistic information in this group of mildly impaired ABI adults.

For the control group digits forward and backward were both correlated with two measures from the listening span task (total recall and omission errors), but not with intrusion or within-task errors.

Baumgarten (2009) found that in the ABI group, the PVIQ scores were correlated with the listening span total recall errors and with the category fluency score on the DKEFS verbal fluency subtest. These correlations suggested a connection between vocabulary knowledge, verbal fluency and performance on a linguistically based WM task. The present study confirmed these findings, in that the PVIQ scores of the ABI group were correlated with the listening span total recall errors. Additionally, PVIQ scores in the ABI group correlated with the digits span forward, digits span backward and all error measures from the listening span task. The correlations between the PVIQ, digits span forward and backward and the listening span measures suggests that these measures share underlying processes for the ABI group, but not in the control group. This finding also suggests that the underlying processes for WM ability and success in these tasks are not just language ability but also general cognitive function and ability. The lack of the correlations between the PVIQ and WM measures in the control group may demonstrate evidence of the effect of cognitive reserve. The theory of cognitive reserve states that an individual's vulnerability to clinical presentation of symptoms after neurological incident depends on their cognitive reserves or protective pre-morbid factors (Satz, 1993). Some of these factors include pre-morbid intelligence, educational level, and occupation. Research has shown that the fewer cognitive reserves present pre-injury, the greater the cognitive impairment after TBI (Ropacki & Elias, 2003). In the present study individuals in the ABI group who had higher PVIQ scores (greater cognitive reserves demonstrated by greater predicted verbal IQ scores) demonstrated better performance on the digits span and listening span measures.

*What types of errors do adults with ABI make on the listening span tasks compared to controls?*

Using the error coding system established in this study, it was hypothesized that the ABI group would demonstrate more intrusion errors, specifically more within-task intrusion errors, on the listening span task than controls. As was found in Baumgarten (2009), the present study confirmed that the ABI group made significantly more total recall errors than controls. Furthermore, the ABI group made more omission errors than the control group; however the total number of intrusions made by each group was not significantly different. The ABI group made more intrusion errors on average in each category and there was a trend for more within-task intrusion errors; however these differences were not significant. Due to the very low number of phonemic, categorical and non-categorical intrusion errors made by both groups, this data was not analyzed further.

As WM and proactive interference (PI) have been shown to be related, the presence of more within-task intrusion errors was predicted to objectively demonstrate increased difficulty in resolution of PI in the ABI group. Within-task intrusion errors were thought to provide evidence of prior learning interfering with recall of subsequent information. However, because there were not clear differences between the groups, it was not possible to determine if this was case. Using the coding system established in this study, the listening span task may have the potential to identify PI through error analysis in a more impaired sample of the ABI population. The lack of statistical significance may reflect limitations of this coding system's sensitivity or simply the lack of difficulty in resolving PI in this group of mildly impaired individuals with ABI.

*Are recall errors on the listening span task and the CVLT-II associated with each other?*

It was hypothesized that recall errors made on the listening span task would not be associated with recall errors made on the CVLT-II. Given the findings of Donders (2006), Jacobs and Donders (2007), and Dejong and Donders (2010) it was thought that the Tompkins et al. (1994) listening span task would be the only tasks to differentiate the ABI group from the controls and that it would not be associated with performance on the CVLT-II.

For the ABI group, the CVLT-II measures did not correlate with any measures from the listening span task.  This finding is in agreement with the hypothesis in that performance on the CVLT-II would not be associated with performance on the listening span task.

For the control group total intrusions on the CVLT-II were correlated with T/F errors on the listening span task, meaning that those who had more intrusion errors on the CVLT-II also had more T/F errors on the listening span task. The long delay cued recall measure from the CVLT-II was negatively correlated with total recall and total omission made on the listening span task; the higher the long delay cued recall score the fewer recall and omission errors made on the listening span task.  These findings in the control group are contrary to the hypothesis, however, it is important to note that only three control participants made T/F errors on the listening span task and that each made only one error. Furthermore, the CVLT-II total intrusions were not significantly different between the two groups.  Therefore, these ‘significant’ relationships may not be very meaningful.

*Limitations and Future Research*

The inclusion of two individuals without TBI (one with a brain tumor, and one with a ruptured brain aneurysm) and one participant who had evidence of an old infarct in addition to a TBI, presents one limitation in this study. However data collected from these participants was not found to be different from the participants with TBI. Indeed, many have argued that the cognitive impairments observed after TBI are similar to those with frontal lobe injury (e.g., Vakil, 2005).

Another limitation of this study was in the analysis of listening span recall errors. There were some errors that occurred more often than others, suggesting that some of the sentences in the listening span task may be more prone to produce a certain type of recall error. For example, sentences in which the target word to be remembered was semantically similar to another word in the sentence seemed to result more frequently in error than other sentences, specifically within-task and categorical intrusion errors, e.g., recalling "mice" for the target " lions" from the target sentence "Mice are smaller than lions". This was coded as both a within-task error and a categorical error. However other sentences such as "Little boys wear dresses" did not results in errors as frequently. Thus, there could be a relationship between semantics and intrusion errors.

A second limitation involving the listening span analysis was the difficulty identifying phonemic and categorical intrusion error types when an omission error(s) occurred in the same set. Since the instructions for the listening span task specify that words may be recalled in any order (not necessarily in the order the sentences were presented in) this created difficulty in differentiating phonemic and categorical intrusion errors. For example in a set of 4 sentences, if the participant made two omission errors and two recall errors, there was no way to determine which specific target words these recall errors (both omissions and intrusions) were associated with. Thus the researchers were often unable to identify phonemic and/or categorical intrusion errors when they occurred in these situations as differentiation of these two types of intrusion errors was dependent on knowing the target word the recall error was made in place of.

The order of administration of the standardized assessment battery and the experimental tasks was alternated only for the participants added in the present study and not in Baumgarten (2009), so the effect of fatigue on the results of the experimental tasks was not able to be fully determined. In the current study, fatigue was not documented during the study session. Mental fatigue has been found to be a common symptom after brain injury and can persist for several years after brain injury (Johansson, Berglund & Ronnback, 2009; Ponsford & Ziino, 2003). Therefore the possible effects of mental fatigue on performance in this study are unknown and future research should control for these potential effects.

Future research should include a population of individuals with moderate to severe impairments in memory and cognition after TBI. In the present study, the ABI group had a generally low level of impairment. This low level of impairment may the reason that there were no significant differences found between the ABI and control groups on the n-back task, the digit span task, or specific types of intrusion errors on the listening span task. These experimental tasks may be more appropriate and sensitive in identifying WM deficits a TBI population with more severe deficits.

*Clinical Significance and Summary*

The study supports prior evidence that WM abilities of adults with ABI are different from those of healthy adults. The listening span task clearly differentiated this mildly impaired group of mostly TBI adults, from controls. The listening span task appears to capture WM that has a linguistic base, including pre-injury vocabulary. The detailed intrusion error analysis did not differentiate the groups, nor were these measures associated with CVLT-II measures for the ABI group. However, the ABI group tended to have more within-task errors, possibly suggesting increased difficulty resolving PI.

Differentiation of the ABI and control groups with listening span task suggests that this task may be effective for use with mildly impaired individuals with ABI to evaluate subtle WM impairments. Speech-language pathologists (SLPs) need quick, valid and reliable measures of WM, especially for individuals who have mild memory and executive function impairments and will likely return to work or college. Neuropsychological reports are not always available to SLPs and when they are, they do not always include WM measures that have a linguistic base, such as the listening span task. Clinicians could consider adding the listening span task in their assessment toolbox for adults with mild impairments, without the need for in-depth error analysis, to assess WM.

Table 1. Demographic information for adults with ABI (n=23) and healthy controls (n=18).

| Group | Gender (M/F) | Age (Yrs.) | Education (Yrs.) | Estimated Verbal IQ** | Years Post-ABI |
|---|---|---|---|---|---|
| <u>ABI</u> | (10/13) | | | | |
| M | | 47.36 | 14.75 | 107.74 | 12.36 |
| SD | | 18.24 | 1.65 | 7.1 | 11.84 |
| Range | | 21-76 | 13-18 | 102-121 | 0.5-59 |
| <u>Controls</u> | (5/13) | | | | |
| M | | 43.73 | 15.44 | 111.44 | - |
| SD | | 14.98 | 1.46 | 7.96 | - |
| Range | | 21-76 | 12.0-18 | 94-124 | - |
| Between Group Comparison | | | | | |
| *p* | | 0.53 | 0.11 | 0.12 | - |

** Adult Reading Test-2nd Edition (NART-2) (Nelson & Willison, 1991).

Table 2. Neurological Information for ABI participants injuries

| Participant | Injury Severity | Neuropathological findings | LOC | GCS* | Yrs post-injury |
|---|---|---|---|---|---|
| 1 | Mild | Concussion, post-concussion syndrome, persistent headache, nausea, vertigo, insomnia and cognitive impairment; head CT and spine x-rays were negative | at accident site | none | 2.79 |
| 2 | Severe | Small frontal subdural hematoma on left portion of brain per CT with multiple punctate intraparenchymal hemorrhages | 4 months | 5 | 16.65 |
| 3 | Severe | Subdural hematoma as reported by participant however not documented by medical records which were unavailable | 6 days | ** | 39.01 |
| 4 | Mild | No medical record of TBI; Intracranial hypotension, mild impairment of sustained attention and processing speed, low average scores of verbal memory, planning and cognitive flexibility | none | none | 6.07 |
| 5 | Severe | ** | 10 days | ** | 20.6 |
| 6 | Severe | Diffuse axonal injury, shearing of left temporal and occipital lobes, subdural hematomas, right tentorium | ** | ** | 2.61 |
| 7 | Mild | Recorded mild head injury, CT scan showed no acute intracranial abnormality | at accident site | ** | 18.41 |
| 8 | Severe | Cerebral contusions, intraparenchymal hemorrhage, cerebral edema | 5 days | ** | 2.63 |
| 9 | Mild | Neuropsychological reports describe mild head injury | ** | ** | 7.39 |
| 10 | Mild | ** | at accident site | ** | 2.07 |
| 11 | Severe | Left temporal subarachnoid hemorrhage, shear injury anterior peduncular fossa, small punctuate hyperintense focus left cerebral peduncle | at accident site | 7 | 5.56 |
| 12 | Severe | Diffuse edema, increased intracranial pressure, possible subarachnoid hemorrhage, | 4 days | 6 | 19.01 |

| | | | | | |
|---|---|---|---|---|---|
| | | small punctuate hemorrhages left posterior thalamus | | | |
| 13 | ** | No medical record of diagnosed TBI; Right frontal tumor identified August 2001 | ** | ** | 6.44 |
| 14 | Moderate | Small right temporal subdural hematoma | at accident site | 9 | 6.57 |
| 15 | Severe | Reports refer to diagnosed TBI July 1971 | ** | ** | 35.11 |
| 16 | Severe | Severe edema, diffuse subarachnoid hemorrhage, possible brainstem injury | 4 days induced | 3t | 1.56 |
| 17 | Severe | Reports refer to TBI in March 1970, documented neurological deficits as sequelae of TBI, no imaging reports available | ** | ** | 37.98 |
| 18 | Moderate | Reports refer to TBI in September 1992; CT scan March 2006 documents old lacunar infarct R medial temporal lobe | ** | ** | 16.19 |
| 19 | Mild | Reports from neuropsychologist, SLP, & OT refer to TBI in November 1990 and document neurological deficits as sequelae of TBI; No imaging reports available | ** | ** | 16.23 |
| 20 | Severe | Brain stem shear | 17 days | ** | 6.04 |
| 21 | Severe | Right intraventricular hemorrhage with bilateral parenchymal hemorrhages | at accident site | 7 | 0.52 |
| 22 | Severe | Frontal & temporal hemorrhages, small posterior subarachnoid hemorrhage | at accident site | 5 | 14.12 |
| 23 | Severe | Diffuse left contusions, small right parietal-occipital subdural hematoma | 2 days | ** | 0.63 |

* Teasdale, G. & Jennett, B. (1974). Assessment of coma and impaired consciousness. A practical scale. Lancet, 2:81-84.

** Information unavailable.

Table 3. Means and standard deviations of performance on neurocognitive standardized tests for adults with TBI (n=23) and healthy controls (n=18).

| | ABI [M(SD)] | Control [M(SD)] | *p* |
|---|---|---|---|
| Aphasia quotient (WAB) (1982) | 99.18 (1.18) | 99.67 (1.03) | 0.18 |
| Executive functions: alternating trails (D-KEFS) | | | |
| Number-letter switching | 9.67 (3.72) | 12.06 (1.76) | 0.03* |
| Number-letter switching v. combined n/l sequencing | 9.74 (3.08) | 9.83 (2.26) | 0.91 |
| Number-letter switching v. motor speed | 10.00 (2.89) | 10.28 (2.22) | 0.74 |
| Executive Functions: verbal fluency (D-KEFS) | | | |
| Letter fluency total correct | 9.57 (2.56) | 12.39 (4.13) | 0.01** |
| Category fluency total correct | 10.91 (3.44) | 13.39 (2.62) | 0.02* |
| Category switching total correct | 9.74 (3.08) | 14.44 (3.26) | 0.00** |
| Category switching total switching accuracy | 10.74 (3.54) | 14.67 (2.97) | 0.00** |
| Interval 1 (0-15 sec) | 10.78 (2.61) | 12.67 (2.93) | 0.04* |
| Interval 2 (15-30 sec) | 9.74 (3.28) | 12.72 (3.37) | 0.01** |
| Interval 3 (30-45 sec) | 9.52 (3.37) | 12.98 (4.19) | 0.01** |
| Interval 4 (45-60 sec) | 9.65 (2.26) | 13.33 (3.38) | 0.00** |
| Speed: simple trails (D-KEFS) | | | |
| Number sequencing | 9.48 (3.84) | 11.33 (3.84) | 0.06 |
| Letter sequencing | 9.74 (3.86) | 11.83 (1.46) | 0.04* |
| Motor speed | 9.96 (2.34) | 11.83 (1.10) | 0.00** |
| California Verbal Learning Test – II (CVLT-II) | | | |
| Immediate free recall | 49.89 (14.90) | 54.39 (10.80) | 0.28 |
| Long-delay recall | | | |
| Free | -0.41 (1.11) | 0.14 (0.98) | 0.11 |
| Cued | 0.48 (1.23) | 1.70 (0.79) | 0.06 |
| Short-delay recall | | | |
| Free | -0.35 (1.19) | 0.31 (0.84) | 0.06 |
| Cued | -0.46 (1.25) | 0.03 (0.95) | 0.18 |

* = $p \leq .05$ (2-tailed)

**= $p \leq .01$ (2-tailed)

Table 4. ABI and control group means and standard deviations for experimental WM measures.

| | ABI [M(SD)] | Control [M(SD)] |
|---|---|---|
| Listening Span | | |
| True/False Errors | .57 (.95) | .17 (.38) |
| Total Recall Errors | 12.04 (5.65) | 6.06 (4.25) |
| Omission errors | 9.61 (4.34) | 4.72 (4.25) |
| Intrusion Errors | 2.39 (2.55) | 1.33 (1.19) |
| Within Task | 2.22 (2.39) | 1.17 (1.10) |
| Phonemic | .09 (.29) | .11 (.32) |
| Categorical | .09 (.29) | 0 (0) |
| Non-categorical | 0 (0) | .06 (.24) |
| Total Recall Errors: | | |
| 2 sentences | .17 (.39) | 0 (0) |
| 3 sentences | 1.91 (1.59) | .39 (.85) |
| 4 sentences | 4.00 (2.15) | 1.61 (1.61) |
| 5 sentences | 5.96 (2.48) | 4.06 (2.51) |
| N-back | | |
| Adjusted Accuracy | 55.85 (1.73) | 58.42 (1.73) |
| Omissions | 3.13 (1.23) | 1.11 (1.23) |
| 0-back | .61 (.47) | .11 (.47) |
| 1-back | .22 (.24) | .06 (.24) |
| 2-back | 2.39 (1.06) | .94 (1.06) |
| False Positives | 1.43 (.89) | .72 (.89) |
| 0-back | .43 (.47) | .11 (.47) |
| 1-back | .30 (.32) | .11 (.32) |
| 2-back | .65 (.62) | .50 (.62) |
| Digit Span | | |
| Digits Forward | 10.13 (2.22) | 10.78 (2.90) |
| Digits Backward | 6.26 (2.45) | 7.11 (2.45) |
| Total (standard score) | 10.04 (2.82) | 10.71 (3.41) |

Table 5. ABI parametric correlational data using Pearson product moment correlations (r).

| | N-Back AA | N-Back O | N-Back FP | DS Forward | DS Backward | List Span RE | List Span OE | List Span IE | List. Span WE | PVIQ |
|---|---|---|---|---|---|---|---|---|---|---|
| N-Back AA | 1 | .99** | -.69** | .28 | .29 | -.22 | -.22 | -.09 | -.12 | -.04 |
| N-Back O | - | 1 | .61** | -.25 | -.27 | .20 | .21 | .09 | .11 | .02 |
| N-Back FP | - | - | 1 | -.44* | -.27 | .14 | .21 | -.06 | -.03 | .11 |
| DS Forward | - | - | - | 1 | .73** | -.55** | -.53** | -.31 | -.35 | .48* |
| DS Backward | - | - | - | - | 1 | -.76** | -.72** | -.45* | -.49** | .58** |
| List Span RE | - | - | - | - | - | 1 | .89** | .67** | .68** | -.67** |
| List Span OE | - | - | - | - | - | - | 1 | .27 | .28 | -.58** |
| List. Span IE | - | - | - | - | - | - | - | 1 | .99** | -.50* |
| List Span WE | - | - | - | - | - | - | - | - | 1 | -.45* |
| PVIQ | - | - | - | - | - | - | - | - | - | 1 |

* Significant ≤ .05 level

** Significant ≤ .01 level

Table 6. Control parametric correlational data using Pearson product moment correlations (r).

| | N-Back AA | N-Back O | N-Back FP | DS Forward | DS Backward | List Span RE | List Span OE | List Span IE | List Span WE | PVIQ |
|---|---|---|---|---|---|---|---|---|---|---|
| N-Back AA | 1 | -.95** | -.80** | .51* | .41 | -.29 | -.17 | -.45 | -.50* | .20 |
| N-Back O | - | 1 | .72** | -.47* | -.35 | .24 | .09 | .56* | .60** | -.23 |
| N-Back FP | - | - | 1 | -.34 | -.28 | .05 | -.04 | .31 | .29 | -.28 |
| DS Forward | - | - | - | 1 | .56* | -.52* | -.48* | -.17 | -.21 | .19 |
| DS Backward | - | - | - | - | 1 | -.57** | -.52* | -.18 | -.07 | .30 |
| List Span RE | - | - | - | - | - | 1 | .96** | .14 | .16 | -0.13 |
| List Span OE | - | - | - | - | - | - | 1 | -.14 | -.10 | -0.14 |
| List Span IE | - | - | - | - | - | - | - | 1 | .95** | 0.02 |
| List Span WE | - | - | - | - | - | - | - | - | 1 | -.02 |
| PVIQ | - | - | - | - | - | - | - | - | - | 1 |

*Significant ≤ .05 level

**Significant ≤ .01 level

Table 7. ABI correlational parametric data for CVLT-II, digit span and listening span using Pearson product moment correlations (r).

| | Free Recall | Short Delay FR | Short Delay CR | Long Delay FR | Long Delay CR | CVLT Intrusions | CVLT Repetitions |
|---|---|---|---|---|---|---|---|
| DS Forward | .37 | .02 | -.22 | -.09 | -.17 | -.06 | -.12 |
| DS Backward | .33 | -.06 | -.17 | -.11 | -.21 | -.10 | -.31 |
| List. Span RE | -.30 | .09 | .18 | .15 | .12 | .07 | .38 |
| List. Span OE | -.22 | .20 | .28 | .26 | .27 | -.03 | .51* |
| List. Span IE | -.30 | -.16 | -.11 | -.13 | -.19 | .20 | -.01 |
| List Span WE | -.31 | -.14 | -.08 | -.10 | -.16 | .16 | -.06 |
| Free Recall | 1 | .69** | .62** | .60** | .60** | -.32 | .20 |
| Short Delay FR | - | 1 | .92** | .85** | .93** | -.52* | .11 |
| Short Delay CR | - | - | 1 | .86** | .92** | -.45* | .15 |
| Long Delay FR | - | - | - | 1 | .89** | -.44* | .19 |
| Long Delay CR | - | - | - | - | 1 | -.47* | .14 |
| CVLT Intrusions | - | - | - | - | - | 1 | .24 |
| CVLT Repetitions | - | - | - | - | - | - | 1 |

* significant ≤ .05 level

** significant ≤ .01 level

Table 8. Control correlational parametric data for CVLT-II, digit span and listening span using Pearson product moment correlations (r).

| | Free Recall | Short Delay FR | Short Delay CR | Long Delay FR | Long Delay CR | CVLT Intrusions | CVLT Repetitions |
|---|---|---|---|---|---|---|---|
| DS Forward | .14 | .21 | .30 | .12 | .20 | .17 | .24 |
| DS Backward | .22 | .41 | .41 | .36 | .45 | .22 | .23 |
| List. Span RE | -.39 | -.42 | -.40 | -.28 | -.49* | -.20 | -.21 |
| List. Span OE | -.44 | -.41 | -.39 | -.34 | -.52* | -.23 | -.20 |
| List. Span IE | .19 | -.05 | -.04 | .21 | .13 | .09 | -.03 |
| List Span WE | .11 | -.12 | -.06 | .20 | .07 | .08 | .01 |
| Free Recall | 1 | .79** | .68** | .86** | .92** | -.23 | .16 |
| Short Delay FR | - | 1 | .86** | .78** | .85** | -.18 | -.06 |
| Short Delay CR | - | - | 1 | .70** | .76** | -.19 | .08 |
| Long Delay FR | - | - | - | 1 | .86** | -.07 | -.00 |
| Long Delay CR | - | - | - | - | 1 | -.18 | .14 |
| CVLT Intrusions | - | - | - | - | - | 1 | .03 |
| CVLT Repetitions | - | - | - | - | - | - | 1 |

* significant $\leq$ .05 level

** significant $\leq$ .01 level

Figure 1. Group x level interaction effect for listening span total recall errors showing group averages across levels.

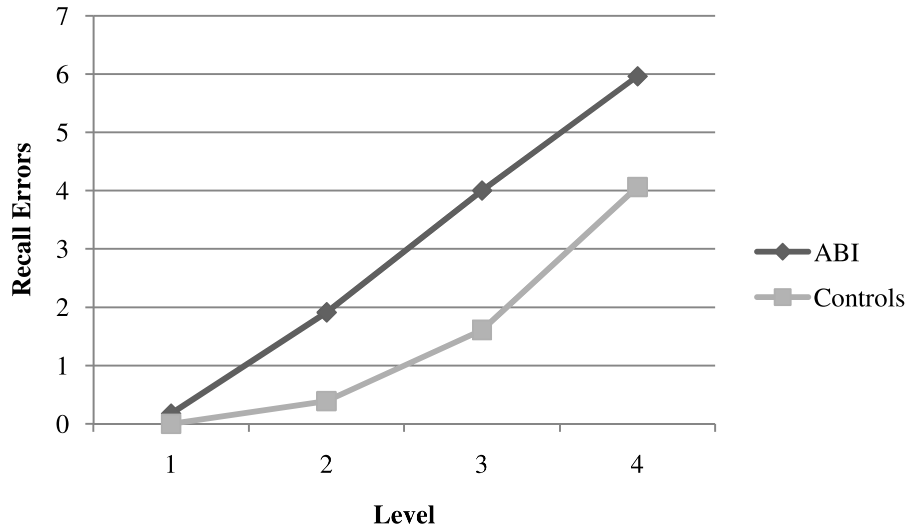


Figure 2. Group x error interaction effect for listening span omissions and intrusions showing group averages and standard deviations.

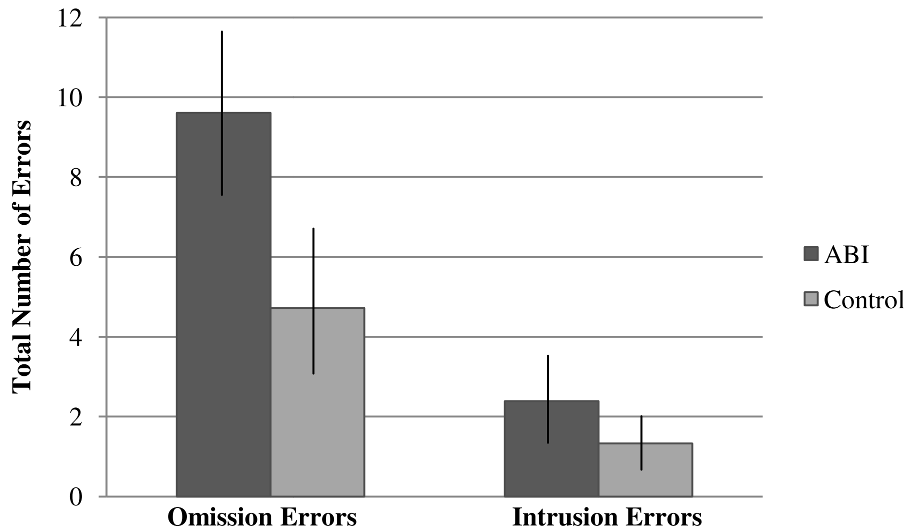
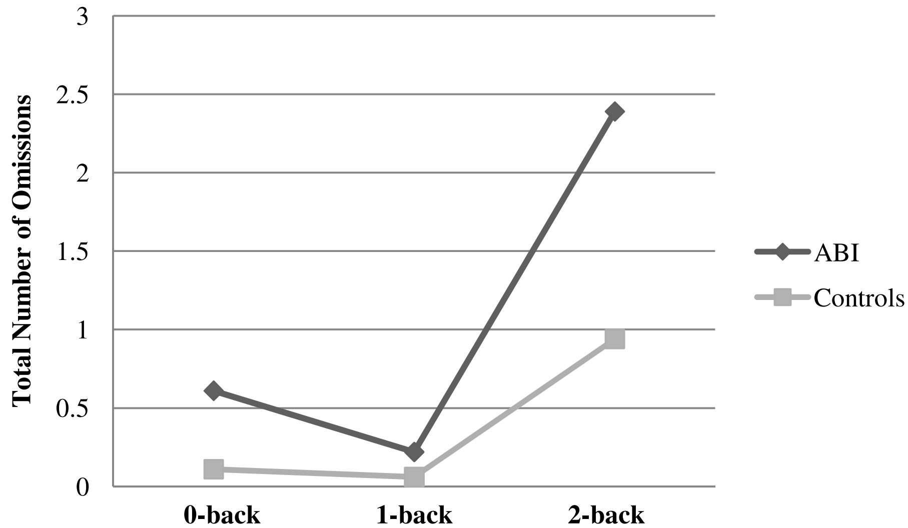


Figure 3. Group x level interaction effect for n-back omission errors showing group averages by level.



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Appendix A. Standardized Tests Administered

| | Subtests Administered | Cognitive/Linguistic Component Evaluated | Author(s) | Year of Publication |
|---|---|---|---|---|
| California Verbal Learning Test, 2nd Edition (CVLT-II) | N/A | Word list immediate & delayed recall & recognition | Delis, Kramer, Kaplan, Omer | 2000 |
| Delis-Kaplan Executive Function System (D-KEFS) | Trails, Verbal Fluency, Design Fluency | Divided attention; verbal fluency; nonverbal fluency | Delis, Kaplan, Kramer | 2001 |
| National Adult Reading Test, 2nd Edition (NART-II) | N/A | Predicted premorbid verbal intelligence | Nelson & Willison | 1991 |
| Wechsler Memory Scale, 3rd Edition (WMS-III) | Digit Span | Immediate & working memory | Wechsler | 1997 |
| Western Aphasia Battery (WAB) | Aphasia Quotient & Reading | Language function: content, fluency, auditory comprehension, repetition, naming, reading | Kertesz | 1982 |

Appendix B. Intake Protocol

Auditory Working Memory in Individuals with Traumatic Brain Injury

After researchers have been contacted by a potential participant indicating their interest and willingness to discuss this study, the following is the initial intake protocol that will be used to during this first contact.

Greetings and Introductions:

"Hi, I'm Shelley Johnson, from the Speech-Language-Hearing Sciences Department at the University of Minnesota. I received a phone message (or email) recently indicating that you would be willing to discuss possible participation in our study. Are you still interested in hearing more about this study? I would like to discuss that with you now. Is this a good time to talk? Or should I call you back at a later time?"

Brief Description of the Study:

Assuming they indicate willingness to continue, a description of the study would follow.

"The purpose of this study is to examine working memory ability in people with traumatic brain injury and in healthy controls. Working memory is a functional system in the brain that describes a person's ability to process and hold information during a task. This study focuses on 3 tasks specifically designed to test working memory. If you choose to take part in this study you will participate in these 3 working memory tasks, along with few other standardized assessments. These standardized assessments will address things like verbal learning and memory, vocabulary, ability to recall words and numbers, and speech and language. It will take approximately 2 ½ hours in one session to complete the experimental tasks. You will be given breaks between testing as needed. To compensate you for your time, you will receive $20.00 for your participation in this study."

"If you are still interested, I'd like to spend about 5 minutes asking you some questions. You are free not to answer any of the questions you do not wish to answer. Some questions have to do with your prior experiences in school, but others are more personal, like 'When you were in school, did you ever have difficulty learning how to read or write?', and 'Have you ever experienced an extended period of alcohol abuse?' All your answers are confidential. Shall I proceed?"

If the individual indicates that the investigator can continue, the following questions with an * will be asked by phone; all questions will be reviewed again at the initial face-to-face meeting.

-----------------------------------------------------------------------------------------------------

Demographic information

*How old are you?________________ *When is your birthday?____________________

*Are you a high school graduate?  Yes or No

What is the last grade you completed? _______________

*Is English your first language? ________________________

If No: when did you learn English ______________________________________

*Do you sign legal documents yourself? (power of attorney)  Yes  or  No

If no, who does? ______________________________________________

*When you were in elementary school, did you have any difficulty learning how to read or write?  Yes or No

If yes, please explain:_____________________________________

*Did you ever receive assistance in school in the form of speech therapy, or remedial help for anything else?  Yes or  No

If yes, please explain: ________________________________________________

*To the best of your knowledge, is your hearing adequate?  Yes or No

If no, please explain: _________________________________________________

*Are you currently on any medications that could alter your thinking?  Yes or No

What medications are you on? ________________________________________________

Injury information:

*When and how were you injured?

_______________________________________________

*Were you hospitalized after your injury?

__________________________________________

*Were you unconscious after your injury? Yes or No

If yes, for how long? ________________________;

*What is the first thing (situation, people, etc) you remember after your injury?

____________________________________________________

*Is TBI your primary disability? Yes or No

*Do you have any other disability, such as blindness, prior learning disability or a mental health disability? Yes or No

If yes: ______________________________________________

Other Medical Information:

*Have you ever been diagnosed with the following?

| | |
|---|---|
| Y / N | Stroke |
| Y / N | Cancer or tumor |
| Y / N | Multiple sclerosis |
| Y / N | Parkinson's disease |
| Y / N | Dementia |
| Y / N | Hospitalized for psychological difficulty |
| Y / N | Periods of unconsciousness |
| Y / N | Previous head or brain injury |
| Y / N | Any other neurological problem |

*Do you drink alcohol? Yes or No

If yes, how much and how often? ____________________

Have you ever received rehabilitation or help for alcohol abuse? ____________________

*Do you use recreational drugs? Yes or No

If yes, how much and how often? ______________

Have you ever received rehabilitation or help for drug abuse? ____________________

*Are you currently receiving rehabilitative therapy?

If yes, what type?_______________________

----------------------------------------------------------------------------------------------------

For participants who are screened out:

Should any participants not meet the selection criteria or be excluded based on identified exclusion criteria, indicated by their answers to the above questions, they will be informed of this over the phone in the following manner. This will vary slightly, depending on which selection criteria they do not meet. Examples of how this would be communicated are provided below:

"You indicated that the primary language you speak is ___________ (e.g. Spanish). However, in this particular study all of the experimental tasks and standardized tests are designed for individuals whose first language is English. So, I appreciate your willingness and I want to thank you for your interest, for this study we need participants whom use English as their primary language.

"You indicated that you had encephalitis when you were 11 years old. Because the purpose of this particular study is to determine working memory of person's with a TBI, we are looking for participants who have medical histories involving only TBI. Individuals who have had encephalitis are likely to have other, additional cognitive and learning problems in addition to those associated with brain injury. So, I appreciate your willingness and I want to thank you for your interest."

For subjects who pass the initial screening and express interest in participating:

"When would you be to meet to sign the consent forms, discuss the program in more detail and get started with the evaluation phase?"

(Date and time)____________________________________________________

"Do you have any questions you would like to ask? If you should have any questions before we meet, feel free to call me (the investigator) at (612) 626-9756."

*Participant Information:

Name:
Address:
Phone:
e-mail:

Closing Remarks

"Do you have any questions you would like to ask? If you should have any questions before we meet, feel free to call me (the investigator) at (612) 626-9756. This is the Dept. of Speech-Language-Hearing Sciences where I work. You may have to leave a message on Voice Mail, but I will return your call as soon as I get it. Also, I will send you a letter or email confirming the date, time and location for our next appointment. I want to thank you for your time, and I look forward to our meeting. Good Bye."

Appendix C. Experimental Task Instructions.

*N-Back Practice Task Instructions as Appearing on Computer Screen*

In this task, you will listen to several sequences of letters. Each sequence will be about 45 seconds long. There will be a break after each sequence. Press any key to continue.

Before each sequence of letters begins, you will be given 1 of 3 different types of instructions. The instruction to follow will change with each sequence. Press any key to continue.

In each type of instruction, you will be asked to respond to certain letters in the sequence. You will be given 2 seconds to respond after each letter in the sequence. Press any key to continue.

The following are practice sequences to allow you to become familiar with the 3 different types of instructions. Press any key to continue.

One instruction will ask you to press the space bar when you hear a certain letter. This letter will be different for each sequence and will be given to you in the instruction before the sequence begins. Press any key to practice.

Press the space bar when you hear “*n*”. Press any key to start.

[*Practice stimulus sequence presented auditorily*.]

Do you have any questions? If not, press any key to continue.

Another instruction will ask you to press the space bar when a letter is the same as the letter that was one place back in the sequence. For example, if you heard the following sequence: L P M M Q you would press the space bar after the 2$^{nd}$ “M”, because it is the same as the letter one place before it. Press any key to practice.

Press the space bar when the letter matches the letter one place back. Press any key to start.

[*Practice stimulus sequence presented auditorily*.]

Do you have any questions? If not, press any key to continue.

The last instruction will ask you to press the space bar when a letter is the same as the letter that was two places back in the sequence. For example, if you heard the following sequence: J D P D X you would press the space bar after the 2nd “D”, because it is the same as the letter two places before it. Press any key to practice.

Press the space bar when a letter matches the letter two places back. Press any key to start.

[*Practice stimulus sequence presented auditorily*.]

Do you have any questions? If not, press any key to finish the practice session.

Practice session complete.

*N-Back Experimental Task Instructions as Appearing on Computer Screen*

Press any key to start.

*0-back Instructions:*

Press the space bar when you hear “*n*”. Press any key to start.

[*Practice stimulus sequence presented auditorily*.]

You may take a break now if you wish. Press any key to continue.

*1-back Instructions:*

Press the space bar when a letter matches the letter one place back. For example, if you heard: L P M M Q you would press the space bar after the 2nd “M”. Press any key to start.

[*Practice stimulus sequence presented auditorily*.]

You may take a break now if you wish. Press any key to continue.

*2-back Instructions:*

Press the space bar when a letter matches the letter two places back. For example, if you heard: J D P D X you would press the space bar after the 2nd “D”. Press any key to start.

[*Practice stimulus sequence presented auditorily*.]

You may take a break now if you wish. Press any key to continue.

*After Final Stimulus Sequence:*

Session complete.

*Listening Span Practice and Experimental Task Instructions*

*Computer Instructions:*

The experimenter will read the instructions now. Press any key to continue.

*Verbal Instructions:*

In this task, you're going to hear some short statements. I will ask you to do 2 different things. First, I want you to show me or tell me whether each statement you hear is true or false. Let's try that part:

Snow is cold.
You eat a mountain.

That part's easy. But now I'm going to make it a little harder. After you decide whether the statement is true or false, I want you to remember the last word of each statement. Then, when I point to you, tell me the last words that you remembered for those statements. It doesn't matter what order you remember the words. Let's try it with the two statements you just heard:

Snow is cold.
You eat a mountain.

Yeah, you've got it. So there are 2 things to do. Point to or say true or false, and remember the last word of each statement. Let's practice a few more. Are you ready?

*Computer Instructions:*

[*Practice stimulus sentence presented auditorily*.]

1 is True
2 is False

[*Procedure repeats until end of practice set is reached*.]

Now have them repeat the final words. When they are done, press 1 to begin practice set B.

[*Procedure repeats until end of practice set is reached*.]

When they are done, press 1 to begin the experiment.

*Verbal Instructions:*

Now we'll go on to the real thing. We'll start with sets of 2 sentences, and increase to sets of 5 sentences. Most people can't remember all of the words when we get to 5 sentences, so don't worry about that. Just remember as much as you can. And, if there are any that you miss or don't quite hear, just go on to the next one. We can't repeat any once we get started. Any questions?

*Computer Instructions:*

[*Stimulus sentences presented auditorily*.]

1 is True
2 is False

[*Procedure repeats until end of set is reached*.]

Now have them repeat the final words. When they are done, press 1 to begin set [*n*].

When they are done, press 1 to go to the next block.

*Verbal Instructions Between Levels:*

Now, we'll move up to [*3, 4, 5*] sentences, so there will be [*3, 4, 5*] words to remember.

*After Final Stimulus Set:*

The experiment is finished. Press any key to end E-prime.