The Effects of Traumatic Brain Injury (TBI), Age, and Practice on Speed of Information
Processing using Two Newly Developed Computerized Tests

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ABSTRACT

Three newly developed computerized tests of information processing (CTIP; Tombaugh, 2000) and a modified version of the PASAT (Adjusting-PSAT; Tombaugh, 2000) are described that measure speed of information processing. The CTIP consists of three reaction time (RT) tests that vary in degree of response complexity according to simple, choice, or semantic processing. The A-PSAT measures speed of information processing using a temporal threshold measure that is obtained by increasing the duration of the interstimulus interval (ISI) when a response is incorrect and by decreasing the ISI when a response is correct. Five experiments were conducted to investigate the sensitivity of these new tests to traumatic brain injury (TBI), age, and practice effects. The current study examined the effect of practice over repeated sessions using brief (20 minutes, 1 week), and longer intervals (3 months, 6 months). Performance measures were based on median response latencies for three reaction time (RT) tests, and threshold scores for the A-PSAT. Results from Experiments 1 and 2 showed that TBI and aging each affected performance on complex tasks that involved a speed component. Results from Experiments 3 through 5 showed that practice effects also affected performance on complex tasks between the first two testing sessions, regardless of the duration between sessions. Based on these results, the potential clinical utility and directions for future research concerning practice effects are outlined.

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To Him, for granting me the serenity.

There is an old song entitled “To Sir with Love” in which a young girl asks, “ how do you thank someone who has taken you from crayons to perfume? It isn’t easy but I’ll try”.

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INTRODUCTION

A longstanding debate exists regarding the nature of attentional and cognitive impairments in persons having sustained a traumatic brain injury (TBI), which can result from a head injury (HI). Cognitive impairments are likely to be present during the first few days following a mild injury, but in most cases these impairments resolve during the first 3 to 6 months. However, some patients continue to complain of decreased concentration and attention despite obtaining scores that fall within the normal range on neuropsychological tests. This suggests that current tests of attention may lack sensitivity in detecting specific types of attentional impairments in TBI patients.

Persons having sustained a TBI frequently complain of decreased attention, concentration, mental slowness, and fatigue. Almost every cognitive task is performed more slowly by TBI patients than by normal controls, and this slowness becomes more evident with increasing task complexity (Whyte, 1996). During the course of recovery following TBI, the severity of many cognitive impairments decreases, but impairments in the speed with which information is processed still remain. Monitoring recovery in processing speed is particularly important because it may underlie other cognitive problems. For example, the common complaint of fatigue among TBI patients may reflect the greater effort needed to compensate for slowness in processing incoming information. Problems with memory may also result because of a reduced ability to process all of the information presented in a specific amount of time. As such, TBI patients are viewed as "slow" because of the additional time they require to process information.

Although attention has not been unequivocally defined, there is general agreement about different cognitive operations that require varying amounts of attentional capacity for their execution (Schmitter-Edgecombe, Marks, Fahy, & Long, 1992). For example, there is a general consensus among researchers that the amount of capacity required to perform a task is a function of whether automatic or controlled processes are involved. Automatic processes are those that impose modest demands on attentional resources and can be performed simultaneously with other cognitive processes. For example, dialing a familiar phone number can be performed while carrying on a conversation. In contrast, controlled processes are those that place great demands on attentional resources, and cannot be performed simultaneously with other cognitive processes. For example, trying to remember a new phone number while carrying on a conversation. Because the two tasks require a conscious effort, they are both dependent on attentional capacity. Thus, performing two effortful tasks simultaneously is likely to result in increased error rates and increased response latencies, or reaction times (RT).

The attentional framework used in the present research is based on the view that attention is a multidimensional rather than a unitary concept, and describes information processing within an attentional capacity system. Attention was examined within a neurocognitive perspective, with a focus directed toward the speed and efficiency with which various types of information are processed. Despite the shared interest in attention between cognitive and clinical neuropsychologists, there has been little overlap between the two fields until recently.

Based on the finding that cognitive operations are slowed following TBI, the

present research examined information processing in head-injured patients and noninjured controls. A major hypothesis of the present research was that attentional deficits in TBI patients are mainly the result of a slowing down in the execution of consciously controlled processes. It was assumed that the rate of transmission of information through the cortex determines the performance of TBI patients on cognitive tasks. Different levels of information processing may exist depending on whether a task involves speed of responding, simple versus complex stimuli, or automatic versus controlled processing. It was postulated that the basic disorder of TBI is in processing multiple sources of information because of difficulty in dividing attentional resources over numerous tasks. Thus, a basic disorder of TBI may be a divided attention deficit upon which other disorders of attention are superimposed as a result of a limitation in information processing capacity, either in terms of speed of processing, or in terms of the amount of information that can be handled simultaneously. It was therefore expected that TBI patients would have more difficulty than controls in processing complex material, and that this difficulty would increase with increases in severity of TBI. To address this issue, various cognitive operations were examined by using tests that varied along a continuum of automatic-controlled processes of attention.

It was also recognized in the present study that the rate of information processing may be slowed by increasing age depending on the specific task administered (Geary & Wiley, 1991; Salthouse, 2001). While many researchers agree that aging affects cognitive slowing, there is disagreement concerning the exact nature of the function relating age to

slowed performance. To monitor recovery over time, it is critical to differentiate normal cognitive functioning from pathological or normal age-associated decline. Thus, it was deemed important to determine whether age would moderate performance on the newly developed tests used in this research. This aspect was explored in Experiment 2.

While the cognitive effects associated with both TBI and aging can significantly decrease performance, practice effects can significantly improve performance due to mere exposure with the test. Failure to account for practice means that the underlying cognitive status may not be adequately assessed. Thus, any knowledgeable interpretation of change in cognitive function over time should consider the effect of previous experience on present performance. Based on the existing evidence that many tests are sensitive to practice effects (Feinstein, Brown, & Ron, 1994; Stuss, et al., 1989) the present study administered tests over repeated sessions to gain insight into practice effects in Experiments 3 to 5. The effects of practice effects were examined by administering the tests at varying intervals to determine the relation between inter-session delay and performance. It is possible that the nature of the task being practiced, the timing of the delay interval between sessions, or an interaction of these two variables may moderate the relation between task and performance.

In view of this, the purpose of the present research was to study the relation between TBI, age, and practice effects on one type of attentional process: speed of information processing. Each of these three major variables is explored in separate experiments and, as such, each factor is discussed separately in the three major sections that follow.

First is a review of the literature on the major components and tests of attention, methodological limitations in TBI assessment, and the rationale and procedures for the current study. Because the present application examined information processing deficits in TBI patients, an overview of the literature on head injury (HI) follows. Issues addressed in this section include definition and measures of severity, symptoms, natural course of recovery, and attentional components as they relate to a head injury.

Background Information

Traumatic brain injury results from a blow to the head, and is one of the most significant neurological disorders in our society, surpassed only by stroke in rate of occurrence (Morse & Montgomery, 1992). Moreover, given that most individuals who sustain a head injury are in their early 20s, there are great costs associated with both the economic and physical welfare of the victim. Expertise in detecting the effects of a head injury is critical to early intervention and rehabilitation.

Measures of Severity

The term concussion refers to the disturbance in neurological function caused by mechanical trauma and is a type of TBI (Bernstein, 1999). The severity of TBI is defined by the acute characteristics of the injury as opposed to the chronicity of symptoms following the injury (Alexander, 1995). The terms minor, moderate, and severe have typically been employed to define the severity of a head injury. Currently, there are three measures generally used to assess severity, and to monitor changes in levels of consciousness following trauma: Duration of loss of consciousness (LOC), length of post-traumatic amnesia (PTA), and scores from the Glasgow Coma Scale (GCS) (Jennett &

Teasdale, 1994). The LOC is simply the duration of coma. However, it is not necessary to experience LOC for a diagnosis of TBI. An injury is mild if LOC is less than 30 minutes, moderate if LOC is 30 minutes to 6 hours, and severe if LOC exceeds 6 hours. Length of PTA refers to the characteristic observation that concussed individuals are initially disoriented and unable to recall or retain information. Thus, PTA is typically measured by asking the patient to recall events following the injury in chronological order. An injury is mild if it involves PTA that lasts less than 1 hour, moderate if PTA lasts less than 24 hours, and severe if PTA lasts more than 24 hours. The GCS involves a separate assessment of motor, verbal, and eye opening according to a set of criteria that reflect the level of cerebral function. This is now carried out at the scene of the accident, or when the patient is first admitted to hospital. Using a 3-15 scale, intact responding is indicated in a GCS score of 13-15 (mild), whereas impaired responding ranges between 8-12 (moderate) and 3-7 (severe) (see Table 1).

Simply using the LOC and PTA to measure the severity of injury was found to be problematic because there was no reliable way to assess whether or not a patient was fully conscious, or to assess the depth of unconsciousness (King, 1997, Richardson, 1990). For example, PTA can be underestimated due to isolated "islands of memory" that occur within a noncontinuous memory of events (King, 1997, p.170). Likewise, PTA can be overestimated by including periods that involve sleep, or by misattributing impaired consciousness resulting from medication, alcohol, or substances to the injury (Whitty & Zangwell, 1977). As a result of such limitations, Jennett and Teasdale (1974) devised the GCS as a reliable and systematic means of assessing depth of coma. Although the GCS

score facilitates an assessment of severity, it is only useful if recorded at the time of injury. Therefore, the GCS cannot be used retrospectively (King, 1997; Teasdale & Jennett, 1974).

Table 1
The Glasgow Coma Scale Response Chart (GCS)

	Examiner's Test	Patient's Response	Assigned Score
1. Eye opening	Spontaneous	Opens eyes on own	4
	Speech	Opens eyes on loud verbal command	3
	Pain	Opens eyes to pain	2
	Pain	Does not open eyes	1
2. Verbal	Speech	Carries on a conversation correctly and is oriented to time and place	5
	Speech	Seems confused or disoriented	4
	Speech	Understands and talks to examiner, but makes no sense	3
	Speech	Makes sounds that examiner cannot understand	2
	Speech	Makes no sound	1
3. Best Motor Response	Commands	Follows simple commands	6
	Pain	Pulls examiner's hand away on painful stimuli	5
	Pain	Pulls a part of his/her body away on painful stimuli	5
	Pain	Flexes body inappropriately to pain	3
	Pain	Decerebrate posture	2
	Pain	Has no motor response	1

Taken from Teasdale & Jennett (1974)

* Range 3-15

To date there are no biologically objective measures to quantify or to infer the severity of neuropathology more accurately than the three behavioural indices presented above. Research has indicated that neuroimaging techniques can detect abnormal function in severe head injuries but their sensitivity is limited in detecting abnormalities in mild head injury (MHI). The diffuse pattern of injury in MHI makes it difficult to detect abnormalities on MRI and CT scanning techniques and other neuroimaging tests: (1) reduced cerebral blood flow (rCBF) has been indicated for severe, but not MHI, (2) changes in electrical brain activity using electroencephalography (EEG) measures is limited to the prediction of epilepsy, and (3) abnormal auditory brain stem evoked responses (ABERs) that map cerebral function in response to auditory stimuli have little value in predicting neuropsychological impairment following injury. Thus, used together, LOC, PTA and GCS are the best measures of outcome following head injury (Richardson, 1990; Teasdale & Jennett, 1974) despite the limitations mentioned above. Unfortunately, measures such as LOC, PTA and GCS scores are only indicators of neural injury and anticipated functional outcome of moderate to severe HI. However, the clinical and behavioural consequences of MHI are more variable, and cannot be predicted from such measures. Therefore, one goal associated with the present research is to evaluate how sensitive the newly developed neuropsychological tests are in detecting the cognitive effects of MHI.

MILD HEAD INJURY (MHI)

Mild head injury (MHI) is characterized by (1) LOC less than 30 minutes, and in some cases there is no LOC but simply a brief period of dazed consciousness

(concussion); (2) A GCS score between 13-15; and (3) duration of PTA less than 1 hour, although some researchers use a period of up to 24 hours (e.g., King, 1997). In addition, MHI patients have no obvious focal signs. More importantly, MHI patients show no indications of cerebral damage using neuroimaging techniques such as MRI and CT. In this respect, MHI is defined negatively based on the absence of focal and neurological indicators (Gronwall, 1991). Despite the absence of focal abnormalities, MHI is characterized by cognitive, somatic, and emotional sequelae that occur immediately following the injury, and can persist for periods beyond 1 year (Alexander, 1995; Binder, 1986; Gronwall, 1991; King, 1997; Ponsford et al., 1996; Tombaugh, 1999).

It is important to distinguish among the various terms that are used when describing MHI. For example, because MHI describes any significant injury to the head and face, it may or may not include brain injury. Bernstein (1999) has suggested that a distinction be made between MHI, in which brain damage is not evident, and mild TBI, in which brain damage is evident. But this supposes that a distinction can be made solely on the basis of brain damage. However, due to the difficulty in detecting underlying brain damage in many MHI cases, the distinction is equally difficult to make. For this reason, both terms will be used throughout this review to describe mild injury.

Symptoms

The symptoms following MHI can begin within hours, days, or weeks following the injury. Thus, theorists generally make a distinction between early and late onset of post concussive symptoms (Alexander, 1995; King, 1997). Early symptoms are predominately somatic and include headaches, dizziness, nausea, fatigue, and blurred vision. Late

symptoms can be somatic (headache, ringing in the ears, double vision, photosensitivity, sensitivity to noise, sleep disturbance, fatigue, decreased tolerance of alcohol), emotional (irritability, anxiety, nervousness, depression), and cognitive (poor concentration, forgetfulness, reduced levels of executive function).

Typically most concussed persons recover from MHI within three months, with the majority asymptomatic within 6 months. However, a significant proportion report persistent postconcussion symptoms (PPCS) beyond 6 months or more after the injury (Alexander, 1995; Binder, 1997; Dikmen, Temkin, & Armsden, 1989; King, 1997). By 1 year, up to 90% of MHI patients recover, but there are still up to 15% that have not recovered (Gasquoine, 1997). Many are more symptomatic than immediately following the injury, and most have a worsening of their entire symptomatology (Binder, 1997; Binder & Rattock, 1989; Bohnen, Twijnstra, & Jolles, 1992; King, 1997). The most common symptoms implicate attention deficits, and manifest in complaints such as (1) "can't concentrate", (2) "forget what I'm doing", and (3) "lose things". A review of the MHI literature further indicates that certain persons may be more vulnerable to the effects of MHI, and as a result, may be more at risk to develop PPCS. Age, education, socioeconomic status, sex, prior HI, psychiatric illness, alcohol/substance abuse, and litigation have all been identified as variables contributing to the development of PPCS (see Binder, 1997 for a complete review).

The most widely accepted explanation of PPCS is that it results from patients' attempts to cope with a multitude of incoming information. Thus, placed within the present perspective, it is the reduction in speed of information processing that is the

primary impairment of MHI patients. Ultimately, the cause of the impairment is less important than how it impacts on a patient's ability to function. Thus, the challenge for researchers is to present clear evidence for the presence of deficits when they exist.

Clearly, assessment of attention provides a comprehensive measure of processing deficits in head-injured persons, and allows a baseline measure against which recovery can be charted. Furthermore, the identification of component abilities that are impaired provides the rationale for choosing a specific rehabilitation strategy. Ultimately, a majority of the people experiencing difficulties arising from MHI can be described within a framework of attention, so a review of the components of attention will be provided.

ATTENTION

Components of Attention

Attention is clearly multidimensional, and there is a continuing controversy as to the meaning of the concept of attention (Ponsford & Kinsella, 1992). As well, various tests exist that are purported to measure specific components of attention (see Table 2). This lack of definition may be one possible reason for the relative lack of studies of attention following brain injury. However, some of the aspects of attention that have developed from recent theories include arousal (an organism's ability to respond), sustained attention or vigilance (an organism's capacity to sustain readiness over a period of extended time in a quiet environment), focused attention (an organism's ability to select and focus on relevant information for conscious processing while ignoring irrelevant stimuli), and attentional capacity/speed of information processing (an organism's capacity for processing information and the rate at which such information is processed) (Ponsford &

Kinsella, 1992).

Arousal. Broadly defined, arousal involves the receptivity of the nervous system to internal or external information (Posner, 1978). These two causes of change in receptivity are identified as the *tonic* and *phasic* aspects of arousal, respectively.

Tonic arousal refers to the slow fluctuations in alertness that relate to circadian (daily) rhythm, food intake, drug effects, etc. Tonic arousal is typically not evaluated by neuropsychological tests, but may be reflected in the patient's overall alertness and ability to respond to stimulation. Thus, a patient who falls asleep during a task is probably inadequately aroused. Measures of tonic arousal are obtained using EEG recordings of brain activity, and indices of autonomic activity (e. g., pupil size, heart rate, electrodermal response). Using such measures, researchers have shown that the majority of even severely injured TBI patients recover normal sleep/wake cycles.

Phasic arousal refers to a basic readiness to respond (orient) to a stimulus, or readiness to make a motor response (van Zomeren & Brouwer, 1994). Ponsford and Kinsella (1992) examined phasic arousal in severely HI patients and controls by introducing a warning signal before the target stimulus. The effects of a warning signal on reaction time (RT) resulted in faster latencies for both groups compared to a condition without a warning. More importantly, the warning decreased latencies equally in both groups on simple and complex tasks, a finding that has been replicated in numerous experiments (see van Zomeren, 1981,1987). Such findings provide no evidence to support an abnormal phasic arousal response in TBI patients. Thus, TBI patients are as sensitive as controls to the effects of a sustained stimulus, and on phasic arousal.

Table 2
Traditional Tests of Attention

Name of Test	Task Demands	Attentional Components Tested
Cancellation Test	Scan for target letters or symbols (e.g., cross off every 'B' in a list of letters)	Sustained Attention
Continuous Performance Test (CPT)	Detect target in an increasing stimulus array (e.g., tap each time you hear the number '8')	Sustained Attention
Trails A* and B **	Join numbers together (A) or alternate joining letters to numbers (B)	Selective Attention
Digit Span **	Retain an increasing series of numbers for immediate recall	Concentration/ Capacity
Digit Symbol **	Fill in the symbol that corresponds to each number presented in a random numerical array (e.g., 2 is *, 6 is ^)	Concentration/ Divided Attention
Arithmetic (WAIS-R) *	Mental/Mathematical Calculations	Concentration
Stroop Test	Suppress automatic response tendencies	Focused Attention
Wisconsin Card-Sorting Test (WCST) **	Change Cognitive Set/ Mental tracking	Divided Attention/Flexibility
Paced Auditory Serial Addition Test (PASAT) **	Mental calculations/ ignore irrelevant information	Divided Attention/ Speed of Information Processing/ Capacity

* denotes strength of test sensitivity to "attention" deficits

Sustained Attention. Sustained attention refers to an ability to maintain a consistent behavioral response over time (Sohlberg & Mateer, 1987). This aspect of attention can be described as a continuous receptivity, or vigilance, to a stimulation covering minutes or hours. As such, sustained attention involves the effects that time have on a task, and has been examined with tasks of vigilance and continuous performance tasks. Such tests are sensitive to time-on-task effects, such as lapses of attention and increased error rates as the task progresses (called the vigilance decrement).

In vigilance tasks a low probability event must be monitored, such as responding to slight changes in stimulus intensity. In continuous performance tasks, stimuli succeed each other at either a pace predetermined by the experimenter (paced) or by the participant (self-paced).

Although TBI patients show fewer correct responses (lower hit rates) to target stimuli and slower reaction times (RTs) than controls, both groups show a similar vigilance decrement (Brouwer & van Wolfelaar, 1985; Parasuraman, Mutter, & Molloy, 1991; van Zomeren & Brouwer, 1987). That is, although TBI patients perform poorly compared to controls on vigilance tasks, (e.g., missing more signals or responding more slowly), their performance is stable over time and does not deteriorate as the task progresses (Brouwer, 1985; van Zomeren et al., 1984, 1987). This lack of decrement in performance over time fails to support the hypothesis that patients are unable to sustain attention, because an impairment is indicated only if performance deteriorates in the latter part of the task.

A second issue concerns the variability of individual performance. For example,

alternating periods of very poor performance with periods of near normal performance might indicate lapses of attention. Based on previous research (e.g., Spikman, van Zomeren, & Deelman, 1996; van Zomeren et al., 1984, 1987, 1994) there appears to be no indication of specific increases in intraindividual variability in RT measures of sustained attention: variability measures are proportional to the increases in mean or median RT. Thus, there is no evidence to suggest an abnormal decline of sustained attention following TBI whether the dependent measure used is time on task or intraindividual variability. A more plausible explanation for the poor test performance of HI patients on sustained attention tasks is slow information processing. As such, results obtained from research of sustained attention in TBI patients can be summarized very simply. Compared to controls, TBI patients show poorer signal detection and longer latencies to signals, but their performance is just as stable as the performance of the control groups.

Focused Attention. Focused attention refers to the ability to focus on relevant stimuli in the presence of distracting, irrelevant stimuli. Distracting stimuli can be external (e.g., noise or visual stimuli) or internal (e.g., response interference due to an inability to suppress an automatic response tendency). An automatic response tendency is one that is highly learned such as naming a printed word rather than naming the color of the ink in which it is printed.

Dencker and Lofving (1958) were the first researchers to assess focused attentional deficits. Two texts were read aloud to mildly concussed participants, during which a recording was played of several persons talking simultaneously. This task required participants to ignore the external distraction (noise) from conversation in order to focus

on the presented text. Immediately following the presentation of each text, questions about the text content were presented. Based on the low error rates it appeared that the interference condition had no effect on the HI persons' ability to focus attention.

Gronwall and Sampson (1974) tested focused attention in mildly concussed patients using a shadowing procedure. Two texts were presented simultaneously through headphones and the participants were required to repeat the text heard only in their left ear, while ignoring the message presented to the opposite ear. The authors concluded that patients were not abnormally sensitive to distraction based on the number of intrusion errors.

A classic test of response interference is the Stroop Test in which test stimuli have to be processed along two conflicting dimensions: colour and word name. This test is composed of three conditions: reading colour words, naming the colour of painted blocks, and naming wholeword colours when the individual letters are printed in another colour (e.g., the word *yellow* printed in blue letters). This last condition is an internal interference condition as the participant must suppress the automatic tendency to read the word rather than name its colour. Although slower in all three conditions, the HI group are not differentially impaired on the interference condition compared to normal controls. This finding has been reported for patients following mild, moderate and severe head injuries (Bohnen, 1991; Ponsford & Kinsella, 1992; Stuss et al., 1985; Thomas, 1977).

Bohnen (1991) modified the traditional Stroop Test by incorporating an alternating condition between colour reading and colour naming. Twenty percent of the coloured words were enclosed within a rectangle. Participants were instructed to *read* these words,

and to *name* the colours of the other words. Thus, the unfamiliar task of colour naming was interrupted repeatedly by stimuli that required the participant to switch back to reading. The modified condition had a significant additional effect on the patient group: it increased the time that the patients needed relative to controls in naming the colours of words compared to the traditional task (88 and 83 in the traditional versus 106 and 97 in the modified for patients and controls, respectively). Clearly, this result was, again, indicative of a general slowing of response.

As with most tasks, TBI patients require more time relative to controls to cope with response interference. Thus, although the performance of TBI patients indicates no evidence for a focused attention deficit, their performance does show evidence of slowed controlled processing. Deland, Vanier, Lambert, and Provost (1992) support this assumption by showing that distraction effects in TBI patients were proportional to their RT observed in a basic task without distraction. They concluded that TBI patients are not impaired in inhibiting automatic processes, but that the controlled process of ignoring irrelevant stimuli in a novel task costs them more time.

Based on the above findings, there is little evidence to indicate increased distraction effects on task performance for TBI patients relative to controls. When auditory or visual distracters are used, TBI patients are able to ignore these as well as controls. Even in conditions that provoke conflicting response tendencies, TBI patients show distraction effects that are comparable to controls. The general finding is that the TBI group is performing slower, with no substantive differences in error rates from the control group.

Attentional Capacity and Speed of Information Processing

Attentional Capacity. Attentional capacity refers to the amount of information an individual can process within a specific time period and is the component of attention most affected by head injury (Cicerone, 1996). A central aspect of attentional capacity is that it is limited (Schneider & Schiffrin, 1977; Weber, 1990). This means that as more stimuli are presented for processing, more effort is required by an individual to successfully perform the task. It is this processing limitation that necessitates stimulus selection. To function effectively, some stimuli are selected while others are neglected. Thus, processing multiple sources of information requires concentration and effort.

One form of attention task that is commonly used to assess attentional capacity is the divided attention task. Such tasks typically require participants to perform two tasks simultaneously, or multiple stimuli must be processed. Slowness in basic psychological processes can have deleterious effects on such complex tasks, particularly under time pressure. Because the number of operations that can be performed within a certain time limit is finite, processing cannot be completed for all sources of information. Thus, the term "divided" refers to the fact that available attentional resources must be divided, and strategically allocated, over several cognitive operations for successful task performance.

A reduction in attentional resources results in difficulty processing information, especially in situations that require strategies, such as allocating limited resources across various subtasks. There is empirical support to suggest that increased attentional capacity on one aspect of a task is believed to result in decreased capacity available for other tasks (Weber, 1990). Accordingly, the more attentional resources that are available, the more

efficiently, or intensely, these resources can be dispersed across a range of activities.

When the demands of a task exceed a participant's processing capacity or speed, the rate at which information can be processed is decreased (Ponsford & Kinsella, 1992). Attention deficits would therefore become apparent with increasing task complexity.

As the ability to divide attention is extremely susceptible under time pressure, and slowness seems to be a primary concern following TBI, it is clear that the critical factor for assessing divided attention is time pressure. Slow information processing may be particularly limiting on divided attention-tasks that require processing multiple stimuli or performing multiple tasks at the same time (Sohlberg & Mateer, 1987). Monitoring and responding to multiple pieces of information has been shown to be difficult for persons having sustained a head injury (Morse & Montgomery, 1992; Ponsford & Kinsella, 1992). This deficit has been linked to a mode of processing that is capacity limited and that processes information according to strategies (van Zomeran et al., 1984; Whyte, 1992, 1996).

Speed of Information Processing. Slowing of information processing is a major consequence of TBI (Brouwer, 1985; Cicerone, 1997; Ponsford & Kinsella, 1992; Spikman, van Zomeran, & Deelman, 1996; Stuss, Stethem, Hugenholtz, Pivik, & Richard, 1989; Timmeran & Brouwer, 1999; van Zomeran & Brouwer, 1994). van Zomeran and Brouwer (1987, 1994) found that slowed information processing was the defining feature of TBI, and King's (1997) review of this same literature shows convergent findings of an impairment in the head-injured patient's ability to perform tasks that require speed of information processing, a conclusion also advanced by Gentilini, Nichelli, and

Schoenhuber (1989). Moreover, studies converge on the finding that slowed information processing is the most salient feature of MHI and is independent of deficits in divided and sustained attention. However, despite this aspect of slowing, studies throughout the literature erroneously conclude that attentional processes are intact, despite a reduction in the resources (e.g, speed and capacity) required for attentional processes. This is because the tests used to assess patient performance are too global to detect and isolate any specific impairment.

In contrast to the absence of sustained, focused, and divided attention deficits is the presence of mental slowness in TBI patients. Spikman et al. (1996) compared the performance of 60 severely head-injured patients to the performance of a matched group of 60 noninjured controls on a series of attention tests. The tests used by Spikman et al. assessed various components of attention such as focused, divided, sustained, and higher attentional control functions. Results showed that the patients performed significantly worse than controls only on tests that involved time pressure (e.g., divided attention tasks). No evidence was obtained to indicate a deficit in sustained attention, in accordance with previous research (Brouwer & van Wolfelaar, 1985; Stuss, Pogue, Buckle, & Bondar, 1994; Whyte, Polansky, Fleming, Coslett, & Cavalucci, 1995). Spikman et al. interpreted their results as indicative of a basic slowness of information processing in their patient group. In a subsequent analysis, these authors controlled for the effects of slowness, and found that the previously obtained group differences disappeared. The results of their second analysis indicate that group differences in attention were due to slowness of information processing. The most important finding is that experimental control for slow

information processing removes most of the differences between TBI patients and normal controls on attention performance (Brouwer, Ponds, van Wolfelaar, & van Zomeren, 1989).

Hartman, Pickering, and Wilson (1992) administered a dual task to severely head-injured patients and a healthy control group. Under time pressure, both groups were required to perform a tracking task while holding a conversation. Results indicated that performance of the patient group on the main tracking task deteriorated significantly more than controls with the addition of the secondary task. In contrast, using a tracking task combined with a self-paced RT task, Brouwer et al. (1989) did not find any differences between their patient and control groups. In addition, Ponsford and Kinsella (1992) investigated the nature of attentional deficits in severely injured TBI patients and although they did not find evidence to support the presence of a sustained or focused attention deficit, they did find evidence to support the presence of an information processing deficit. However, the nature of this slowness is still an open question.

Summary. Difficulty in dividing attention is a frequent and persistent complaint among TBI patients. Individual performance on a divided attention task is determined by the processing strategies and level of skill required to perform a task. However, other major determinants are an individual's speed of cognitive processing and ability to allocate attention between subtasks by switching or by time-sharing processing resources. Accordingly, a divided attention task is one that places heavy demands on attentional capacity. For this reason, divided attention errors may be more accurately termed attentional capacity errors.

Because attentional capacity is decreased in concussed individuals, the speed at which they are able to process information is also decreased. In this sense, the terms *attentional capacity* and *speed of information processing* are flip sides of the same coin (Weber, 1990). Likewise, attentional capacity and information processing capacity are highly linked because the amount of information that can be processed in any given time is a function of the amount of information that can be attended to within that same time. As such, attentional capacity is measured according to the accuracy and speed at which information can be processed. Thus, there exists an intricate connection between speed and capacity.

Information Processing: Theoretical Models

Empirically, a systematic evaluation of attention is lacking in neuropsychological assessment. Attention is used loosely by clinicians and researchers as an umbrella term to cover a variety of processing difficulties. To further complicate matters, most tests of attention have not been developed within a theoretical model of attention. Research that leads to establishing a theoretical framework for models of attention is hampered by disagreement over how to define and assess attention. Researchers disagree about the various processes of attention and the validity of the numerous tests purported to measure such processes. Consequently, tests are based more on clinical anecdote than on solid empirical research. However, clinical models are now being described and validated with experimental research.

Some researchers have attempted to relate mental slowing to a specific stage of information processing between stimulus and response using Sternberg's (1969) additive

factors logic. Other researchers have adopted Schneider and Schiffrrin's (1977) distinction between automatic and controlled processing to describe information processing. These two theories are described below.

Sternberg's Model. According to Sternberg's "additive factors" logic, information processing involves a serial sequence of 4 stages: 1) stimulus encoding, 2) memory scanning, 3) response selection, and 4) response execution. Sternberg's method assumes that stages in a serial information processing model can be isolated by manipulation of task variables that assess a particular stage. For example, stage 1 can be manipulated by varying stimulus quality, stage 2 by varying the size/similarity of a memory set, and stage 3 by varying stimulus-response compatibility. Accordingly, it is possible to determine whether two task variables affect the same or different processing stages based on RT as the sum of the component stages. Thus, if two variables affect the same stage, each variable will contribute to processing time within that particular stage, and their effect on mean RT will result in a statistical interaction. In contrast, if two variables affect different stages, each variable will contribute to processing time at different stages, and, thus, their effect on mean RT will result in an additive effect, not an interactive effect.

Empirical evidence shows that the central processes (e.g., stimulus encoding, memory comparison, and decision-making/response selection) are the primary loci of cognitive slowing (Gronwall, 1996; Schmitter-Edgecombe et al., 1992; Shum, McFarland, & Bain, 1990). In addition, studies show that it is the decision-making process that is primarily affected following TBI (Gronwall & Sampson, 1974; Miller, 1970; Shum et al., 1990). Other evidence, however, suggests that stimulus encoding and memory

comparison may also be affected by severe TBI (e.g., Haut, Petros, Frank, & Lamberty, 1990). Shum et al. found that severely brain damaged patients were impaired on the encoding process up to 1 year post injury, but this impairment improved after 1 year following the injury. Thus, the difficulty with encoding following severe TBI may improve over time, although prolonged RTs are still noted for degraded stimuli.

Information processing may not be the only factor that affects performance on attention tasks. In a complex task, the use of an inefficient control strategy may impair performance despite a normal processing capacity (van Zomerén & Brouwer, 1987). Control strategy refers to the executive functions of the brain that involve planning, programming, and regulating goal-directed behaviour (Lezak, 1983). Thus, a very efficient control strategy may compensate for a decrease in processing capacity. Strategies may direct information processing according to task requirements. Accordingly, more recent theories of attention tend to emphasize two areas of focus: automatic and controlled processing.

Schneider and Schiffrin's Model. According to the influential model advanced by Schneider and Schiffrin (1977), there are two forms of attention: Automatic and Controlled. Automatic processing occurs without conscious control and has no capacity limitations (e.g., dialing well-known numbers on a telephone). Controlled processing, in contrast, requires conscious control and has a limited capacity and processing rate (dialing a telephone number using letters rather than digits on the keypad). Such a two-process model specifies a distinction between familiar and novel situations. Automatic processing is based on the activation of learned sequences that proceed automatically until the

demands of a task require a conscious effort by the individual. Controlled processing typically occurs in novel situations where prior experience is not readily available.

Within this two-process model there is also a dichotomy specified by the qualitative nature of attentional errors. The first class of errors is termed Focused Attention Deficits (FADS) and occurs when automatic responses interfere with a task that requires controlled processing (e. g., reading a word printed in coloured ink rather than naming the ink colour). The second class of errors is termed Divided Attention Deficits (DADS) and occurs when the demands of a task exceed one's conscious processing capacity or speed, thus limiting the resources available to perform the second task (e.g., holding a conversation while performing an otherwise simple mathematical calculation such as addition). Because dividing attention requires allocating attentional resources between two or more tasks simultaneously, Schneider and Schiffman concluded that DADS result from limitations in the rate at which information is processed. Speed of information processing is therefore a central construct in divided attention.

Parasuraman et al. (1991) hypothesized that if mild TBI affects both automatic and controlled processing in sustained attention, then differences in vigilance performance between persons with TBI and matched controls under both degraded and undegraded conditions should appear. In contrast, if primarily controlled processing is affected, group differences should be observed when stimuli are degraded, but not otherwise.

Sustained attention performance of patients with mild TBI was examined within 1 month of injury using a vigilance task with 2 levels of stimulus degradation (undegraded, highly degraded). In the undegraded condition, vigilance performance for patients,

uninjured case-matched controls, and college students was highly accurate and remained so across the entire task period. In the degraded condition, performance declined over time in a similar fashion for all three groups. Although TBI did not lead to a greater rate of deterioration in vigilance performance in the degraded condition, it did produce lower overall levels of sensitivity in target detection. These results suggest that during the first month after mild TBI, vigilance performance is unimpaired under normal task conditions, but may decline under task conditions that require sustained effortful processing. These findings join a growing body of evidence showing that mild TBI can lead to measurable deficits in cognitive functioning.

Contrary to their predictions, Parasuraman et al.'s (1991) findings show that vigilance performance after mild TBI is comparatively normal under conditions that encourage automatic processing of stimuli, as well as under conditions that require controlled, effortful processing of stimuli because the vigilance performance of both TBI patients and uninjured controls deteriorates equally over time.

Any impairment in the ability to access and process information may require extreme effort to perform tasks on the part of the head-injured person, thus explaining the common complaint of fatigue among this population. Furthermore, because it takes so long for the head-injured person to process information, he or she is judged to be "slow". This slowed processing speed may also explain the memory problems experienced by these individuals due to a reduction in their ability to register, or encode, information. Thus, assessing the state of attentional processes at any given time is critical to understanding the current limitations, and, possibly, the future abilities of the head-injured

person.

Because Schneider and Shiffrin emphasize capacity limitations, their model provides a framework for describing the pathological limitations of attention following head injury. It is the speed limitation of controlled processes that appears to be the central, underlying deficit in TBI victims. According to Schneider and Shiffrin's theory, the available processing time is a limiting factor on performance in divided attention tasks that require controlled processing. Thus, the time required for a controlled process, using mental chronometric (measurement) procedures such as RT provides an estimate of attentional capacity. As such, the present research proposes to examine differences in processing speed between groups of TBI patients and controls. Because speed is affected by capacity limitations, any observed group differences are expected to be exacerbated by manipulating task complexity. In this way, the present research delineated two dimensions underlying effortful attention: capacity and speed.

Summary. Slowed information processing appears to explain most of the attention deficits observed after mild head-injury (Cicerone, 1996; Gentilini et al., 1989; Ponsford & Kinsella, 1992; van Zomeren & Brouwer, 1994). It appears that patients with TBI perform better on tasks which are fairly automatic or less demanding, although this may require greater subjective cognitive effort than normal. On tasks which require more deliberate and controlled allocation of attention for adequate performance, the increased, or multiple task demands, may exceed available resources and the patients with TBI are unable to sustain effective processing. The principal effect of the increased task demands is thus to markedly reduce the speed of controlled cognitive processing.

In the two-process model of Schneider and Shiffrin, automatic processing is described as a reliable, effortless process proceeding to a level of abstraction determined by prior learning. On the contrary, controlled processing is described as a more vulnerable process subject to FADS and DADS. It will be clear that an analysis of attentional deficits after TBI should ask at least two questions: (1) is automatic processing still efficient and effortless after TBI, and (2) is controlled processing disturbed to an abnormal degree by DADS? As the concept of DADS relies not only on speed but also on control strategies, this aspect is critical to performance.

It should be noted that performance deficits of HI persons are apparent on measures of processing speed, but not on other performance measures such as accuracy. This finding may have implications for the clinical and functional evaluation of MHI patients, since the quality of these patients' accomplishments can be adequate, but their performance may still be compromised by slowing. Processing speed appears to be a primary factor in limiting attention, especially on tasks requiring controlled processing. Thus, processing speed should emerge as a particularly sensitive index of a patient's ability to return to work or school.

Indices of Information Processing

Despite the importance of assessing and monitoring the recovery from the effects of concussion, few clinical tests are available for measuring the speed of information processing. Neuropsychological tests may help track recovery in global attentional deficits, but their utility in detecting subtle deficits in speed of information processing is limited. Furthermore, it is virtually impossible to predict post-concussion symptoms from

other neurological indices of impairment such as PTA and LOC. As such, the ability to monitor patients' recovery from the effects of TBI is restrained by the inability of clinical tests to detect a processing deficit.

Three core parameters in measuring the efficiency of information processing are speed of performance, accuracy of performance, and effects of increasing load or complexity. Speed and accuracy provide the best assessment of the efficiency of controlled processing and the effects of increasing processing load (Schneider & Schriffrin, 1977; Ponsford & Kinsella, 1997). Therefore, to adequately measure information processing speed, a test must either vary the rate at which information is presented to an individual or measure the amount of material that is presented within a specific period of time. Variations in presentation speed will affect how much information can be processed within a specific interval. Few neuropsychological tests are currently available to satisfy this criterion. Thus, few neuropsychological tests are sensitive to deficits in information processing capacity. The few that do exist are the Trail Making Test (Reitan & Wolfson, 1985), Symbol Digit Modality Test (Smith, 1982), Digit Symbol Substitution Test (Wechsler, 1997), and Paced Auditory Serial Addition Task (PASAT; Gronwall & Sampson, 1974).

Two tasks that enable a direct examination of the effects of increasing complexity are Reaction Time (RT) Tests and the Paced Auditory Serial Addition Test (PASAT). Because these two measures of attention are able to capitalize on the relation between capacity and speed, they are sensitive to the reduced attentional capacity in TBI patients. These tests are described below, and discussed according to the theoretical basis and

rationale for their use in the proposed study.

Reaction Time Tests

Reaction time represents a behavioral measure of information processing which may be reflected in any of the areas of attention (sustained, focused, divided). It is based on the concept that attentional deficits will manifest when the amount of information to be processed exceeds the capacity of the system (Mateer & Mapou, 1996). Studies have demonstrated that this slowing is not the result of sensory or motor impairments (Sohlberg & Mateer, 1989).

Theoretical explanations (e.g., additive factors) have suggested that a slowdown occurs in the cognitive stages of stimulus encoding and response selection. Using Sternberg's (1969) method of additive factors (stimulus encoding, memory comparison, response selection, motor preparation), Sanders (1983) used tasks believed to influence each stage and found that although patients were sensitive to specific task variables, the general effect of slowness in any task was a more robust phenomenon than any specific effects. For the total group, results obtained from the RT tasks provided no conclusive evidence that concussion affects particular stages of information processing. Research with HI individuals suggests that the speed at which HI persons respond is decreased in direct proportion to the amount of information that must be processed before the response is made (Sohlberg & Malteer, 1989). Thus, the time required for controlled processes, as estimated with RT methods, gives a direct estimation of attentional capacity (Salthouse, 1988; van Zomeren & Brouwer, 1994). Assuming that the person is performing a task to the best of his or her ability, a particular task could be considered to provide a measure of

the individual's maximum capacity of attention in that area.

Reaction time as an experimental technique was first used by Obersteiner (1874) to evaluate the mental capabilities of psychiatric patients. In 1922, two French studies reported prolonged RT in postencephalitic patients, and in 1938 Conkey found that postencephalitic patients had difficulty concentrating on tasks. Mental slowness was the outstanding feature of these patients. Therefore, RT seemed an adequate method of investigation of head-injury. Ruesch (1944) was the first to use the RT technique with HI patients. He studied 25 patients with recent HI, 32 patients suffering from chronic posttraumatic syndromes, and 25 controls. Ruesch observed that both patient groups were slower than controls and concluded that RT could have clinical utility. With the growth of cognitive psychology, RT has become conceptualized as a measure of speed of processing, and experimental RT paradigms have repeatedly shown that RT is sensitive to information processing (Bleiberg, Garmoe, Haloern, Reeves, & Nadler, 1997; Bohnen, Jolles, Twijnstra, Mellink, & Wijnen, 1995; Collins & Long, 1996; Gentilini et al., 1989; Ponsford & Kinsella, 1992; Strauss, Spellacy, Hunter, & Berry, 1994; van Zomeren & Brouwer, 1987, 1994). As such, RT has been used extensively to study a wide variety of mental activities in both normal and neurologically impaired populations. It has been repeatedly demonstrated that RT measures give important information about cognitive efficiency. Thus, it is possible to use these measures to gain useful information for predicting a HI person's ability to cope with the complexities of both occupational and social settings (Gronwall & Wrightson, 1974; Miller, 1970). It has not been possible during the first few days after injury to identify those patients who will later develop PCS

using standard tests or neurological measures. However, using RT as a measure of processing, Maddocks and Saling (1996) detected the effects of concussion 5 days following a sports injury, and Cremona-Meteyard and Geffen (1994) detected similar effects 1 year following injury. Due to the sensitivity of RT to the effects of concussion, these tasks show promise as valuable supplements to neuropsychological assessment.

A review of the literature on RT reveals a differential sensitivity of test forms to the effects of concussion. Choice RT (CRT) is more sensitive to the effects of concussion than simple RT (SRT). CRT tasks require a participant to discriminate among two or more stimuli by making alternate responses (e.g., left key vs right key). In contrast, SRT tasks require a participant to make one response to one stimulus. Although both simple and complex tasks have been used to assess mental slowness, researchers have repeatedly demonstrated that CRT tasks elicit larger differences between TBI and control groups (van Zomeren & Brouwer, 1994). Choice RT is also more effective than SRT in detecting residual impairments in TBI patients (Ponsford & Kinsella, 1992; Stuss et al., 1989).

Earlier researchers such as Norman and Svahn (1961) and Miller (1970) identified slowness in TBI groups using CRT to a visual stimulus but no group differences were found using SRT. Gronwall and Sampson (1974) tested visual CRT in 12 mild TBI patients and concluded that central processing time was significantly increased following trauma, a finding confirmed by Schneider and Schiffman (1977). van Zomeren and Deelman (1978) reported a follow-up study covering two years on a group of 57 young brain-injured males divided into 3 subgroups according to severity of injury. Reaction-time discriminated among subgroups, and a significant improvement during follow-up

examination was shown. Choice-reaction time discriminated severe from mild TBI patients better than SRT and continued to do so throughout the entire follow-up period.

Ponsford & Kinsella (1992) tested very severe TBI patients consecutively admitted to a rehabilitation program and orthopaedic controls with a large battery of attention tests, including a simple and four-choice reaction time test. Patients were tested in the first year after injury, some in the acute phase and some in the chronic stage of recovery. It was found that TBI patients were significantly slower than controls and that this difference was significantly larger in the CRT. It appeared that the RT of the TBI group was disproportionately affected by an increase in task complexity. Thus, the consensus appears to be that TBI reduces the speed of complex decision-making and information processing abilities.

The disproportional effect of processing speed on patients compared to controls when the number of stimulus-response alternatives increases is called the complexity effect (Benton, 1986; van Zomeren & Deelman, 1978). In addition to the number of stimulus response alternatives, complexity can also be manipulated by decreasing the stimulus-response compatibility. This means that the response is not directly indicated by the spatial location of the stimulus.

It makes sense that an increase in test complexity produces a decrease in TBI patients' performance. Given the increase in task demands, a brain injured person must struggle with slowed processing to make increasingly complex decisions. Such a struggle on the part of the injured person is consistent with individual complaints of slow thinking and difficulty in performing multiple tasks simultaneously. However, although CRT is

more effective than SRT in revealing the residual deficits of a head injury, SRT is important in establishing a minimum level of performance. Thus, SRT provides a baseline of performance (Tombaugh, 1999) against which complex processes can be gauged. As such, baseline data obtained from SRT is critical in determining how complex tasks impact on cognitive processing.

Despite the potential usefulness of RT tests in assessing TBI, there has been little research investigating the relation between RT and traditional neuropsychological test performance. One of the few studies in the area found a linear relation between cognitive impairment and RT performance: Those who were the most impaired demonstrated the slowest RT (Elsass & Hartelius, 1985). These researchers concluded that not only was RT a valuable supplement to neuropsychological assessment, but that it was especially sensitive to progressive cerebral disease.

Jakobsen, Baadagaard, Thomsen, and Henriksen (1987) examined whether RT could predict PCS. They tested 55 patients at 1-5 days post-injury using an auditory SRT test. Results showed significant increased RT in patients having PCS 1 month after the injury compared to patients without PCS. Patients reporting PCS symptoms at 3 months post injury also showed increased RT relative to those without PCS. However, one aspect of the Jakobsen et al. study worth mentioning is their use of the SRT paradigm: If the complexity of their test is varied using a CRT paradigm, it may be possible to predict with greater certainty those at risk for PCS. This assumption is based on prior results that show CRT as a better task than SRT in discriminating between control and TBI groups.

Collins and Long (1996) investigated the relation between SRT, CRT, and

neuropsychological test performance as assessed by the Impairment Index of the Halstead-Reitan Neuropsychological Test Battery (HRBI). Collins and Long (1996) reasoned that if RT was correlated with the HRBI and assessed the same abilities, then there would be little reason to add an RT test to an already lengthy test battery. Median RT scores and intraindividual variability (SD) of RT scores were evaluated in three groups: Impaired TBI, nonimpaired TBI, and normal controls. In all three groups there was a significant correlation between RT and level of cognitive functioning such that lower cognitive functioning resulted in increased RT. In addition, SRT, speed of information processing (as measured by CRT), and intraindividual variability of RT scores continued to be in the impaired range for many brain-injured individuals, who, according to the Impairment Index, had fully recovered from their cognitive deficits. Median RT scores were better at discriminating between impaired TBI patients and normal controls, but intraindividual variability of RT scores was better at discriminating between nonimpaired TBI patients and normal controls. Collins and Long concluded that by adding the two RT tests to the neuropsychological test battery, more accurate predictions can be made about a patient's level of cognitive functioning.

The results of Collins and Long's study indicate that when Impairment Index test scores are used alone to make a statement about level of cognitive functioning, some patients will be classified as "recovered" when they are actually still having difficulty with the speed and efficiency with which information is processed. Told that they are now functioning in the normal range of cognitive abilities, persons having sustained a head-injury will expect to function as they did prior to the trauma. Family members and

employers will expect the same. When the patient cannot perform or maintain performance at his or her pre-trauma level of functioning because of a slowed information processing rate, other psychological, social, and occupational problems may develop. Therefore, adding two short RT tests may facilitate a more accurate prediction about a patient's current level of cognitive function, help clinicians make better treatment recommendations, and also help patients to understand and work with their residual deficits.

Summary. Measurement of RT has been demonstrated to be a valid and reliable method of assessing cerebral function with the same sensitivity and specificity as more time-consuming neuropsychological examinations. Neuropsychological tests assess processing abilities to varying degrees, but none of them represent a "pure" measure of information processing ability. For example, performance on various subtests is also affected by a variety of other abilities such as psychosensory, tactile form discrimination, manual dexterity, coordination of movement, visual-spatial skills, and problem-solving. Although RT can be affected by other factors, it is generally a much purer (direct) measure of speed of information processing and cognitive efficiency. However, the degree of "purity" is affected by the complexity of the RT task. The most simple RT tasks appear to be unaffected by such factors as strategy or knowledge that come into play in more complex RT tasks (Collins & Long, 1996).

The conclusion above is based on studies that have found that CRT is more sensitive to the effects of TBI than SRT (SRT seems to be prolonged after head injury of all indices of severity, but shows maximal recovery within one year post-injury). In

contrast, CRT shows more impairment with injuries of greater severity and continues to show recovery more than two years after injury (see van Zomeren, 1981, for a review). Because it has been well documented that RT is impaired in TBI patients, it seems logical that a measure of simple response time and of more complex speed of information processing would provide valuable information about cognitive functioning. The most sensitive tasks for revealing cerebral dysfunction are therefore those tasks that test functions involving the greatest number of cortical and subcortical areas simultaneously. This feature certainly applies to attentional tasks, especially those based on processing speed: In fact, RT values have been shown to be more dependent on volume than on site of cerebral lesion (Tartaglione, Bino, Manzano, Spadavecchia, & Favale, 1986). Thus, the more complex the task, the more the individual's response will be affected by other factors (Miller, 1970, Collins & Long, 1996). For this reason, using both SRT and CRT measures provides valuable information about predicting a person's ability to perform in the everyday world (Gronwall & Wrightson, 1974).

Paced Auditory Serial Addition Test (PASAT)

The Paced Auditory Serial Addition test (PASAT) is a neuropsychological test used by clinicians and researchers to measure attention and speed of information processing (Brittain, La Marche, Reeder, Roth, & Boll, 1991). Gronwall and Wrightson (1981) determined that the PASAT is highly sensitive to deficits in information processing, and Ponsford and Kinsella (1992) confirmed that performance on the PASAT reflects slowed information processing. Comparative data is available for both normal (Sampson, 1956) and head-injured populations (Gronwall, 1977).

Sampson (1956) developed the original version as an instrument for stimulus-response research, and used the test to examine the effects of changes in duration and frequency of visually presented stimuli. Sampson used a projector to present participants with a series of single digit numbers (1-9), each displayed on a 2" x 2" glass slide. The participants were required to add each number to the one that directly preceded it such that the second number was added to the first, the third to the second, the fourth to the third, and so on. Using this Visual Paced Serial Addition Test (VPSAT), Sampson demonstrated two major effects: 1) an increase in the presentation rate of numbers produced an increase in errors, and 2) practice effects were observed on subsequent testing sessions.

Gronwall and Wrightson (1974) used an auditory version and demonstrated the sensitivity of the PASAT to subtle cognitive deficits and persistent post-concussive symptoms after MHI. In their version, the same 60 numbers are presented aurally in four consecutive fixed experimental trials, each differing in the rate of digit presentation (pacing). The task is presented at four different paces: 2.4 s, 2.0 s, 1.6s, and a 1.2s interstimulus interval (ISI). A practice trial consisting of 10 numbers delivered at the slowest rate precedes the testing session. Dependent measures are the number of correct responses for each rate of presentation, with a maximum score of 60 for each paced trial. For each pacing, the percentage of correct responses is computed for each trial (maximum 60), as is the error rate as a percentage of the total number of responses across all paces (maximum 240). Scores may also be computed according to seconds per correct response, and averaged across trials to provide a composite score of correct responses per second.

The time in seconds to produce a correct response is estimated by dividing the duration of a trial by the total number of correct responses of the trial (e.g., for 45 correct responses in the 2.4 sec trial with a total duration of 140 seconds, the average speed per response is $140 \text{ sec} / 45 \text{ correct} = 3.11 \text{ sec}$). These computed scores are considered to be highly sensitive to speed of information processing (Gronwall & Sampson, 1974). Computing an average time per response also allows a direct comparison of performance when other versions of PASAT are used (e.g., Levin, 1983 uses 25 digits, and Levin, Mattis, & Ruff, 1987 uses 50 digits). Cut-off scores of composite time per correct response are provided to classify less than 3.2s as normal, 3.2-5.0s as borderline, and scores greater than 5.0s as impaired.

Persons having sustained a concussion perform well below average on the PASAT immediately following the injury (Stuss et al., 1989), but show improved performance within 30 to 60 days (Lezak, 1995). However, while most mildly concussed persons show improved levels of performance on the PASAT within 60 days, there are many who continue to show a marked impairment on this test (Lezak, 1995). Roman, Edwall, Buchanan, & Patton (1991) concluded that among concussed persons, those who have the most diffuse damage are also those who have the lowest scores on the PASAT, and King (1996) recommended the PASAT as the measure most likely to demonstrate predictive and clinical utility in PCS assessment. Thus, prior research using the PASAT illustrates that this test can be a valuable indicator of information processing efficiency.

Validity and Reliability. The PASAT's split-half reliability is approximately .9, so the test has high internal consistency (Egan, 1988; Lezak, 1995). Performance scores across the different trials are highly correlated (.75-.95). Test-retest correlations are

also high (.9). The test is moderately correlated to other tests of attention, such as Digit Span, Stroop Tests, Trail-Making Test, Visual Search and Attention Test (Lezak, 1995). Dreary, Langan, Hepburn, and Friar (1991) found that PASAT loaded highly on a "freedom from distraction factor " identified as a third factor in the WAIS-R. Similar results were obtained by Sherman, Strauss, Spellacy, and Hunter (1995) who obtained strong correlations between this third factor and scores on The Trail Making Test, and the PASAT. None of the memory measures correlated with the Freedom From Distractibility Factor, and many neuropsychological tests were moderately correlated with more than one WAIS-R factor. This finding is important because it highlights the multidimensional nature of most neuropsychological tests. Therefore, within any population, certain tests may not provide a "pure" measure of the construct they purport to measure. In contrast, tests such as the PASAT, that load highly on the third attentional factor, show promise as a useful test in understanding and detecting the precise deficit underlying performance in TBI adults. Therefore, Gronwall's claim that the PASAT is an index of concentration and attention seems to be valid: There is corroborative evidence for construct validity.

Clinical Utility and Sensitivity to TBI. The clinical utility and sensitivity of the PASAT to reduced information processing capacity following mild to severe head-injury has been repeatedly demonstrated (Gronwall, 1977; Gronwall & Wrightson, 1974, 1981; McMillan & Gluckman, 1987; Ponsford & Kinsella, 1992; Schneider & Schriffrin, 1977). Gronwall and Sampson (1974) demonstrated that concussed patients performed worse than matched controls on the PASAT. Compared to normal controls and accident victims without concussion, patients with MHI demonstrated slowed information processing

capacity. They also complained of problems with fatigue, concentration, irritability, and intolerance to noise. The finding that accident victims without concussion performed as well as normal controls on the PASAT indicates that "noncognitive" effects associated with head injury (e.g., shock, emotional trauma, and hospitalization) did not affect the test results. Of particular importance in identifying the nature of cognitive deficits in TBI patients is Gronwall and Sampson's (1974) finding that severely concussed patients were able to perform an unpaced version of the PASAT error-free. This finding supports the suggestion that TBI patients are capable of processing and manipulating incoming information, but are incapable of executing mental operations at fast rates.

Using the PASAT to Monitor Recovery from TBI. Used as an objective measure of the reduction in patients' information processing rate following concussion, the PASAT also holds promise as a clinical application to monitor recovery from TBI. For example, Brooks, McKinley, Symington, Beattie, & Campsie (1987) found that the PASAT was a powerful predictor of employment status following TBI. Gronwall and Wrightson (1975) used the PASAT to determine the appropriate time for TBI patients' return to work using a cut-off score of 1 standard deviation below the control mean as a criterion score. These authors also used the PASAT to reveal the cumulative effect of repeated head injury: PASAT scores were lower in 20 young adults suffering from a second concussion compared to a matched group suffering from a single concussion.

Gronwall and Wrightson (1981) found that PASAT scores correlated with tasks requiring complex processing and speed, and Kanter (1984) found a strong relation between PASAT scores and performance on nonverbal tests requiring processing speed.

O'Shaughnessy, Fowler, and Read (1984) monitored patients' recovery from MHI using cognitive tests 1 week following injury and again at 6 months. Deficits were identified by the Trail Making Test, Erickson Memory Scales, and the PASAT. Although many cognitive tests were administered to the patients, only scores on the PASAT were related to patients' subjective complaints regarding their postinjury behavioral changes. Duration of PTA was not predictive of severity of deficit, rate of recovery, return to work, or personality changes. Furthermore, Gentilini et al. (1989) did not find any differences in memory function between patients with MHI and controls, despite their complaints, but did find differences between these groups in complex attention processes. Thus, MHI patients may misinterpret their attention deficits as memory deficits (Raskin & Rearick, 1996).

Many patients with MHI have PASAT scores falling within normal limits 30 to 60 days after injury, but some individuals show no improvement in test performance and continue to perform at levels that are significantly below normal (Gronwall, 1977; Gronwall & Sampson, 1974; Lezak, 1995). Those having more severe head injuries have test scores that are low and remain low, showing no significant gains with repeated testing (Lezak, 1995; Ponsford & Kinsella, 1992; Stuss et al., 1989). Roman et al. (1991) suggested that patients having head injuries that produced diffuse damage are those most likely to perform poorly on the PASAT. It may be that head injury results in reduced brain-stem reticular activation resulting in a reduced rate of information processing (Gronwall, 1987; Brittain et al., 1991). As such, the PASAT presents as one of the most promising tests to guide and clinically assist in patient rehabilitation.

The PASAT appears to have two components which may explain its sensitivity to processing deficits after head-injury. The first of these factors is the demand for rapid processing, as observed in the finding that reducing the requirements for speed of information processing reduces the test's sensitivity (Cicerone, 1996, 1997; van Zomeren & Brouwer, 1994). For example, Thomas (1977) found that TBI patients' PASAT scores were not decreased when she used a slower rate of presentation, which further supports the notion of slowed information-processing as the critical performance factor.

The second factor to explain the PASAT's sensitivity to TBI is the extent of controlled processing required to perform the task. Complex tests require effortful processing, so they place a heavy demand on processing capacity; a demand which is necessary to demonstrate the subtle cognitive disturbances of MHI patients. Moreover, many researchers have obtained an interaction between processing speed and task complexity due to respondents' increasing need to monitor multiple sources of information (Godefroy, Lhullier, & Rousseaux, 1996; Loken, Thornton, Otto, & Long, 1995).

Schneider and Schiffman (1977) found that TBI patients were slower than controls, particularly on CRT tasks. It appears that the reaction times of the TBI subjects were disproportionately affected by the increased complexity of their task. However, on the PASAT there was no disproportionate deterioration in error rates of the TBI group with increased rate of digit presentation. Although the patients performed more slowly than controls across all paces, there was no significant interaction between group and pacing. Thus, a greater complexity effect was obtained for the patients on the RT tasks, but not on the PASAT.

Although Schneider and Schiffrin's study did not provide evidence to support a deficit in focused attention, it did provide evidence of a speed-accuracy trade off for the TBI patients. When possible, patients tended to sacrifice speed to maintain accuracy, and when this was not possible (as on the PASAT) they made more errors than controls. These results challenge the widely held assumptions that head-injured patients not only perform more slowly than controls, but also make more attentional errors, have difficulty sustaining attention, and show poor self-regulation of their attentional resources. However, these results are consistent with the previous research (e.g., Gronwall & Sampson; 1974, Miller, 1970; van Zomeren, 1981; Brouwer & van Wolfelaar, 1985; Stuss et al., 1985) which showed reduced speed of processing for the TBI participants, but not significant reductions in accuracy or performance over time compared to controls. It is clear that caution should be exercised in interpreting the neuropsychological test performance of TBI patients, being careful to separate out speed of performance from quality of performance.

Moderator Variables on PASAT Performance. Gronwall and Wrightson (1981) found that the PASAT loaded chiefly on a factor of attention, concentration and information processing capacity, and this factor had no substantial correlation with a factor of verbal competence. This finding was taken to support their claim that the PASAT was not significantly correlated with general intelligence or arithmetic ability (Egan, 1988). However, some of these claims have been challenged recently. For example, Brittain et al. (1991), Dreary et al. (1991), and Egan (1988) have all observed significant correlations between PASAT performance and various measures of intelligence including the Weschler

Adult Intelligence Scale-Revised (WAIS-R).

Nettelbeck (1987) noted that the PASAT involves speed of intake which sometimes is correlated with general intelligence. Furthermore, it seems logical to relate mental calculations to mathematical ability. Consequently, a person's IQ and math ability may moderate PASAT scores. Finally, it is well established that cognitive processes can be affected by age (Brittain et al., 1991, Salthouse, 1996, 2000). In fact, Gronwall (1977) cautions "serial addition is not suitable for children or elderly patients" (p. 368). However, Ward (1996) reported no performance advantage on the PASAT for younger compared to older participants, despite an observed advantage on Digit Span for the younger group. Ward suggested that the discrepancy was due to the older groups' ability in retrieving well-established number bonds.

Recently, Crawford, Bisson, and Allan (1998) investigated whether age and IQ are related to PASAT performance. One hundred and fifty-two healthy participants were administered the PASAT, the full length WAIS-R, and the Nelson (1982) National Adult Reading Test (NART). The authors reasoned that if the PASAT showed a strong relation to IQ, then scores could be interpreted relative to an estimate of premorbid intellectual ability. Because NART is highly correlated with WAIS-R and is resistant to the effects of TBI (e.g., Crawford et al., 1998) and other neurological conditions, it was used to estimate premorbid PASAT performance (e.g., an average score may represent impairment for an individual of high premorbid ability). This estimate of premorbid PASAT performance was then used as a measure against which to compare a patient's obtained score.

The difference between the predicted (145) and an obtained score (102) for one

patient was 43. According to Crawford et al., less than 10% of a healthy sample would be expected to show a discrepancy of this size. Based on this large discrepancy between predicted and obtained PASAT scores, the authors concluded that an attention/concentration deficit qualified as a differential deficit in that it exceeded the current averaged level of deficit on a standard measure of intellectual ability. This finding is in accord with McMillan and Glucksman (1987) who reported that the PASAT was the only measure among a battery of neuropsychological tests that yielded a statistical difference between MHI and healthy controls groups.

Using 4 trials of 61 digits (2.4-1.2 sec) Crawford et al. found that the PASAT loaded highly on the third factor of the WAIS-R (the attention/concentration factor). There was also a linear effect of age: Lower PASAT scores were associated with higher age, which is consistent with other measures of attention and speed of information processing (e.g., Brittain et al., 1991). Thus, all of the studies discussed above are in agreement that low PASAT scores may be indicative of impaired information processing, provided other variables (e.g., age, IQ, skill) are considered. Such studies indicate that there is a need to delineate the mental components tested by the PASAT.

Despite the evidence that the PASAT has promising clinical applications, its practical application is limited. Due to the constant speed of responding, both TBI patients and normals find the test stressful and, as such, clinicians have reservations in administering the test. Respondents cannot process at a rate which is compatible with their current level of processing speed. Tombaugh (1999) has innovated a new version of the PASAT (Adjusting-PASAT) that allows a precise calculation of a temporal threshold,

defined as the point where speed of digit presentation outstrips a person's ability to process information. This threshold should be sensitive to the cognitive effects of TBI on speed of information processing.

The Adjusting-PASAT (A-PASAT)

Tombaugh (1999) has developed a modified version of the PASAT in an attempt to make it more user friendly, yet at the same time increase (or maintain) its sensitivity to deficits in speed of information processing. Tombaugh combined the traditional PASAT methodology with a psychophysical titration (stair-step) procedure for determining processing thresholds. The procedure used in this Adjusting-PASAT (A-PASAT) adjusts the interstimulus interval (ISI) between digits contingent on the correctness of a participant's response. As such, the ISI increases whenever an incorrect response is given, and decreases whenever a correct response is given. This procedure minimizes frustration because the person does not have to endure a large number of trials presented at an interval that is beyond his or her processing ability (e.g., 1.2 s with the traditional PASAT).

The A-PASAT also enables more precise calculation of the temporal threshold by determining the speed of digit presentation that exceeds a participant's capacity to process such information. The traditional PASAT is unable to determine the level at which deficits in speed of information processing occur because it uses a series of 4 ISIs (2.4s, 2.0s, 1.6s, and 1.2s) that remain constant throughout the testing session rather than varying as a function of correct response. This variation of ISI as a function of correct response is an essential feature for determining a person's processing threshold. Thus, the A-PASAT achieves a more precise measure of processing speed and capacity by using

increases and decreases in the response-contingent ISI to calculate the fastest presentation rate at which responding is accurate (Tombaugh, 1999). The exact procedure for this test is presented later in the method section.

Summary. Use of RT tests is based on the empirical finding that simple and complex RT tasks are sensitive to subtle deficits in information processing. Simple RT tasks require a minimal amount of conscious control which means that scores on these tests indicate mainly slowness of information processing. As the task demands increase, so does the time needed to process the information required to make a response. As such, SRT can be used as a baseline to determine how increasing stimulus complexity impacts on processing capacity. Unfortunately, RT tasks, like the PASAT, are restricted in the clinical setting due to inadequate norms for interpreting test results, and imprecise measurement techniques. Furthermore, little research has been conducted to compare the clinical sensitivity of RT to standard neuropsychological tests.

Recent follow-up studies covering periods from 3 months to 7 years postinjury have confirmed that poor concentration and slowness are among the more common problems reported by mild head-injured victims. Thus, their frequent complaint of poor concentration and fatigue, while not readily detected in standard tests, would be evident in situations requiring speed of information. Forgetfulness could also result, not because of a memory impairment per se, but because the attentional demands of life surpass the injured person's capacity for processing information. As such, tests that assess speed of information processing would be most effective in detecting subtle TBI deficits, and may well resolve the discrepancy between subjective complaint and objective performance.

PRESENT RESEARCH

Overview

Based on the lack of sensitivity of standard tests to the effects of MHI, a sensitive test of head injury is needed. Because the organic basis of MHI is undetectable using neuroimaging techniques, it is imperative to infer how well a patient is recovering by measuring change over time on a specific deficit. In terms of measurement, tests assessing speed of information processing and RT will best satisfy the first requirement.

An overview of the literature presented above reveals that the PASAT and RT tests show promise as sensitive indicators of TBI. Both tasks incorporate demands for rapid information processing, and have consistently been reported to discriminate between TBI and controls. Based on the research presented above, the sensitivity of these tasks is likely to be due to the interaction of processing speed and capacity demands placed on the TBI patient. Controlled studies that assess neuropsychological functioning following TBI consistently converge to find an impairment on tasks that are sensitive to speed and capacity of information processing (Bohnen, et al., 1992). Although there is convincing evidence for slowed information processing following TBI, this slowing has not yielded to componential analysis.

Clearly, attention is not a unitary process and cannot be assessed with a single test. Tests of attention must isolate the effects of specific component processes if they are to successfully isolate a processing deficit. Furthermore, the data obtained from tests of attention should not be interpreted in isolation. Rather, the data should be interpreted relative to all other tasks and conditions. As tests inevitably tap several components of

attention, a low score on one test may be due to a general slowing rather than to an impaired function for any one particular component. For this reason, the present research incorporated a hierarchical design with tasks varied along a continuum of complexity. This design helped to determine any differential effects of slowing on automatic and controlled attentional processes due to TBI, and to isolate these effects within a continuum of processing (automatic-controlled). In this way, the level of complexity most affected by information processing deficits was ascertained.

The problem of evaluating neuropsychological functioning after MHI is likely to be dependent on the adequate selection not only of control subjects and statistical methods, but also of test procedures that tap those specific functional aspects more impaired after concussion. As such, it was theorized that the use of newly developed RT tests and the A-PASAT would provide additional information about the speed and efficiency of information processing, and thus, increase neuropsychological test accuracy. Preliminary research using a normal population indicated that the new A-PASAT is sensitive to information processing and minimizes stress. In addition, the new RT tests showed that response latencies increased as a function of test complexity. Thus, there exists potential for these tests as clinical measures in both assessing and tracking recovery from TBI. The current project was exploratory in that it was the first evaluation of these tests using TBI patients. The employed measures were sensitive to speed of processing, and allowed for an assessment of several levels of processing complexity believed to influence patient performance. The theoretical framework for this design is presented below.

A Continuum of Processing Complexity

All of the studies discussed above reveal that attentional deficits following TBI are largely the result of a slowing down of information processing. Hence, the TBI patient will experience more attentional deficits than healthy controls, and will be confronted with more challenges given his or her limited capabilities in situations demanding global cognitive functions. Based on previous research, the present research varied the level of task complexity to gauge the severity of TBI, and to assess processing differences between TBI and control groups.

Conceptual Organization. Because TBI patients have difficulty with attention, some patients will have difficulty processing information which, in turn, affects the way they encode material into memory. TBI patients may fail to appreciate the organization or semantic relations within the stimulus material. For example, they may not utilize or identify the categorical information in the stimuli presented (Morse & Montgomery, 1992). Qualitatively they may fail to cluster or organize responses according to meaningful relations. Thus, problems on tests of concept learning that involve higher level abilities such as alternating attention, memory, reasoning and executive function, are frequent in TBI patients (Donders & Kirsch, 1991; Morse & Montgomery, 1992). It may be the flexibility required in "changing set", or the focus on overall organization of the task, rather than on fragments, that poses the challenge for TBI patients.

Memory processes (i.e., retention), in contrast to encoding processes, have been shown to be relatively intact in all TBI patients regardless of severity (Schmitter-Edgecombe et al., 1992), although studies have demonstrated slowing of a memory

comparison process (Sininger, Klatzky, & Kirchner, 1989; Stokz & Gaillard, 1986).

Previous studies have also demonstrated that severe TBI patients perform within normal limits on measures of memory span (e.g., digits forward, Baddeley, 1976, 1986), and on rates of forgetting (Baddeley, Wilson, & Watts, 1995). Thus, the present research is based on the assumption that TBI patients' memory problems are largely the result of impaired encoding strategies and slowed transmission between neural nodes.

A general effect of TBI appears to be the shearing of long nerve fibres (white matter) as parts of the brain move relative to each other at the moment of impact. In more severe cases, there may also be axonal damage in the brainstem and local contusions of cortical gray matter. The most common locations of these contusions are the frontal and temporal areas. It is therefore conceivable that the nonspecific slowing described by Brouwer (1985), as a decrease in strength of associations, is between conceptual nodes. Such a decrease in associative strength between nodes could be related to diffuse lesions of white matter, whereas additional impairments of cognitive control processes are related to local cortical contusions and axonal damage of the brainstem. In support of this assumption, Timmeran and Brouwer (1999) have suggested that mental slowness after TBI is a result of global slowing of associative strength between nodes, possibly as a result of diffuse axonal injury or structural loss of axonal tissue.

It is also possible that cognitive processes requiring less processing capacity may be more resilient to brain injury. One explanation for the relative intactness of memory processes in previous research is that the tasks used may be less attention-demanding (more automatic) than the tasks used to assess other processes. Encoding requires

conscious organization and elaboration of meaning based on stimulus relations. In short, this process requires a controlled effort. Thus, limitations to memory processes in TBI patients may only be evident on tasks requiring controlled processing. For example, perhaps constraints may be found in memory processes if the task requires categorizing words under time pressure according to semantic organization in long-term memory. Increasing task complexity or switching the category exemplars required to perform a comparison task should affect response latency according to a capacity deficit hypothesis.

One method commonly used in CRT assessment is the matching-to-sample task. In this task participants are required to identify which of two comparison stimuli was identical to a simultaneously presented sample stimulus. Only one of the comparison stimuli is identical to the sample stimulus. The participant must press one of two buttons as quickly as possible after the stimuli have been presented. Response latency in such tasks increases as a function of task complexity of the stimuli (Myerson, Hale, Wagstaff, Poon, & Smith, 1990), is inversely related to cognitive functioning (Salthouse, 1988), is directly related to aging (Rabbitt & Goward, 1994), and prolonged in patients having sustained diffuse brain damage (Wogar, van den Broek, Bradshaw, & Szabadi, 1998).

It is thus possible to adapt this method to a semantic search (RT test) as a measure of the capacity to process abstract verbal concepts. Based on the research that shows both TBI patients and aging persons have problems in RT as a function of complexity and controlled processing, this modified task may reveal deficits in the speed and flexibility required to change cognitive set. Furthermore, the memory problems of both TBI patients and healthy older adults may really be due to a problem in encoding material in a

meaningful and organized manner. Comparison of the patient groups and controls may indicate that performance differences increase as a function of sample-to-match relatedness, and the speed required to change semantic set after presentation of a category prime.

The present study was one of the first to implement an RT discrimination paradigm based on a conceptual judgement between stimuli rather than on their physical properties. It was believed that this higher level of processing would be very sensitive to the effects of TBI. Previous studies utilizing categorical information did not obtain any differences between TBI patients and controls, but it is believed that this result was because the attentional manipulation used in such studies did not tax the attentional resources of TBI patients enough to show a deficit. This is an issue that requires further investigation and was addressed in Experiment 1 within the present research.

It is also important to recognize the potential limitations in generalizing the effects of any one study to the general population. For example, performance on many tasks may diminish with increasing age (Horton, 1992). The participants used in Experiments 3 through 5, tended to be young adults, ranging in age from 18-21. But, it is also important to determine how the effects of age impact on speed of information processing. The presence of age effects indicates that age-appropriate scores (norms) are required for any meaningful interpretation of performance. To this end, Experiment 2 in the present study explored how age would moderate performance. Individuals of various age ranges were recruited within the community to determine the effects of age on exposure to three RT tests.

To provide a background on the major aspects and perspectives concerning cognitive function and age, an overview of the literature on aging follows. Issues addressed in this section include perspectives on how age impacts on attention; most notably, the reduction in capacity due to a general slowing of cognitive processes.

AGE AND COGNITIVE FUNCTION

Significant declines in several major aspects of cognitive function develop with age. However, such changes do not develop uniformly within or across cognitive domains. The magnitude of change, and the age of onset at which changes become observable depends on the cognitive function being assessed. One explanation is that older adults have a limited capacity, or more limited resources in terms of attentional energy, to effectively engage in elaborate encoding and recall strategies. Consequently, the greatest performance problems for older adults occur on tasks that require substantial processing effort. Consistent with this hypothesis is the finding that free recall is an effortful process requiring that a participant engage in self-initiated activity while either encoding or retrieving information. In contrast, recognition recall is facilitated due to the provision of external cues, thus placing less demand on internal, self-initiated processes. Because age differences are most evident on free recall tasks, the role of limited effort in aging holds credence.

Evidence indicates that normal aging is more often associated with inefficiencies in conceptual processing because it requires more substantial cognitive resources and self-initiated processes than required with perceptual processing (Salthouse, 1991). McKone and Slee (1997) suggested that a lasting association among stimuli requires establishing a

meaningful connection among stimuli. A meaningful connection requires using active, explicit processes that are highly affected by depth of processing. Explicit processes have been described as requiring controlled, conscious encoding (e.g., rehearsal of word-pairs) (Jacoby & Kelley, 1987). On the other hand, implicit processes are unconscious, automatic (e.g., item priming) and only require establishing a perceptual connection without the need for elaborative processing. Consistent with this dissociation, Reingold and Goshen-Gottsein (1997) reported that older adults perform poorly on explicit tasks compared to younger adults, whereas age differences on implicit tasks are virtually nonexistent.

Sauzeon, N'kaoua, Lespinet, Guillem, and Claverie (2000) investigated the incidence of several factors that they believed contributed to age-related memory impairment. Variables manipulated were quality (level of processing encoding conditions), the degree of effort and elaboration during encoding (passive, active) and the influence of retrieval support (cued versus free recall). Results indicated that middle and old-age participants showed more benefit from cued versus free recall for all memory tasks. In addition, the results indicated a differential effect of conceptual processing between the middle and old-age groups. Specifically, age differences were attenuated by deep and active processing associated with retrieval support. In this case, memory decline is generally explained as the result of the inefficiency of the initiation of deep processing during the encoding and retrieval phases. In agreement with Reingold and Goshen-Gottsein (1997), evidence indicates that normal aging is more associated with inefficiencies in conceptual, or explicit, processing which requires substantial cognitive

resources, or self-initiated processes than with perceptual, or implicit processes.

The literature is consistent in reporting an empirical benefit for distinctive elaborations, and in finding that younger adults have better performance than older adults on recall due to actively generating deep elaborations during encoding. The factors that mediate age differences in performance are not clearly understood, but the observation of greater age differences as delay or processing load increases, suggests that different components of working memory may be differentially affected by aging. Possibly, mechanisms that maintain lower memory loads are relatively unaffected by aging, whereas those mechanisms that maintain higher memory loads are more affected as age increases. Moreover, executive components may be differentially affected by advancing age.

The deleterious effect on the flexibility and power of the central executive system is reported throughout the literature on memory and aging. Presumably, the root of the problem is biological, so that an age-related decline may be attributable to an age-related deterioration in the effectiveness of frontal systems in the brain. At the psychological level, this equates to a decline in processing resources, or attention, on tasks that “overload” an aging cognitive system.

Attention and Age

Attention is often viewed as an indicator of capacity, or energy to support cognitive processing. This capacity view deems attention as a limited “commodity” necessary to support information processing (McDowd & Birren, 1990). From this view emerges a picture of cognitive aging as a global reduction in attentional resources which impacts on the efficiency with which cognitive processes are executed. A reduction in processing

efficiency may require older adults to use all available capacity for performing a task, thus leaving little capacity remaining for processing a concurrent task.

Numerous studies have reported an absence of age-related differences in sustained attention (Albert, 1988). As discussed earlier, tests that evaluate sustained attention assess the ability to track a stimulus in a simple task for an extended period of time, such as tracking a letter (e.g., B) or a repeated sequence of letters ("F before X"). Salthouse (1982) conducted seven independent studies of sustained attention to indicate that performance on this task shows little change in participants 20 to 75 years old. In fact, the results showed that there is less than 1 SD of change between 20 and 80 years of age.

Focused attention is another aspect of attention and is usually assessed by research paradigms that require a participant to focus on a target stimulus while ignoring irrelevant information (e.g., detection of a target within an increasing number of nontargets). Some very early studies reported age differences in the ability to ignore irrelevant information (e.g., Rabbitt, 1965), but later studies have questioned this finding (e.g., Gilmore, Tobias, & Royer, 1985). Older participants are as able as younger ones to correctly identify a target within an array of nontargets if the probable position of the target is known, thus indicating that the ability to use the organization of a spatial array is preserved with age. It is possible that prior findings that reported age differences were confounded by difficulties in perceptual discrimination rather than difficulties in the attentional ability to ignore irrelevant stimuli.

The varying aspects of attention may be affected by age in different ways. For example, although aging adults have the ability to ignore irrelevant information in a spatial

array, research findings suggest a different pattern when information must be mentally manipulated, as discussed earlier. In fact, Stankov (1988), in a comprehensive study of attention and age, reported that changes in attentional flexibility and concentration may actually underlie the age changes associated with fluid and crystallized intelligence.

Because crystallized intelligence is based on acquired knowledge, it develops rapidly over the first 20 years of life and then remains stable for decades. Fluid intelligence, on the other hand, is based on biological factors and the integrity of the central nervous system, so it is differentially affected by age depending on the degree of insult to the CNS (e.g., hypertension, diabetes, head injury, alcoholism, stroke, etc). Stankov found that partialing out the effects of an attentional flexibility component practically eliminated the age-related decline in fluid intelligence.

Rabbitt (1965) found that older adults are less able to select and focus on a single input when presented with other, competing inputs. This early finding has extended to more current reports of an age-related decrease in the ability to inhibit irrelevant information. Thus, the disinhibition hypothesis has become more fully supported through subsequent research. On direct tests, older adults have continued to show susceptibility to the presence of irrelevant information (Sauzeon et al., 2000). The argument has been made that irrelevant material is especially detrimental to performance when the task is demanding and requires processing effort. On this view, older adults are significantly slowed in situations that tax their limited processing capacity.

Attentional Capacity

The most typically used procedure to assess attentional capacity is the dual-task

paradigm, in which two tasks must be performed simultaneously. One of the most common dual-task procedures is the dichotic listening task which involves simultaneously presenting a series of letters, digits or words to each ear through headphones. The participant is required to report both series. Dichotic listening tasks have reported large age differences. Such differences in processing may be the result of problems in the ability to focus attention (e.g., number of omissions and number of intrusions), and in the ability to switch attention (e.g., incomplete responses, mixed responses, and responses pertaining to the opposite ear). However, other dual-tasks procedures have failed to produce similar decrements with age. So, there are mixed results with respect to age-related decrements in tasks requiring dual processing.

Hasher and Zacks (1979) were one of the first researchers to hypothesize that “automatic” processes (familiar and well-practiced skills) be differentiated from “effortful” processes (tasks involving novel or complex material). Automatic processes require less attentional capacity than effortful processes, and, as such, various dual-task procedures may differ in the degree to which they rely on each type of processing. Consequently, dual-tasks that require automatic processing would be easier to perform than tasks that require more effortful processing, with greater age differences emerging in those tasks that require effortful processing.

It is also possible that age differences only emerge in tasks that require a rapid rate of response. For example there is a processing discrepancy on the WAIS such that the Performance subtests (e.g., Picture Arrangement, Symbol Digit) show a greater decline than the Verbal subtests (e.g., Vocabulary, Information). The decline on the Verbal scale

for older adults usually does not exceed 1 SD below the performance of younger adults until participants reach 80 years of age. Conversely, the decline on the Performance scale drops more than 1 SD by 60 years of age. This Verbal-Performance discrepancy has been such a prolific finding in aging research that it has been termed the “classic aging pattern” (Albert, 1988).

Heaton, Grant, and Matthews (1991) provided normative data on the Halstein-Reitan Neuropsychological Battery using young, middle-aged, and older adults ($N = 553$) and found that age affected performance on the Category Test, Tactual Performance, and the Trail-Making Test. In contrast, the only subtest of the WAIS that was affected by age was Digit Symbol. It has also been noted that the Verbal scale on the WAIS-R evaluates skills and knowledge that have been acquired early and reinforced throughout one's life. Such reinforcement of knowledge leads to skills that are so well-learned and practiced that they may be insensitive to subtle age-decrements in ability. However, the Performance scales measure the ability to learn and to manipulate material that is novel and complex. In addition, a speed component contributes to the final score on this scale. Thus, the Performance subtests measure psychomotor, perceptual, and integrative abilities.

Horn and Cattell (1967) interpreted the Verbal-Performance discrepancy according to “crystallized” and “fluid” intelligence. The Verbal-Performance discrepancy has also been described as a consequence of the increased slowing seen in the elderly. This explanation is supported by the fact that most of the Performance subtests are timed whereas the Verbal subtests are not. This aspect requires that participants respond within a requisite time limit. However, when Performance subtests are administered without the

time constraints, the age decrements are not eliminated. Given additional time, older participants benefit more than younger participants, but they do not reach the level of performance shown by young participants. Therefore, the Verbal-Performance discrepancy remains even when speed requirements are not required. Thus, there is convergent evidence for an overall, general slowing in information processing with age (Albert, 1988; Salthouse, 1982; 1985; 1991; 1996; 2001).

General Slowing

All studies of age-related decline in cognitive performance should address the issue of general slowing. General slowing refers to the observed phenomenon that for any given cognitive task, regardless of task complexity, the response times of older adults are slower than those of younger adults. Furthermore, the performance of older adults is more affected than that of young adults as the task becomes more complex, referred to as the age-complexity phenomenon (Sliwinski, 1997).

Almost every reference concerning aging discusses loss of speed as a primary manifestation of increased age. A strong theory specifies a mechanism that is responsible for slowing such as a uniform degradation of synaptic transmission (Birren, 1974) or information loss at each transmission (Myerson et al., 1990). This type of theory predicts that RT tasks should show increased latencies for older compared to younger adults. An age effect would indicate increased slowing in older adults when reaction time is used as the dependant variable. Research consistently shows that in most cognitive tasks, RTs become slower as age increases (Ratcliff, Thapar, & McKoon, 2001; Salthouse, 1996; Sliwinski, 1997).

A related issue is whether RTs of older adults increase disproportionately from those of younger adults as a function of task complexity. Traditional RT measures such as Simple and Choice tasks involve different decision processes: Simple RT only demands that attention be allocated to the onset of an event for the purpose of eliciting a discrete response to one stimulus. In contrast, Choice RT demands that attention be allocated to more than one stimulus so that a response is based on a decision process. The typical research strategy is to determine how quickly one task is performed relative to the other. Performance differences among tasks are then attributed to differences in the demand placed on cognitive processes. In a typical aging study, the tasks are varied according to difficulty, and any observed age differences in RT are interpreted as evidence for general slowing. Furthermore, if the older adults are slower than the younger adults on simple tasks, then they should show more slowing on more difficult tasks.

The question then becomes whether the data can be explained using an additive, or a multiplicative model. For example, Birren (1974) and Welford (1977), the pioneers on the issue of speed of response, shared a belief that slowing could account for many behavioural changes, but they adhered to two different views of slowing. Welford believed that the differential slowing between young and older adults was due to a constant increment in speed loss with age. Accordingly, age differences on simple and complex tasks were the same. In contrast, Birren believed that despite the constant increase across tasks for older adults, this increase was most pronounced on difficult tasks. Birren's multiplicative model is one of interaction between age and task difficulty, while Welford's additive model is one of a constant age difference across task difficulty.

Support for a multiplicative model was provided by Cerella, Poon, and Williams (1980) in a meta-analysis of 18 published studies. In each, RTs of young persons were measured and compared with older persons in relation to various levels of task difficulty. Cerella reported consistent findings across studies of an Age x Task interaction to support a multiplicative model. This finding can be interpreted as providing support for the current view of aging as a reduction in processing resources as task difficulty increases.

However, not all studies report disproportionate slowing among the elderly when task difficulty is increased. Sternberg (1969) devised a procedure to estimate the rate at which persons search for information. In this procedure, items are presented for memorization until recognition performance is perfect. Marsh (1975) did not find differences between young and older adults on a task using a Sternberg search procedure, but this study appears to be the exception. Others (Madden, 1986, Salthouse & Somberg, 1982) used the same type of task and found more slowing for the elderly as the search task became more difficult.

The dominant trend in early models of information processing was to break down cognitive processes into functional components, and to study these components in isolation. Models were based on characteristics of subcomponents, and the interrelations among various subcomponents. A more holistic approach studies the cognitive system as a unified whole, with less emphasis on attributing a deficit to one specific component while others remain virtually intact. Deficits are more likely to be widespread and affect the whole system, but specific deficits may not be observable until a specific circumstance arises. For example, deeper processing may be more difficult for older adults because

processing resources are limited. Thus, there is a consequent failure to perform on tasks that require greater effort on the assumption that older adults are not able to process as fast as young adults. Such an age by level of processing interaction was demonstrated by Eysnyk (1979). Results showed that young participants spontaneously employ deeper levels of processing than older adults. Based on this finding, Eysnyk suggested a processing deficit hypothesis to account for the age decrements in his study.

Most early proponents of a general slowing phenomenon adhere to the view that a general mechanism is responsible for age decrements in performance; one that affects the entire cognitive system (e.g., Hale, Myerson, Faust & Fristoe, 1995; Lima, Hale, & Myerson, 1991). Accordingly, cognitive slowing was independent of the type of processing involved. A more modified approach is based on the assertion that general mechanisms do not provide plausible explanations for age differences in cognitive slowing because of statistical interactions, such as Age x Treatment. Obtaining such an interaction implies that selective cognitive components are affected by age, and are dependent on the task involved. However, Salthouse (2001) has argued that statistical interactions do not preclude a general slowing because interactions can still result due to (a) the existence of specific influences, in addition to more general influences, that impact on age, (b) a differential reliance on processes that are related to the underlying, or, general factor, (c) a mathematical influence (e.g., multiplicative or proportional) on the general factor that increases the differences among age groups with increases in the magnitude of the treatment effect, (d) a statistical artifact due to differential power or reliability measures in discriminating among the variables. Therefore, the existence of statistical interactions

should not be taken as evidence of selective age-related effects in a debate concerning the existence of a general slowing.

Convincing support for general age-related slowing comes from finding that the direction and magnitude of age differences in certain speed measures can be predicted from knowledge of age differences in other measures. Systematic relations between age and measures of slowing have been indicated by various findings such as median correlations of .45 between age and slowing (Salthouse, 1985), analyses of age trends from perceptual speed tests in psychometric tests such as the Symbol Digit Substitution Test, Visual Matching, and Cross Out Tests (Kail & Salthouse, 1994), and performance on the Finding A's (Ekstrom, French, Harman, & Dermen, 1976) showing negative correlations with age in both cross-sectional and longitudinal studies (Schaie & Willis, 1993). Furthermore, Schaie (1989) obtained larger age-related declines in longitudinal comparisons than in cross-sectional comparisons. This latter finding is important as it eliminates the possibility that differences are an artifact of different cohort groups.

In addition to the dominant trend of increased slowing in older compared to younger adults is the finding that older persons show marked individual differences. Individual differences in speed of response are greater among the old than the young (Botwinick, 1984, LaRue, 1992). In fact some older people perform faster than some of their younger counterparts. Based on literature concerned with speed and aging, Salthouse reported coefficients between age and speeded behaviours ranged from .15 to .64. This means that only 2 to 41% of the variance associated with speed can be explained by age. Other factors such as education, lifestyle, and physical health make it difficult to disentangle cause and

effect. However, a distinctive feature that emerges from a review of the literature is good, direct evidence of response slowing with age that becomes greatest on the most complex tasks.

To understand this slowing, researchers have begun to focus on Brinley (1965) plots that demonstrate the relation between young and older adults' RTs. Slopes of Brinley plots have been interpreted as showing the degree to which cognitive processes of older persons are slowed relative to younger persons (Ratcliff et al., 2001). In what has been termed a Brinley function, a regularity in the data occurs that approximates a straight line with a slope that ranges between 1 and 2.5 (Cerella, 1991, 1994; Faust, Balota, Spieler, & Ferraro, 1999; Fisher & Glaser, 1996; Maylor & Rabbitt, 1994; Ratcliff et al., 2001; Sliwinski, 1997; Spieler, Balota, & Faust, 1996). Initially, slopes of a Brinley function were taken as supporting evidence for a general slowing hypothesis because RTs for younger persons could be transformed into RTs of older persons by a multiplicative constant: the slope of the Brinley function. Moreover, regression analyses based on Brinley plots have shown that the mean RTs of older adults can be predicted based on knowing the mean RTs of younger adults (Sliwinski, 2001). Such modeling has resulted in RTs that are linear with a negative intercept. Slopes that are linear with negative intercepts imply an old-young relation that is not proportional because a strictly proportional relation would have an intercept of 0. Negative intercepts indicate that the ratio of old to young latencies will increase as the absolute value of the young adults' RTs increase. Based on this finding, many researchers argued that age-related cognitive slowing is determined by the amount rather than the type of complexity. But this mainstream approach to aging has raised

questions concerning the uniformity of slowing across various cognitive processes and tasks.

One question raised by Ratcliff, Spieler, and McKoon (2000) concerns the finding that the slope of Brinley plots may not be a measure of relative slowing between young and older adults, but instead may be a measure of the relative variance in RTs across conditions. Ratcliff et al. suggested that the slope of a Brinley plot is typically 1.5 because the standard deviation of older adults' RTs is typically 1.5 time greater than the RTs of younger persons. The implication of this finding is that theories of aging should be centered around understanding the cognitive substrates that produce the latency distributions. Specifically, an understanding of the underlying mechanisms that produce latency distributions may allow a better understanding of how such mechanisms change with age, and result in a greater spread of distribution, or increased variance.

Another issue raised in the use of Brinley plots is that this analysis involves plotting the speed of young adults against those of older adults typically in the above 60 age range. As such, this is not addressing aging as much as it is addressing "old age". Sliwinski (2001) states that models of aging should account for differences among all age groups, rather than between samples at the opposite ends of the aging continuum.

A recent and prominent theory that has been proposed to explain some of the age differences in performance on many cognitive tasks is the processing speed theory (Salthouse, 1996). The central hypothesis in the theory is that increases in age are related to decreases in the speed with which cognitive operations are executed. A consequence of slowed processing speed is impairments in the quality and quantity of the information

required to perform relevant operations. Substantial reductions in age-related variance after controlling for simple measures of processing speed have been found when a variety of memory measures served as the criterion variable. Using factor analyses procedures, Salthouse (1996) demonstrated that statistical control of a general speed factor substantially reduced the age-related variance for all measures having significant age relations. Salthouse interpreted this finding as an implication that many of the age-related influences in his specific measures were shared with the general speed factor. As a primary purpose of the present research was to determine the age-related differences in speed of information processing, special emphasis will be placed on this ability.

Processing-Speed Theory

Salthouse (1985;1992; 2001) proposed a processing-speed theory to account for observed cognitive differences that are systematically related to age. The theory centers around two major assumptions: (1) performance in many cognitive tasks is limited by general processing constraints which have detrimental consequences for performance scores, and (2) speed of processing is a processing constraint that is heavily influenced by increases in age. The perspective advances the view that the speed with which an individual performs a cognitive activity is a function of the ability to execute the operations involved in the activity, as well as the speed with which the operations are performed. Although other factors can contribute to age-differences in cognitive performance, Salthouse claims that a reduction in speed of processing is a major contributor to age effects.

There are two distinct mechanisms associated with the processing-speed theory:

The limited time mechanism and the simultaneity mechanism. The limited time mechanism is based on the notion that the time available to perform later operations is restricted when a great portion of the available time has been used to perform earlier operations. In effect, if complex operations are dependent on the products of simpler operations, and fewer of those products are available because of slow execution speed, then the most prominent effects of slowness would be evident in the speed and accuracy of the later, or more complex operations. In this way, a mechanism is provided to explain the complexity effect in which a positive relation exists between task complexity and the magnitude of age differences in speed and accuracy of performance (Salthouse, 1985; 2001).

The simultaneity mechanism is based on the notion that the quality or quantity of information is diminished over time due to either decay or displacement. Furthermore, under rapidly changing conditions, information that was once necessary one minute may become obsolete the next, rendering it obsolete or inaccurate for the current task requirements. In effect, when the rate of processing is slow, relevant information is less likely to be useful because it is impoverished (degraded) by the time that later operations are completed. However, the processing-speed perspective centers more on the slower speed of activating and processing information, rather than on the rate of information loss.

An important implication of the simultaneity mechanism is that the capacity of various processing "systems" such as working memory will be affected, and have a deleterious effect on higher-order processes such as elaboration, abstraction, and integration that are critical to successful cognitive performance. In this way, speed alters

the effectiveness of more complex processes of cognitive functioning as an indirect consequence of slowed performance. A reduction in processing efficiency may require older adults to use all of their available capacity for performing a task such that little capacity remains to efficiently process cues that could later assist in retrieval of information (Earles & Kersten, 1998). An age-related decrease in memory would therefore be more apparent for tasks that require more cognitive effort compared to those that are less cognitively demanding. The cognitive effort that is required to perform cognitive activities may tax the processing resources of older adults, thus prohibiting successful encoding of activities. Salthouse's processing-speed theory is also compatible with aspects of controlled versus automatic processing in that complex, or controlled operations are differentially affected compared to automatic, or less complex operations. As such, the processing-speed theory can also explain deficits observed in memory as discussed earlier.

Salthouse (1992) has demonstrated that age-related variance in cognitive performance is markedly reduced when perceptual speed is statistically controlled. Earles and Coon (1994) conducted phone interviews of adults aged 18 to 87 who had participated in a previous study in which they performed a series of cognitive tasks. The participants were called 2 to 182 days later after their participation in the activities, and were asked to describe the activities. Using composite measures, processing speed was found to be associated with 70% of the variance in memory for activities, suggesting that a decline in the efficiency of effortful processing contributes to age differences in memory after a lengthy interval. In a similar vein, Earles (1996) found that age-related variance in

memory for performed and unperformed tasks was reduced by 75% when perceptual speed was controlled. This research suggests that limitations in effortful processing capabilities appear to be important to age differences in memory.

Despite the variety of explanations that have been proposed, there is still controversy over why aging results in reduced speed of processing. One of the early explanations advanced by Birren (1956, 1964, 1970, 1974) suggests that the fundamental loss of speed associated with aging is a reflection of a fundamental change in the nervous system, rather than a mere performance factor associated with cognitive abilities. Birren argues that slowing affects every aspect of the nervous system, and not just the peripheral processes associated with sensory input and motor output. However, this view has not been supported as many psychologists are hesitant to assume that reductions in speed due to aging are linked to brain functions, mainly because this assumption implies that the central nervous system deteriorates with age. Nevertheless, the evidence is strong that the central nervous system is involved in age-related speed loss. The focus is that the loss of functional brain cells associated with increases in age either lowers the strength of neural signals or increases the strength of background noise. This results in an internal signal-to-noise ratio that becomes reduced with increases in age. To compensate for the reduced signal-to-noise ratio, the older nervous system integrates neural information over an extended period of time. This may explain why older adults are slower to process information than younger adults. This theory is general, and may also be used to encompass a reduction in capacity with increasing age. As previously discussed, speed and capacity may be functionally equivalent indices of the same underlying process.

Parallel Distributed Processing Models. Parallel distributed processing models (PDP), are neural network models based on one processing system, and, therefore, stand in stark contrast to stage- processing models. In PDP models, knowledge is represented in weights that reflect the strength of connections, or links, between sets of processing units (Seidenberg & McClelland, 1986). Typically, knowledge is represented by the summed pattern of activation across processing units. Cognitive activity is instantiated by evoking a pattern of activation operationalized as the strength among connection weights across processing units.

The first model developed by Seidenberg and McClelland (1986) is a learning model that uses back propagation to resolve noise within the various layers by using hidden units. These units adjust weights among connections to eventually arrive at a correct output. This model can be applied to age deficits in cognitive processing by viewing the brain as a neural network composed of processing links and nodes.

In addition, because a neural model is a learning model it addresses how various skills are acquired. Moreover, because the model is an implemented form of modelling, it can be damaged to observe any changes in behavioral patterns. If the model were lesioned by damaging connection weights or by eliminating hidden units, performance should indicate a distinct impairment relative to what would be predicted by an intact system. Thus the question arises: are there different patterns of performance that are a direct consequence of damage to various components of the network, rather than distinct processing "stages"?

A neural model could explain the slowing pattern observed in older adults by

assuming an impairment in the computations necessary for deriving output. Because knowledge is represented by how processing weights are distributed at a given time, differences in processing weight may vary over time, and thus, the differences reflect the fluctuations and instability of an aging system. Normal processing would be the result of a relatively stable network and would not be subject to such transient effects. In short, an aging system begins to deteriorate and produces the same patterns of performance that were observed during initial learning due to diffuse damage from weak and slow connections.

Aging in a neural network represents the brain as composed of links and nodes, and processing involves cycling information through the network according to the strengths and weaknesses of connections among nodes within the system. Cognitive processing is represented by the propagation of a signal at the input level to a response at the output level. Reaction time is simply the sum of the time required for the input signal to reach output. As such, latency is provided by the number of links that must be traversed, times the delay per link. The reference model (Cerella & Poon, 1983) defined aging as a destructive process that breaks links at random with a constant probability over time. Due to broken links within the system, a signal must be rerouted, or detoured, along a processing path. Each detour increases the time taken to reach output so that final latencies are increased.

The advantage of connectionism is that such theories can be tested quantitatively by observing how a processing model replicates the human data. It is also noteworthy that computational computer models show the same "graceful degradation" of performance

seen in aging individuals. A reduction in processing speed induced in computational models seldom shows a localized catastrophic loss in one particular type of processing. Instead, what is observed in these models is a diffuse reduction in the efficiency of a broad range of processing, similar to what results in the performance of aging humans. Therefore, analyses of speed manipulations in computational models are consistent with the assumptions of a processing-speed theory. A weakness, however, is that connectionist models do not incorporate a specific process that simulates memory. However, the strength of connections due to past experience could be somewhat memory related, but this aspect addresses remote learning more than it addresses attention, or functional capacity.

If neural representation is the key to understanding the processes responsible for slowing, then automaticity versus controlled processes can be incorporated into Goldberg and Costa's (1981) hypothesis. On this view, the neural system follows a developmental shift, progressing from an initial unilateral (right) representation for learning new material, to a bilateral representation as the task becomes familiar. It should be noted that this bilateral representation does not include information that is redundant. That is, neural representations in each hemisphere operate in synchrony, but the kind of processing is hemisphere-specific. Stimulus attributes and cognitive strategy may interact to determine which hemisphere plays the more dominant role at any given time. This would require attentional shifts as the task requires.

Following Goldberg and Costa's perspective (although not explicitly stated by these authors), processing information in the right hemisphere may not be the only problem in

aging. A left-hemisphere processing deficit may be causal in the failure to establish appropriate engrams (memory traces) necessary for the right hemisphere's task description. Consequently, more discriminant stimulus functions, as needed during elaborate encoding, and feature integration are not possible because the left hemisphere lacks a function mandate. If, as Goldberg and Costa assert, skill equates to hemispheric shifts, then cognitive aging may equate to an inflexible processor. The result is a failure to correctly allocate processing resources.

Because normal performance would depend on the proper operation of a defined neural circuitry, a deficiency in attentional shift may equate to the inability to ignore irrelevant information, or the inability to shift attention as the task requires. Furthermore, if one does not have the resources to focus on stimulus attributes, the integration and selection of specific stimulus aspects needed for further processing would be transient. Also, because processing strategies require attentional shifts, it would be necessary to maintain the selected process while simultaneously processing its correspondent process, called the "descriptive". According to this view, it may be that the aging adult suffers from an impaired "division of labour".

Hemispheric shifts may be the substrate underlying the fine tuning of a process termed skill. Defined in this way, skill makes a distinction between attention and intention. One cannot process with intent when the resources for doing so are transient. Thus, the cognitive problems exhibited by aging adults should, therefore, be explored within the context of attentional deficits, particularly as they relate to levels of callosal arousal.

Summary. Research on cognitive functioning and aging shows an age-related performance decrement in complex tasks requiring an active manipulation of information or a division of attention between concurrent tasks. Working memory, that allows one to hold one piece of information while processing others, has been shown to be less efficient with aging. It has been suggested that a major factor contributing to age differences in working memory and in other controlled processes is a reduction of information processing resources. The magnitude of age differences increases as the processing requirements involved in the task increase.

Salthouse in his (2001) processing-speed theory postulated the existence of both a limited and a simultaneity mechanism to explain the relation between speed and cognition. When processing is slow, processes necessary for cognitive operations may not be completed (limited time), or all relevant information is not available when needed, resulting in impairments in critical operations evident in either higher error rates or repetitions of operations that consume processing time. Empirical results, such as longer latencies for old compared to young adults are evidence of this latter aspect.

To properly assess processing speed, it is important to choose measures that will reflect compromised cognitive functioning. For example, one measure of processing speed should be fairly simple so that most of the variance in performance can be attributed to how quickly one can execute the relevant operations, rather than to variations in the amount of knowledge one must possess to perform the task. When more complex measures are used, such as lexical decision reading speed, it is very difficult to parse out the variance associated with speed from the variance associated with the quality or

quantity of general verbal abilities. Furthermore, construct evaluation should rely on multiple measures to minimize the specific variance associated with one measure and to maximize the construct-related variance. Using multiple measures also serves to increase reliability estimates due to aggregation. Because the present research incorporated a hierarchical design with tasks varied along a continuum of complexity, the design helped to ascertain the differential effects of slowing on automatic and controlled attentional processes due to aging, and to isolate these effects within a continuum of processing (automatic-controlled). In this way, the level of complexity most affected by an age-related decline in information processing deficits was determined.

OVERVIEW OF TESTS AND RATIONALE

The problem of evaluating neuropsychological functioning is likely to be dependent on the adequate selection not only of control subjects and statistical methods, but also of test procedures that tap those specific functional aspects more impaired after concussion or throughout the normal aging cycle. As such, it was theorized that the use of newly developed tests would provide additional information about the speed and efficiency of information processing, and thus, increase neuropsychological test accuracy.

Preliminary research using a normal population indicated that the new reaction time tests showed that response latencies increased as a function of test complexity. Thus, there exists potential for these tests as clinical measures in both assessing and tracking recovery from TBI. The current project was exploratory in that it was the first evaluation of these tests using TBI patients. The employed measures were sensitive to speed of processing, and also allowed for an assessment of several levels of processing complexity

believed to influence patient performance.

In the present study, a range of tasks was used to assess how increases in processing load impact on attention, in particular, speed of information processing. This design allowed a comparison among measurements of speed of information processing, and accuracy of performance for various levels of complexity. Two of the tasks, RT and the A-PASAT enabled a direct assessment of the effects of increasing complexity or load on tasks: a feature that has been shown to be critical in the examination of information processing. As stated earlier, Gronwall and Wrightson (1974) demonstrated the sensitivity of their PASAT to subtle cognitive deficits and persistent post-concussive symptoms after MHI. To reiterate, their traditional version uses the same 60 numbers presented aurally in four consecutive fixed experimental trials, with each trial differing in the rate of digit presentation (pacing). Presentation rates are varied across four different paces using a progressively smaller (2.4s, 2.0s, 1.6s, 1.2s) interstimulus interval (ISI) with each pacing. Their practice trial consists of presenting 10 numbers using the slowest pacing (ISI) prior to the testing session. Their dependent measure is the number of correct responses for each presentation rate, with a maximum score of 60 for each trial. For each pacing, the accuracy rate is computed as the percentage of correct responses for each trial (maximum 60), as is the error rate as a percentage of the total number of responses across all paces (maximum 240). Performance scores may also be computed according to seconds per correct response, and averaged across trials to provide a composite score of correct responses per second. Gronwall & Sampson (1974) reported that these computed scores are highly sensitive to speed of information processing.

Using the traditional version, Stuss et al. (1989) showed that persons having sustained a concussion perform well below average on the PASAT immediately following the injury, but show improved performance within 30 to 60 days (Lezak, 1995). However, while most mildly concussed persons show improved levels of performance on the PASAT within 60 days, there are many who continue to show a marked impairment on this test (Lezak, 1995). Roman et al. (1991) stated that those concussed persons having the most diffuse damage are also those who have the lowest scores on the PASAT. Moreover, King (1997) promoted the PASAT as the measure most likely to provide predictive and clinical utility in PCS assessment. Again, prior research suggests that the PASAT can provide valuable insight into cognitive processing efficiency.

The RT and A-PASAT tasks were selected to assess speed and capacity as measures of information processing. Another aim was to assess the relative effects of increased complexity on reaction time in the control and experimental groups and to compare these results to those obtained on traditional neuropsychological tests. Excluded from this study were persons having a history of head injury or neuropsychiatric disorder, including alcoholism or chronic drug abuse, as well as those having a learning disability. The exclusion of these individuals was to avoid confounding the effects of head-injury with other possible sources of reduced processing efficiency.

Using repeated administrations of a test is a viable method of collecting information about the ongoing status of attentional processes during recovery. Unfortunately, a person given the same test more than once may show improved scores simply by developing better strategies, becoming more at ease in the test situation, or just by becoming more

familiar with the test. Therefore, any improvement in performance does not necessarily indicate an improvement in neurological status. The effects of practice on performance should be interpreted before any meaningful assessment regarding recovery can be provided. This present project was also unique in that participants in Experiments 3 through 5 were tested over repeated sessions, with the between-testing interval manipulated over several delay periods.

PRACTICE EFFECTS

An important clinical application of neuropsychological measures is to assess changes in cognitive function over time. One purpose of retesting individuals is to monitor recovery of function, and to make inferences regarding the course of a disease (Lezak, 1995). Clinical neuropsychological practitioners employed in either research or clinical setting may be required to perform and interpret serial neuropsychological tests. The need to perform successive assessments is necessary to monitor the progression of a disease process (e.g., dementia, multiple sclerosis) or to monitor recovery from an injury (e.g., head injury). Nowhere is this more true than in the field of neuropsychology. There is a growing need in the health and rehabilitation fields to monitor patient recovery through prolonged assessment of performance and behaviour. As such, there is a critical need for information derived from serial testing (test-retest).

Serial testing is increasing within clinical practice because many tests lack equivalent alternative forms (Rawlings & Crewe, 1992). Furthermore, test-retest procedures are the most direct and accurate means of assessing change in an individual's level of function. Unfortunately, without an understanding of how repeated testing affects

test results, a clinician is not able to ascertain the precise magnitude of change observed.

The repeated administration of the same neuropsychological test battery may result in gains in the patient's performance due to practice effects alone. Consequently, an individual's performance may improve due to prior experience with the tests, thereby obscuring actual changes in neuropsychological function. Moreover, improvement due to practice may be especially pronounced on measures of executive function (Basso, Bornstein, & Lang, 1999).

Measures of executive function tend to present examinees with novel problem-solving aspects, and they assess the capacity to generate appropriate solutions within specific time periods. During the course of initial testing, examinees are likely to develop strategies for successful performance, and to refine these strategies with repeated exposure to the test. In addition to improving test scores, responses become more automatic and require less attention and concentration than was previously required during initial testing. Consequently, what is being measured during reassessment of performance may be entirely different from what was assessed during the initial assessment.

Rawlings and Crewe (1992) reported that 97% of all neuropsychological evaluations performed by members of the National Academy of Neuropsychologists employed the Wechsler Intelligence Scale -Revised (WAIS-R). Because intellectual functions are affected by TBI, psychologists typically use the WAIS-R to monitor recovery from the injury despite the knowledge that practice effects on the WAIS-R are well established: scores improve over repeated administrations provided the absence of factors that adversely affect cognitive and motivational status. But, as stated earlier, practice effects

involve a combination of memory for item-specific factors of the test, as well as memory for the procedural aspects of the task (Rapport, Brines, Axelrod, & Theisen, 1997).

Repeated exposure to a procedural task results in improved performance due to the increased familiarity with the task, and the development of a strategy for approaching the task. On tests such as the WAIS-R these two aspects of practice are inextricably confounded. Practice effects involving memory for specific items occur on subtests that have a single solution that is easily remembered (e.g., object assembly). In addition, practice effects for procedural tests occur due to improved strategies and memory for general task demands (e.g., block design).

When a test is used serially, as in a test-retest procedure, information is required concerning changes in performance scores due to practice. Such information is required with both normal and clinical populations. However, in order to determine whether observed changes in performance upon re-assessment are due to recovery or practice effects, a psychologist must also have information concerning the reliability of the test employed. Test reliability refers to the degree to which test scores are free from the effects of measurement error (McCaffrey & Westervelt, 1995). Changes in an individual's score on the same test from one assessment to another may result from measurement error, which reduces the reliability, and thus, the generalizability of performance.

Although the most common tests used in neuropsychological assessment do have data on test-retest reliability, the data provided is not clinically informative. For example, the few studies that have explored the test-retest reliability of the WAIS-R report that reliabilities "are statistically and clinically very robust" (Matarazzo, Camosy, & Jacobs,

1980, p.82). Statements like this imply that the WAIS-R has a high test-retest reliability in both clinical and normal samples using varying test-retest intervals. However, the reliability of the WAIS-R is based on reliability coefficients. This means that a correlation coefficient of .90 represents high test-retest reliability. But this coefficient does not necessarily indicate that group mean performance is highly stable from test to retest. For example, a reliability coefficient of .90 could be obtained if participants systematically increase or decrease their scores on the retest (relative to the initial test) but their relative rank order is preserved. Because all scores may increase or decrease on retest due to within-subject variability, but at the same time the rank order of the scores remains the same, the coefficient can still remain high. This is because test-retest reliability coefficients do not take the impact of practice effects into consideration (McCaffrey & Westervelt, 1995). Therefore, high psychometric reliability, or test stability, is represented by a sizeable test-retest correlation. In contrast, high clinical reliability would be demonstrated by the absence of a meaningful change in performance score.

Rawlings and Crewe (1992) reiterate the early view of Matarazzo and Herman (1984) that the psychometric definition of test reliability is not synonymous with a clinical interpretation of test reliability. Consequently, reliability coefficients do provide useful psychometric information, but they are not adequately informative in evaluating the potential impact of practice effects. The issue of practice effects and the development of statistical procedures for assessing change in clinical scores in neuropsychology is now being addressed. However, despite the increased awareness of controlling for the effects of repeat testing, data are lacking. While it is becoming more apparent that issues

regarding reliability and practice need to be more thoroughly addressed, what is lacking are estimates of practice with longer test-retest intervals (e.g., months vs days or weeks). What is needed are results that allow a more accurate interpretation of test scores, and information that will allow judgements regarding whether an improved score lies within the range of expected variation or represents significant clinical improvement. This is the reason for increasing reliance on methods such as the Reliable Change Index (RCI) advanced by Jacobson (1989) and later operationalized by Jacobson and Traux (1991), or the Reliable Change Index With Practice as suggested by Chelune, Naugle, Luders, Sedlak, and Awad (1993) (see Appendix F for a full review). Another technique involves using alternate, yet equivalent, test forms. However, many tests do not have parallel forms available, and, as Anastasi (1988) points out, gains are still reported at retest, albeit less than with the identical test instrument. Shatz (1981) suggested using the standard error of measurement (SEM) to set up confidence intervals around a patient's score to partial out practice effects from other factors related to improved performance (i.e., recovery of function).

Despite the importance of reliability coefficients in determining how consistently a test instrument measures a construct over repeated sessions, such coefficients do not provide the information required to determine the meaning of individual change over time.

Practice effects on RT tests

There is a small literature base that has examined practice effects on RT tests (see McCaffrey, Duff, & Westervelt, 2000 for a complete compendium). Wilson, Watson, Baddeley, Emslie, and Evans (2000) found no practice effects when individuals without

brain injury were administered a SRT test five days a week over a four-week period.

Feinstein, Brown, and Ron (1994) also observed no practice effects when healthy participants were administered a SRT test over an eight week period. In fact, Feinstein et al. noted a slight increase in latencies over time. However, healthy participants showed improved performance on a CRT test that included both warning and cued conditions. Interestingly, their performance on the PASAT also improved over the eight weeks.

Conflicting results have been reported by Spikman, Timmerman, van Zomeren, & Deelman (1999) who found no improvement for healthy controls on a CRT test when it was administered over four sessions (initial baseline testing, 3, 6, and 12 months later). The task involved depressing a target light while ignoring a non-target stimulus. But, Spikman et al. did find improved performance over four weeks when the task involved a four-choice CRT test in which the target alternated between a visual and auditory stimulus. These researchers also reported improved PASAT performance over the same four-week period. Conflicting results are also evident in McCaffrey, Ortego, Orsillo, Nelles, & Haase (1992) who reported a 200 ms improvement in performance on a SRT test when it was administered twice over a 7-10 day period.

Based on the literature that is available, it appears that RT tasks requiring more complex processing may show practice effects compared to simpler tasks that seem to remain fairly stable over time. The differential effect of practice on simple and complex tasks seems to emerge when there are differences in the level of strategy required to perform the tasks. However, in most SRT and CRT tests, there is very little strategy to construct for successful performance. As such, one of the goals of the present research

was to ascertain the effects of complexity on performance using three RT tests that placed increasing demands on controlled cognitive processes.

Practice effects on the PASAT

Gronwall (1977) suggested that there was a significant practice effect on the PASAT only between the first and second test administrations, with further practice producing only "negligible improvement" (p.369). The PASAT was administered three times at 24-hr intervals, and again at 33-days. The gain in total correct responses was approximately 10% between the first and second test administrations, 3.3% between the second and third, and almost 0% between the third and final tests (33 days). The overall practice effect was 13.3%. However, Stuss, Stethem, and Poirier (1987) obtained practice effects on a one-week retest as high as 18% in their sample of 60 normal adults aged between 16-69 years.

One possible reason for the improved scores is that the first test is not tapping the participants' full potential, suggesting that the first trial is really a practice trial. Based on the stability of performance after the second presentation, Gronwall (1977) reports that practice effects tend to be minimal. However, Gronwall's contention that most of the practice effects for the PASAT occur during the first and second administration has been challenged by researchers such as Feinstein et al. (1994) and Stuss et al. (1989). Feinstein et al. demonstrated that the practice effect may extend over five testing sessions separated by 2 - 4 week intervals. Similar results were obtained by Stuss et al. (1989) who found steady improvements in performance of their controls across four presentations, levelling off at the fifth trial. However, the mean score for the fourth administration was 1 standard

deviation higher than the first with most of the gains occurring between the first and second administration.

Hohol et al. (1997) reported that the PASAT was the most sensitive to practice tests of all the subtests of the Brief Repeatable Battery of Neuropsychological Tests (BRB) which is composed of a Selective Reminding Test, Spatial Recall Task, Symbol Digit, and Word List Generation. Rudick et al. (2001) and Cohen, Fischer, and Bolibrush (2000) also stated that practice effects were most notable on the PASAT. However, they only reported high test-retest correlations and stated that no procedures were implemented to examine the "learning effect". Fischer, Rudick, Cutter, and Reingold (1999) reported practice effects on the PASAT over the first three to four administrations using a 3-second ISI modified for use with MS patients, but did not indicate if all sessions reached significant levels. Schwengelbeck, Ossege, Malin, and Sindern (2002) tested MS patients and a control group over three sessions (baseline, 5 days, and 20 days later). The control group was composed of 10 patients with clinical MS, but without an acute relapse in the six months prior to testing. The PASAT showed progressive improvement over the first sessions for the patient group but not for the controls, suggesting real improvement. However, the control group was only composed of 10 persons while the patient group was composed of 27 persons, which may explain why significance was not reached for this group. Thus, the issue of practice effects on the PASAT extending more than two sessions remains unclear.

One issue that may influence the effects of practice is the increased rate of presentation as the trials progress (Dyche & Johnson, 1991). During the first

administration, particularly on the last and fastest (1.2 s) trial, participants may be very anxious. As such, participants find this test very stressful. Lezak (1995) states "I do not ordinarily use the PASAT. However, I keep it availablewhen subtle attentional deficits need to be [detected]" (p. 373). It would therefore not be surprising if this anxiety caused a decrease in the ability to perform the task. However, during subsequent administrations participants know what to expect and approach the task in a less anxious state. Thus, their performance on the second test administration is better compared to their performance on the first. Consequently, practice effects are an important consideration when using the A-PASAT, as in any serial testing procedure, especially since the issue surrounding performance beyond two sessions is still unresolved. Furthermore, previous results using the traditional PASAT were based on number of errors, which often are not even clearly defined. Given that the A-PASAT uses a threshold of response as the dependent measure, the effects of practice on speed of response is paramount.

The present study also assessed the effects of practice effects by administering the tests at varying intervals. It was expected that most of the practice would occur during the second administration, and thus, scores obtained from the second session would provide an accurate baseline measure of performance. It was predicted that the performance scores obtained using this baseline measure would be devoid of any effects of practice.

A preliminary project addressed practice effects by administering the A-PASAT at baseline and then 20 minutes later. Subsequent experiments administered the A-PASAT, RT tests and neuropsychological tests at various intervals over repeated sessions.

Summary. The field of neuropsychology requires tests that are sensitive to

deficits in cognitive functioning. Based on the lack of sensitivity of standard tests to the effects of MHI, a sensitive test of head injury is needed. Because the organic basis of MHI is undetectable using neuroimaging techniques, it is imperative to infer how well a patient is recovering by measuring change over time on a specific deficit. However, current tests do not control for the effects of practice, and erroneously assume that gains in performance reflect gains in recovery of function. In terms of measurement, tests assessing attentional capacity provide the best index of recovery, as slowness and shallow processing are the hallmark symptoms of head injury. In terms of true changes in performance that are the result of recovery, practice effects should be controlled. Thus, the present research also examined how performance on the new tests of information processing capacity and reaction time were affected by repeated sessions.

GENERAL METHOD

Participants

All participants were recruited from the Ottawa-Carleton community. Prior to assessment, a consent form was reviewed with all participants, and signed by both the researcher and participant. A brief interview was conducted to screen participants for neurological disease, head injury, learning disabilities, psychiatric, and other medical illnesses. All participants had normal or corrected to normal vision and were native English speakers. Specific participant demographics are provided for each experiment.

Tests

Experimental Tests

All experiments (except Experiment 3) employed three Computerized Tests of

Information processing (CTIP): a simple RT test, a choice RT test, and a semantic RT test. In addition, all experiments administered either a visual (A-PVSAT) or an auditory Adjusting-Paced Serial Addition Test (A-PASAT) test (the term A-PSAT will be used when referring to both versions). For the three CTIP tests, ten practice trials were followed by either 30 or 50 experimental trials. For the A-PSAT, 12 practice trials were followed by 200 experimental trials. Following the A-PSAT, a test of addition was administered. To avoid the impact of extreme scores, median scores rather than mean scores were analyzed for the RT tests and the A-PSAT data. All analyses were inspected for any violation of assumptions associated with the procedure used, and all pairwise comparisons employed a Bonferroni adjustment using an overall alpha level of .05

Simple RT. The participants were required to press the space bar on the computer keyboard when a single, capital "X" appeared in the center of the monitor. Participants were told to use their dominant hand and to respond to the "X" as quickly as possible. This test was used to obtain a baseline measure of the participant's reaction time.

Choice RT. The participants were required to press either the "z" (Left) key with their left index finger or the "?" (Right) key with their right index finger in response to a word stimulus (Kite = Right; Duck = Left).

Semantic Search RT. Four categories were used in this task: Weapon, Furniture, Bird, and Fruit. One of the categories was presented and remained on the screen for 3500 ms, followed by a word which may or may not be a category exemplar. Participants were required to press either the Left (Yes) or Right (No) key to indicate whether or not the

stimulus word belonged to the presented category.

Adjusting-PSAT. Nine digits (1 to 9) were presented using a Windows PCM WAV file format recording of a male speaker. Participants were required to add the most recent number to the one previously presented and say the answer out loud. The experimenter entered the participant's response using the computer keyboard. Twelve practice trials were administered. Practice trials began with a single digit followed by second digit 3000 ms later. Experimental trials began with the presentation of a single digit followed by a second digit after a 2400 ms interval. The duration between the presentation of stimuli (ISI) was modified using a titrated/stair-step procedure. Whenever a response was correct, the ISI was decreased by 20 ms. In contrast, whenever a response was incorrect, or missed, the ISI was increased by 20 ms. This procedure provides a performance threshold that is based on a 50% correct response rate. This threshold represented the shortest ISI. In the present research study, a test session ended after 200 trials.

Two versions are available that consist of either complex or simple numbers as the response. In the complex version, the presentation order was the same for all participants with the sum of two consecutive numbers ranging between 2 to 18. In the simple version, the presentation order was the same for all participants and was prearranged so that the sum of two consecutive responses never exceeded 10 (response range is 2 to 10). Restricting the range of the response reduced the differential effect of math ability on test scores. The impact of response range was explored in Experiment 3.

As indicated above, two versions of the A-PSAT are also available that use either a

visual (A-PVSAT) or an auditory (A-PASAT) mode of presentation. In the visual version, numbers are presented on a computer monitor. In the auditory version, numbers are presented by a male speaker through headphones worn by the participant. The impact of modality of presentation was explored in Experiments 3 and 4.

Traditional Neuropsychological Tests of Attention

The Trail-Making Test (TMT) (Reitan & Wolfson, 1985). The TMT is a visuomotor tracking test (Lezak, 1983) which requires a participant to join as rapidly as possible 25 randomly located numbers in numerical sequence (Trails A). Participants are then required to join 25 numbers and 25 letters in an alternate numerical-alphabetical sequence (Trails B). The time required to complete each test, TMT-A and TMT-B, provided the dependent measure. The TMT is frequently included in both geriatric and TBI studies because it requires organized visual search, motor tracking, and the ability to follow single and alternating sequences.

Digit Span (Forward and Back) (Schmidt & Tombaugh, 1995). In Digit Span Forward the experimenter read a series of digits at the rate of one per second. The participant was required to repeat these digits in the exact order (forward) in which they were presented. In Digit Span Backward the experimenter read a series of digits at the rate of one per second, and the participant was required to repeat the digits in the reverse order (backwards) in which they were presented. The dependent measure on both tests was the total score. Digit Span was chosen because it has been shown to remain fairly constant throughout the lifespan with possible slight declines for older adults and cognitively impaired individuals (Baddeley, Wilson, & Watts, 1995). Furthermore, it was important

to use a self-paced attention test to differentiate performance from an externally-paced test such as the A-PSAT.

Symbol Digit Modality Test (SDMT; Smith, 1982). Nine different symbols, each associated with one of the digits 0 through 9, were shown to the participant. With these visually present, the participant was required to quickly write the corresponding number in a box below each symbol for a period of 90 seconds. The dependent measure was total number correct. Symbol Digit was chosen because it also provides a measure of cognitive flexibility. Few normal adults have problems with this aspect of the task, but the test has been shown to be sensitive to age and cognitive difficulties with sequencing and response inhibition often seen in TBI patients (see LaRue, 1992).

Computerized Addition Test (Tombaugh, 1999). The Computerized Addition Test is a test that requires the participant to add two single or double digit numbers that are presented on a computer monitor. The purpose of this test was to ascertain the addition skill of each participant. Speed of response (RT), and number of correct and incorrect responses were recorded.

EXPERIMENT 1

The Effect of Traumatic Brain Injury (TBI) on Information ProcessingIntroduction

Experiment 1 was designed to determine how TBI affects performance on the newly developed RT tests, the A-PSAT, and three neuropsychological tests. It was predicted that the different levels of test complexity would help to identify any differential effects that TBI had on processing speed.

METHOD

Participants

Thirty head-injured persons participated in Experiment 1. The TBI group consisted of participants who were recruited and tested at the Ottawa Hospital-General Campus as part of a study conducted by Drs. Tombaugh, Rees, Marshall, and Smith (personal communication, 2002). The TBI group was further classified into two groups according to their level of severity (mild, severe). Persons suffering from mild TBI were recruited from the emergency department at The Ottawa General by Dr. S Marshall and included those patients having a brief LOC, and were tested within 6 weeks of their injury. Persons suffering from severe TBI were recruited from practicing neurologists and through Dr. Marshall's practice using posted public announcements. The major characteristic of both TBI groups was that they were still suffering from the impact of TBI in their daily life. A healthy control group was matched for age, education, and gender to the TBI participants, and consisted of fifteen healthy participants having no history of neurological disease, head injury, learning disabilities, psychiatric and other medical illnesses. This resulted in three groups: two TBI

groups (Mild, Severe) and a matched healthy control group.

Procedure

All participants signed a consent form prior to testing. The Mild TBI group was tested as part of Dr. Marshall's extensive test battery which included three neuropsychological tests (Trails A, Trails B, Symbol Digit, Digit Span). Dr. T. Tombaugh completed the testing using the three RT tests (simple, choice, semantic) and the Adjusting auditory PASAT (A-PASAT), and also tested the Severe TBI group using the same sequence of neuropsychological tests (Trails A, B, Symbol Digit, Digit Span), followed by the three RT tests, and the A-PASAT.

RESULTS

Mean age, years of education and number of males and females for each group is presented in Table 3. Summary data for all tests according to Group is provided in Table 1 (Appendix A). Pairwise comparisons using a MANOVA confirmed that groups were equated for age, education, and gender.

Table 3

Demographic information for groups by age, years of education, and gender

Group	<u>Age</u>		<u>Years of education</u>		<u>Gender</u>		N
	M	SD	M	SD	M	F	
Mild TBI	30.9	14.9	14.0	1.5	8	3	= 11
Severe TBI	38.6	15.0	14.0	2.0	7	7	= 14
Control	35.6	15.7	15.0	3.0	5	10	= 15
Total	35.0	15.2	14.3	2.2	20	20	= 40

Reaction time tests

A repeated measures analysis of variance (ANOVA) was conducted to determine if there were any overall differences in performance latencies among the three RT tests for the three groups. Median scores, rather than mean scores, were analyzed due to the tendency of reaction time data to be highly skewed. Using median scores avoids the directional “pull” that extreme scores exert on mean scores. All pairwise comparisons employed a Bonferroni correction adjustment using an overall alpha level of .05. Results indicated a significant effect of Test, $F(2,74) = 115.95, p < .001$. This effect indicates that latencies increased as test complexity increased from simple, to choice, to semantic as seen in Figure 1. There was also a significant effect of Group, $F(2,37) = 3.41, p < .05$. Pairwise comparisons revealed longer latencies for the Severe TBI group compared to both Controls (+ 244 ms) and the Mild TBI group (+ 240 ms). Differences between the Mild TBI group and the Control group were minimal (- 4 ms) and did not reach significance. The Group x Test interaction was also significant, $F(4, 74) = 3.04, p < .02$. Pairwise comparisons revealed that the source of this interaction was due to longer latencies on the semantic test for the Severe compared to both the Mild TBI and Control groups. This result indicates the impact that severe TBI has on more complex processing. Performance and error summary scores are shown in Table 1 (Appendix A).

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Insert Figure 1 about here

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Figure 1. Three RT tests for TBI and Control groups.

Within-session performance. To determine if there was any differential within-session practice on the three RT tests across groups, each test was further analyzed by dividing the 30 trials into separate blocks, with a block composed of 10 trials. This resulted in 3 blocks for each test. All block analyses used a repeated measures ANOVA to determine if there were any within-session differences in performance across blocks for the three groups. Block data for each of the three tests is shown separately in Figure 2. Performance and error summary scores are shown in Table 2 (Appendix A).

Simple RT. A repeated measures ANOVA was conducted to determine if there were any within-session differences in performance over blocks for the groups. There were no significant effects or interactions to report.

Choice RT. A repeated measures ANOVA was conducted to determine if there were any within-session differences in performance over blocks for the groups. Again, there were no significant effects or interactions to report.

Semantic RT. A repeated measures ANOVA was conducted to determine if there were any within-session differences in performance over blocks for the groups. Results indicated a main effect of Group, $F(2, 35) = 4.31, p < .02$. Pairwise comparisons revealed significantly longer latencies for the Severe TBI group compared to both the Mild group (+ 407 ms) and Controls (+ 470 ms). The Block effect was not significant. The Block x Group interaction was significant, $F(4, 70) = 3.01, p < .05$. Pairwise comparisons showed that this interaction was the result of significantly longer latencies (+ 178 ms) for the Mild TBI group compared to Controls only on block 1. Of more interest is the longer latencies produced by the Severe TBI group compared to the other two groups on the semantic RT test, which shows the differential effect that severe TBI had on processing- speed when processing became more complex.

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Insert Figure 2 about here
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Figure 2. Within-session latencies for three RT tests for TBI and Control groups.

A-PASAT

Threshold data. The A-PASAT scores were analyzed using a one-way ANOVA on the average medians for the threshold scores among the groups. Because the goal of the present research was to assess *speed* of response, threshold was chosen as the primary measure for analysis. This threshold measure represents the shortest ISI (e.g., shortest time) that occurred for a correct response over the 200 trials. Median scores, rather than mean scores, were analyzed due to the tendency of latency data to be highly skewed. As shown in Figure 3, results indicated a main effect of Group ($F [2, 37] = 5.41, p < .01$) with higher threshold scores occurring for the Severe TBI group compared to the Mild TBI and Control groups (+ 367 ms and + 436 ms, respectively). Performance and error summary scores are shown in Table 1 (Appendix A).

Figure 3. A-PASAT threshold scores for TBI and Control groups.

Within-session performance. To examine within-session performance among the groups, the A-PASAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials. The average of the median ISI for each block was analyzed using a repeated measures ANOVA with Groups as the between factor. Block data for each group is plotted in Figure 4. Results indicated a main effect of Group ($F [2,37] = 8.13, p < .01$) with longer ISIs for the Severe TBI group compared the both the Mild TBI group (+ 529 ms) and the Control group (+ 570 ms). There was also a main effect of Block, $F (7, 259) = 8.54, p < .001$. Pairwise comparisons showed that this Block effect was the result of progressively shorter ISIs (faster decline) among the first four blocks (first 100 trials) compared to the last 4 blocks. However, the Block x Group interaction was also significant, $F (14, 259) = 5.04, p < .001$. Pairwise comparisons revealed that the source of the interaction was due to a gradual increase in ISIs over blocks for the Severe TBI group while both the Mild TBI and the Control groups showed a progressive decrease in ISIs over trial blocks, with a steeper decline over the first 4 compared to the final 4 blocks.

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Insert Figure 4 about here

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Figure 4. A-PASAT block data for TBI and Control groups.

Threshold trial number. Because the threshold provides the measure of fastest speed, it is important to determine at which trial the threshold occurred. For example, if threshold was not achieved until the final trial (trial 200), then it is not a good indicator of a person's threshold. This is because additional trials may have resulted in even faster speed of response and lower thresholds. Therefore, to determine if an appropriate number of trials was administered, the relation between threshold and trial number was explored.

To determine if thresholds occurred earlier within the session as a function of TBI, the trial numbers at which threshold was achieved were analyzed. A univariate ANOVA using Groups as the between factor revealed a main effect of Group, $F(2, 37) = 5.93$, $p < .01$. Pairwise comparisons revealed that the trial at which threshold was achieved was significantly different for the Severe TBI group compared to both the Mild TBI and Control groups (86 vs

152 and 163, respectively). This is not surprising given the earlier finding of increased ISIs for the Severe TBI group as trials progressed. The difference between the other groups was not significant. Threshold trial numbers for all groups occurred prior to the final trial (trial 200) indicating that a sufficient number of trials had been administered to all groups.

Accuracy data. The total number of correct responses were analyzed using a one-way ANOVA among the three groups. There was a significant effect of Group, $F(2, 37) = 8.25$, $p < .01$. Pairwise comparisons revealed this effect was due to a greater number of correct responses for the Control compared to the Severe TBI Group (+ 21), and also a greater number for the Mild compared to the Severe TBI Group (+ 19). These findings show that in addition to slower responses, the Severe TBI group also produced more incorrect responses compared to the other two groups. Given that the A-PASAT procedure increases the ISI by 20 ms whenever a response is incorrect, the accuracy data help to explain the progressive increase in ISIs within the session.

Neuropsychological tests

A univariate ANOVA was conducted on each of the three neuropsychological tests with Groups as the between factor. All scores were converted to percentiles using age appropriate norms provided in the test manuals. Results are shown in Figure 5.

Digit Span. Digit Span showed no significant difference among Groups, despite the trend for a higher recall score for the Mild TBI and Control groups compared to the Severe TBI group.

Trails A and B. On Trails A there was a main effect of Group ($F[2, 37] = 5.20$, $p < .02$) with longer latencies for the Severe TBI group compared to the Mild TBI and Control groups.

Performance for the Mild TBI and Control group was virtually identical.

Trails B showed a main effect of Group, $F(2, 37) = 9.13, p < .01$. Pairwise comparisons revealed that this effect was due to longer latencies for the Severe TBI group compared to the Mild TBI and Control groups. As obtained for Trails A, performance for the Mild TBI and Control group was virtually identical.

Symbol Digit. Symbol Digit showed a main effect of Group, $F(2, 30) = 5.21, p < .02$. This finding was due to lower scores for the Severe TBI group compared to the Mild TBI and Control groups. No significant differences were found between the Mild TBI and Control groups.

Computerized Addition Test. Due to the small number of participants that completed the addition test, this test was not analyzed.

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Insert Figure 5 about here
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Figure 5. Neuropsychological tests for TBI and Control groups.

Correlational analyses. Pearson correlations were conducted to determine the relation among A-PASAT threshold scores and the three neuropsychological tests. Tables 3-5 (Appendix A) provides correlations for each test. Low correlations were obtained between the A-PASAT and the traditional tests of attention for the Mild TBI and Control groups. This finding supports the notion that the A-PASAT measures something different than the traditional neuropsychological tests; namely a processing-speed component that is not captured in most traditional measures of attention. However, moderate correlations were obtained between the A-PASAT with both Digit Span and Trails A and B for the Severe TBI group. Of particular interest is the high correlation between the A-PASAT and Symbol Digit for the Severe TBI group. Since this latter test has been shown to be highly sensitive to severe impairment in TBI patients (Ponsford & Kinsella, 1992), its strong relation with the A-PASAT suggests that both are capturing a processing component that is compromised in severely head-injured individuals.

DISCUSSION

Experiment 1 was primarily designed to determine how TBI impacts on performance on the newly developed RT tests and the A-PASAT. It was hypothesized that TBI would have the greatest impact on tests that required the greatest cognitive effort, and when speed of information processing was central to performance. As predicted, performance on both the semantic RT test and the A-PASAT was most affected by TBI.

The present findings are in agreement with others who found reduced speed of information processing for a severely injured TBI group (e.g., Cicerone, 1997; Godefroy, Lhullier, & Rousseaux, 1996; Ponsford and Kinsella, 1992). The reduction in speed observed on the A-PASAT and the semantic test is indicative of the interaction between information

processing speed and the demands of increased stimulus complexity because slowing is more pronounced as the demands to monitor multiple sources of information increases. This interplay of speed and complexity is exactly what was observed in the present Group x Test interaction as shown by longer latencies on the semantic test for the Severe compared to both the Mild TBI and control groups. This finding coupled with finding that the Severe group also produced higher threshold scores on the A-PASAT shows the impact that TBI has on more complex processing.

The semantic RT test requires processing that is more controlled compared to the simple and choice RT tests which require processing that is more automatic. Based on the distinction between controlled and automatic processes it was expected that the semantic RT test would show the greatest decrement in performance. This expectation was confirmed in the present findings. However, performance on the SRT and CRT was less affected by TBI, with no significant group differences obtained on these tests. This was an unexpected finding as it was predicted that significant group differences would be obtained on tasks having a speed component, particularly for the Severe TBI group. However, performance for the Severe group did indicate a trend toward slower performance for all RT tests that was especially pronounced on the semantic task. In addition, group differences were significant for the A-PASAT which supports the prediction that performance on tasks that involve active processing would show marked slowing, while performance on tasks that involve shallow processing show slight slowing for the TBI group.

The A-PASAT accuracy data showed that in addition to slower responses, more errors were made by the Severe TBI Group compared to the other two groups. However, slowness

and error rates are linked on the A-PASAT due to the titrated procedure that increases the ISI by 20 ms whenever a response is incorrect, and decreases the ISI by 20 ms whenever a response is correct. Thus the accuracy data represent the flipside of the slowed processing that was observed for the Severe group.

The neuropsychological test results showed significantly lower performance for the Severe TBI group compared to the Mild TBI and Control groups on two tests (Trails A and B, and Symbol Digit). In contrast, performance for the Mild TBI and Control group was virtually identical. These findings are in agreement with previous research that has failed to differentiate mild TBI groups from healthy controls using traditional tests of attention. However, finding a significant performance decrement for the Severe TBI group supports the prediction that TBI would be most affected by complex processing involving a speed component. Since Trails B, Symbol Digit and the A-PASAT all require attentional flexibility to successfully alternate between numbers, letters or symbols, and also involve a speed component, this result supports the prediction that task complexity and speed of processing would attenuate performance for severe TBI patients.

EXPERIMENT 2

The Effect of Age on Information- Processing

Introduction

The results from Experiment 1 showed that TBI had a detrimental effect on speed of information processing. Given the general slowing that has been documented in the literature on aging, it was expected that age would also mediate performance, particularly as test complexity and the demand for response speed increased. As in head injury, a reduction in

information processing may require that older adults use all of their available processing capacity for performing a task. Thus, older adults may have little capacity remaining for the simultaneous processing of cues that could later assist performance. This should mean that performance on more cognitively demanding tasks is poorer in older than younger adults. Thus, an increase in the complexity of a task should have a greater detrimental effect on the performance of older compared to younger adults. To this end, Experiment 2 was conducted to obtain performance scores for both the A-PASAT and the RT tests with reference to specific age populations. It was predicted that a general slowing of response times would be evident for the older group on all tests. Moreover, it was expected that this slowing would be most evident on the more difficult tests, such as the semantic RT test and the A-PASAT.

METHOD

Participants

Sixty healthy participants living independently were recruited from the Ottawa area. Participants were asked to volunteer for the study by signing a recruitment form and were later contacted by telephone to arrange a time for testing. All testing was conducted either at Carleton University or at a previously arranged location. All participants had normal or corrected to normal vision and were native English speakers, and were screened for any neurological, mood, or psychiatric disorders. Age groups were formed by equally dividing participants into three groups: Young (18-30), Middle-Aged (35-55), and Older (60-80). This resulted in 20 participants for each age group.

Procedure

The procedure was identical to Experiment 1. The order of tests followed the same

sequence with the three RT tests (simple, choice, semantic) administered, followed by the three neuropsychological tests (Digit Span, Trails A and B, Symbol Digit,) followed by the A-PASAT and the Computerized Addition Test.

RESULTS

Mean age, years of education and number of males and females in each group is presented in Table 4. Summary data for all tests according to Group is provided in Table 1 (Appendix B). Pairwise comparisons using a MANOVA confirmed a group difference for age ($F [2,57] = 252.93, p < .001$), but with groups equated for education.

Table 4

Demographic information for groups by age, years of education, and gender

Group	Range	Age		Years of education		<u>Gender</u>		
		M	SD	M	SD	M	F	N
Young	18-30	20.4	2.47	14.00	1.30	6	14	= 20
Middle	30-55	47.5	9.90	15.00	2.80	7	13	= 20
Older	60-80	69.3	6.20	15.00	2.90	13	7	= 20
Total						26	34	= 60

Reaction time tests

A repeated measures ANOVA was conducted to determine if there were any overall differences in performance latencies among the three RT tests and the three age-groups.

Results indicated a significant effect of Test, $F (2, 114) = 314.86, p < .001$. The Test effect

indicated that latencies increased as test complexity increased from simple, to choice, to complex as seen in Figure 6. The Group effect was significant, $F(2, 57) = 6.74, p < .01$.

Pairwise comparisons indicated that latencies increased as age increased. However, this Group effect is interpreted with reference to the RT tests due to the significant Test x Group interaction, $F(4, 114) = 5.30, p < .01$. Pairwise comparisons revealed that the source of the interaction was due the Older group having longer latencies compared to both the Middle and Young groups that were especially pronounced on the semantic test.

Figure 6. Three RT tests across three age-groups.

Within-session performance. To determine if there was any differential within-session practice effect on the three RT tests across groups, each test was further analyzed by dividing

the 30 trials into separate blocks, with a block composed of 10 trials. This resulted in 3 blocks for each test. All block analyses used a repeated measures ANOVA to determine if there were any within-session differences in performance across blocks for the three groups. Block data for each of the three tests is plotted in Figure 7. Performance and summary scores are shown in Table 2 (Appendix B).

Simple reaction time. There were no significant effects or interactions to report for either the Group or the Block latencies.

Choice reaction time. A repeated measures ANOVA was conducted to determine if there were any within-session differences in performance over blocks for the three groups. Results indicated a main effect of Group, $F(2, 57) = 3.54, p < .05$. Pairwise comparisons revealed significantly longer latencies for the Older group compared to the Young group. The Block effect and the Block x Group interaction were not significant.

Semantic reaction time. A repeated measures ANOVA was conducted to determine if there were any within-session differences in performance over blocks for the three groups. Results indicated a main effect of Group, $F(2, 57) = 6.13, p < .01$. Pairwise comparisons revealed significantly longer latencies for both the Middle and Older groups compared to the Young group. The Block effect and the Block x Group interaction were not significant.

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 Insert Figure 7 about here

Figure 7. Within-session RT latencies for three age-groups.

A-PASAT

Threshold data. The A-PASAT scores were analyzed using a univariate ANOVA on the average medians for the threshold scores among the three age groups (see Figure 8). Results indicated a trend toward higher thresholds as age increased, but these differences did not reach significance. However, throughout the testing process it was noted that the younger participants were less able than older participants to mentally add numbers. This was confirmed by the young group's slower performance on the Computerized Addition Test compared to both the middle and older group's performance. Thus, it was possible that any age effects in speed of processing were "washed out" by the young group's lower ability in addition.

To ascertain that the effects of age was not confounded by addition ability, a separate analyses was conducted on the threshold scores using scores on the Computerized Addition Test as a covariate. Using an analysis of covariance (ANCOVA) any effects of addition were partialled out from the A-PASAT threshold scores. Results now showed a significant effect of Group, $F(2, 42) = 3.82, p < .03$. Pairwise comparisons indicated that the Group effect was indeed due to lower thresholds for the young compared to the older group. Thus, the initial hypothesis of decreased speed with advancing age was supported.

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Insert Figure 8 about here

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Figure 8. A-PASAT threshold scores for three age-groups.

Within-session performance. To examine within-session performance among the three age groups, the A-PASAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials. The average of the median ISI for each block was analyzed using a repeated measures ANOVA with Groups as the between factor. Block data for each group is plotted in Figure 9.

Results indicated a main effect of Block, $F(7, 399) = 31.44, p < .001$. Pairwise comparisons showed that this Block effect was the result of progressively shorter ISIs (faster decline) among the first four blocks (first 100 trials) compared to the last 4 blocks. There were no other significant effects or interactions.

Figure 9. A-PASAT block data for three age-groups.

Threshold trial number. To determine if thresholds occurred earlier within the session as a function of age, the trial numbers at which threshold was achieved were analyzed. A one-way ANOVA using Groups as the between factor revealed no significant effects, which indicated that threshold trial numbers were comparable among the three age-groups. Threshold trial numbers ranged between 119 and 156 indicating that threshold was achieved prior to the final trial, and confirmed that a sufficient number of trials was presented to participants.

Accuracy. The total number of correct responses were analyzed using a one-way ANOVA among the three age-groups. There were no significant effects to report, indicating that accuracy rates were comparable among the three age-groups.

Neuropsychological tests

A univariate ANOVA was conducted on each of the three neuropsychological tests with Groups as the between factor. Results are shown in Figure 10.

Digit Span. Digit Forward showed no significant differences among Groups. In

contrast, Digit Backward showed a main effect of Group, $F(2, 57) = 3.58, p < .05$. Pairwise comparisons revealed that this effect was due to a higher recall score for the Middle and Older groups compared to the Young Group. This result was unexpected, but logical, given the older adults' superior ability in performing mental operations with numbers without a speed component. Furthermore, low variability among groups contributed to this effect.

Trails A and B. On Trails A there was a main effect of Group, $F(2, 57) = 4.93, p < .02$. Pairwise comparisons revealed that this effect was due to lower performance for the Older group compared to the Middle and Young groups.

Trails B also showed a main effect of Group, $F(2, 57) = 5.35, p < .01$. Again, pairwise comparisons revealed that this effect was due to lower performance for the Older group compared to the Middle and Young groups.

Symbol Digit. Symbol Digit showed a main effect of Group, $F(2, 57) = 9.27, p < .001$. Pairwise comparisons revealed that this effect was due to higher scores for the Young group compared to the Middle and Older groups.

Computerized Addition Test. The Addition Test showed a main effect of Group, $F(2, 57) = 43.13, p < .001$. Pairwise comparisons revealed that this effect was due to shorter latencies for the Older and the Middle groups compared to the Young group ($M = 1062$ ms, 1179 ms, vs 1464 ms, respectively). This result is critical, given the earlier suggestion that the young adults' speed on the A-PASAT was confounded by their relative inefficiency in mental addition. This finding supports the conclusion that young adults do not possess the addition skills of the two older groups. As a result, the young adults' speed of performance on the A-PASAT was compromised.

Figure 10. Neuropsychological tests for three age-groups.

Correlational analyses. Pearson correlations were conducted to determine the relation among A-PASAT threshold scores, the addition test, and the three neuropsychological tests. Tables 3-5 (Appendix B) provide correlations for each test. All correlations between the A-PASAT and the neuropsychological test were low to moderate.

DISCUSSION

Experiment 2 was primarily designed to determine how age affects performance on the newly developed RT tests and the A-PASAT. Because the present study recruited participants of various ages, and employed tests with varying degrees of complexity, it was possible to determine if there were any performance differences based on test complexity. It was hypothesized that age would have the greatest impact on tests that demand a high level of concentration, particularly when speed of information processing was a factor in performance. As predicted, performance on both the semantic RT test and the A-PASAT was most affected by age.

The semantic test requires that the participant quickly conceptualizes incoming information in order to simultaneously integrate it with other incoming information. This requires processing that is more controlled than automatic, and is precisely the type of processing that was predicted to show an age-related decrement. Performance on the SRT and CRT was less affected by age, which showed that performance on tasks that involve more passive processing show slight age decrements, but performance on tasks that involve active processing show marked age decrements.

No detrimental effects of age were found when digit span was administered. This finding is in agreement with the general finding that declines associated with aging are

relatively subtle on tasks in which a string of items is presented to a person who must then repeat them in the same order (Craik, Anderson, & Kerr, 1995; La Rue, 1992). Thus, as the task advances from passive reproduction to active reorganization, age effects emerge.

Evidence indicates that normal aging is more often associated with inefficiencies in conceptual processing because it requires more substantial cognitive resources and self-initiated processes than required with perceptual processing. As such, older adults may be viewed as having an impairment in initiating a deep level of elaboration because such depth requires more attentional resources. Consistent with many other cognitive aging studies, the young adults showed a processing advantage relative to the older adults in the rate of information processing on the newly developed tests.

The initial failure to find age differences on the A-PASAT should alert researchers to the sensitivity of certain tests to a participant's prior knowledge. The older group showed better performance compared to the younger group, but this discrepancy was shown to be the result of the older adults' superior addition skill. Because the A-PASAT evaluates skills and knowledge that may have been acquired early, and reinforced throughout one's life, this particular skill is so well-learned and practiced by the older adults that the A-PASAT was rendered insensitive to subtle age-decrements. However, when age groups were equated for performance on the addition test, leaving only processing speed as the variable of interest, age differences emerged with higher thresholds and longer ISIs for the older compared to the young group.

The results obtained for the older age group parallel those found in Experiment 1 using a severe TBI group. This finding is critical to a perspective that suggests reductions in speed of processing and attentional capacity are the best indicators of cognitive status. Thus, future

attempts to isolate the aspects of attention most affected in clinical samples might profit from specifying information processing components such as processing speed, and processing complexity when complexity is defined by the stimulus, self versus externally paced response, and automatic versus controlled processing demands.

EXPERIMENT 3

The Effect of Practice and Response Range on Two Versions of the A-PSAT

Introduction

Experiments 1 and 2 showed that TBI and age affect speed of information processing. However, in order to track performance over time a test is typically administered more than once. Performance on a second test may show either a decrement or an improvement in performance depending on whether a person is recovering from, or progressing into a disease. However, as stated earlier, the effects of practice must be delineated from performance scores in order to obtain a true picture of an individual's cognitive status. Therefore, Experiment 3 was a preliminary project designed to determine the effect of practice on the A-PSAT when it was administered twice within a 20 minute interval. Although practice effects are well recognized, data about practice effects involving PSAT performance are limited. Thus, the effect of two consecutive A-PSAT administrations was initially explored in Experiment 3.

Experiment 3 was also conducted to determine if differential effects of practice occurred between modalities (visual, auditory). Originally, Sampson (1958) presented digits visually using the PSAT. The auditory presentation was not used until Gronwall and Sampson (1974) developed their audiocassette version for use with TBI patients. Recently, Bateman (1997) and others (e.g., Diamond, Deluca, Heakyung, & Kelley, 1997; Hiscock, Caroselli, & Kimball,

1998) revised the PASAT for visual presentation on a computer screen. All of these authors reported differential performance between the two PSAT versions with superior performance on the visual compared to the auditory presentation. Thus, modality of presentation has been shown to be related to PSAT performance, and therefore, is an important factor to explore using the newly developed computerized version (A-PSAT). If performance depends primarily on the ability to rapidly process information, then A-PSAT results should be similar for both the visual and auditory modalities. If, however, a participant's verbal response interferes with the reception or retention of an aural stimulus more than a visual stimulus, then the cognitive demands may be different for the two modalities. If so, the auditory version may be assessing an interference factor in addition to speed of information processing.

Another factor that may impact on A-PSAT performance is number complexity. There may be a differential contribution of problem difficulty, or complexity, based on the use of simple (sums equal to or less than 10) compared to complex (sums greater than 10) number lists. Research on mental arithmetic has shown that problems having sums greater than 10 take longer to solve than do problems having sums equal to or less than 10 (Johnson, Roethig-Johnston, & Middleton, 1998). To examine this issue, both complex and simple number lists were used for both modalities to determine any effects of response range. In the context of the present experiment, if sums greater than 10 require more processing than sums equal to or less than 10, then this should be evidenced by increased latencies for the complex number list. This combination of modality and list resulted in a 2 (Modality: Visual, Auditory) x 2 (Number list: Simple, Complex) factorial ANOVA with repeated measures (Session 1, Session 2).

It was predicted that threshold scores would be higher in the auditory compared to the

visual version. It was also expected that thresholds would be higher for the complex compared to the simple number list. Finally, it was predicted that performance would improve over the two sessions, with lower thresholds and higher accuracy scores occurring in the second session.

METHOD

Participants

Sixty undergraduate students participated in the present experiment¹. Participants were randomly chosen from a pool of Psychology undergraduate students at Carleton University, who received course credit for their participation.

Procedure

Four groups were formed to compare the effects of presentation modality (visual, auditory) and number list (simple, complex). Half of the participants (N= 30) received the visual version of the A-PSAT and the other half (N=30) received the auditory version. Within each of these groups, half received the simple number list and the other half received the complex number list (see outline below for group design). Each participant was administered the A-PSAT twice, with a 20 minute interval between each test session. During the 20 minute interval between sessions, participants were administered three traditional neuropsychological tests in the following order: Digit Span, Trails A, B, and Symbol Digit.

¹ Data obtained from Royen, J. (2001), unpublished research, Carleton University.

Diagram 1. Experimental design for Experiment 3.

Number List	Modality		
	Visual		Auditory
	Simple	Simple-Visual	Simple-Auditory
	Complex	Complex-Visual	Complex-Auditory

RESULTS

Mean age, years of education and number of males and females for each group is presented in Table 5. Pairwise comparisons using a multivariate analysis of variance (MANOVA) confirmed that groups were equated for age and education.

Table 5

Demographic information for A-PSAT groups by age, years of education, and gender

A-PSAT group	<u>Age</u>		<u>Years of education</u>		<u>Gender</u>		
	M	SD	M	SD	F	M	N
Auditory-Simple	23.6	4.7	13.6	1.2	8	7	= 15
Auditory-Complex	23.0	5.0	13.7	1.5	10	5	= 15
Visual- Simple	24.5	6.6	14.1	1.7	6	9	= 15
Visual-Complex	27.1	7.8	13.6	.91	6	9	= 15
Total	24.6	6.2	13.6	1.3	30	30	= 60

Threshold data. The A-PSAT scores were analyzed using a repeated measures (ANOVA) on the average of the median threshold scores for modality (visual, auditory) and number list (simple, complex) over the 2 sessions.

As seen in Figure 11, there was a main effect of Modality with lower thresholds occurring within the visual modality compared to the auditory modality on both Session 1 (Visual 1058 ms vs Auditory 1543 ms) and Session 2 (Visual 757 ms vs Auditory 1228 ms), $F(1, 56) = 34.15, p < .001$. In addition, there was a main effect of Session such that thresholds were significantly lower in the second compared to the first session for both modalities, $F(1, 56) = 265.80, p < .001$. These results indicate a significant practice effect. The main effect of number list (simple, complex) was not significant, and there were no significant interactions.

Reliability estimates were also obtained for the A-PSAT over the two sessions ($r = .94, p < .001$). This large correlation coefficient reflects the high test-retest reliability of the A-PSAT, but given the observed practice effects associated with this test, the obtained reliability measure clearly shows the difference in stability of test versus stability of performance. This finding was similar across modality.

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 Insert Figure 11 about here

Figure 11. Threshold scores for two A-PSAT groups over two sessions.

There are two potential sources of practice effects: One is the result of practice occurring over repeated sessions; the second is the result of practice within a session. As described above, practice effects between sessions were shown by shorter ISIs on the second session. Within-session practice effects are typically shown by improved performance toward the end, compared to the beginning, of a test session. Such a determination requires that a fixed ISI is used which allows the participant's response speed to reflect the effects of practice. However, it is difficult to directly demonstrate within-session practice effects with the A-PSAT because it uses a titrated procedure to "push" the participant to respond at a progressively faster pace. In this situation, threshold scores would be expected to progressively decline within a session. However, these scores cannot be taken as evidence for a practice effect as they can when compared between sessions. Consequently, within-session effects on the A-PSAT were used to provide an overview of the distribution of scores in the

same way as they were used in Experiments 1 and 2. In addition, changes in the distribution of performance between sessions were used to further examine practice effects.

Within-session performance. To examine the practice effects, ISI values within each session were divided into separate blocks. Because each test administration consisted of 200 trials, a block was composed of 25 trials. This resulted in 8 blocks for each session. The average of the median ISI for each block was analyzed across the two sessions. Performance on the visual and auditory modalities are plotted separately, but each is collapsed across number list due to the failure of this variable to differentially affect performance. All analyses used a repeated measures ANOVA. Block data for each modality is plotted in Figure 12. Overall performance and error summary scores are shown in Table 1 (Appendix C).

Visual. Results indicated a main effect of Session ($F [1, 38] = 141.85, p < .001$) with shorter ISIs occurring in the second compared to the first session. There was also a main effect of Block, $F (7, 266) = 293.43, p < .001$. Pairwise comparisons indicated that the Block effect was due to shorter ISIs throughout the 8 blocks, with the greatest difference occurring among the first four blocks (first 100 trials) compared to the last 4 blocks (last 100 trials). The Session x Block interaction was also significant, $F (7, 266) = 18.72, p < .001$. Pairwise comparisons revealed that the source of this interaction was due to a practice effect that produced a faster decline on blocks 1 through 4 (trials 25 to 100) on session 2 compared to session 1.

Auditory. Results indicated a main effect of Session ($F [1,38] = 238.86, p < .001$) with shorter ISIs occurring in the second compared to the first session. There was a main effect of Block, $F (7, 266) = 124.72, p < .001$. Pairwise comparisons indicated that the Block

effect was due was due to shorter ISIs throughout the 8 blocks with a greater difference occurring among the first four blocks (first 100 trials) compared to the last 4 blocks (last 100 trials). The Session x Block interaction was significant, $F(7, 266) = 16.73, p < .001$. Pairwise comparisons revealed that the source of this interaction was again due to a practice effect that produced a faster decline on blocks 1 through 4 (trials 25 to 100) on session 2 compared to session 1.

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 Insert Figure 12 about here

Threshold trial number. It was also of interest to determine if thresholds would occur earlier within the A-PSAT on repeated testing. This could be observed by comparing the trial numbers at which the threshold was achieved over the two sessions. A repeated measures ANOVA revealed no significant effects of Session, Modality, or Number list on the threshold trial which ranged between 158 and 180. Therefore, the trial at which threshold was achieved was prior to the last trial (trial 200), confirming that a sufficient number of trials had been administered.

Figure 12. Block data for the visual and auditory A-PSAT over two sessions with a 20-minute delay interval.

If a participant is showing an effect of practice on the second session, then one would expect that the trial number at which threshold was achieved would occur earlier in the second session. Given that thresholds were lower and ISIs were shorter in the second compared to the first session, it was important to determine why threshold trial numbers did not occur earlier in the second session. As discussed earlier, the A-PSAT was designed to measure threshold scores, such that a correct response resulted in a 20 ms decrease in speed of presentation, while an incorrect response resulted in a 20 ms increase. This titration procedure can result in two consecutive trials that consist of either two correct responses, two consecutive incorrect responses, an incorrect response followed by a correct response, or a correct response followed by an incorrect response. As a participant becomes more efficient, the likelihood of two consecutive correct responses may increase. Because two consecutive correct responses result in a faster presentation rate, the participant can become more efficient and approach threshold at a faster rate. Increased efficiency is evident in Figure 12, which shows a steeper decline in ISIs among the first four blocks on session 2, but similar to session 1, ISIs reach asymptote in block 5. This would explain why threshold scores were lower in the second session, but the trial number at which it occurred remained consistent. To test this, a repeated measures ANOVA was conducted on the number of times a correct trial was followed by an incorrect trial for sessions 1 and 2. Results confirmed a main effect of Session ($F [1, 59] = 106.52, p < .001$) indicating that more incorrect responses followed a correct response on session 1 compared to session 2 ($M = 83$ vs 69).

Accuracy data. The accuracy scores were analyzed using a repeated measures ANOVA on the average of the median scores for number of correct responses on threshold scores for

modality (visual, auditory) and number list (simple, complex) over the 2 sessions. Figure 13 shows the main effect of Modality which indicated that the total number of correct responses was significantly greater in the visual modality compared to the auditory modality, $F(1, 56) = 29.73, p < .001$. A main effect of Session indicated that the total number of correct responses was significantly greater in session 2 compared to session 1, $F(1, 56) = 186.71, p < .001$. There were no other significant main effects or interactions. Again, results were equivalent for simple and complex numbers between sessions.

Figure 13. Total number correct responses for A-PSAT groups over two sessions.

DISCUSSION

There were three major objectives in this preliminary study: First, to determine the effects of practice on two computerized versions of the A-PSAT; second, to determine the effects of presenting stimuli in the visual and auditory modalities, and third, to determine the effects of

using a simple or complex number list.

The results showed significant practice effects on performance for both the visual and auditory modalities of the A-PSAT. This finding suggests that one administration of this test may not provide an adequate measure of baseline performance against which performance on subsequent administrations can be compared. Although the improvement in performance for both modalities was equivalent over the two testing sessions, ISIs were consistently shorter in the visual compared to the auditory modality.

Gronwall and Sampson (1974) suggested that individuals process information along a single channel having limited resources. If the A-PSAT provides an index of the speed at which information is processed along a single channel, then both visual and auditory versions should yield similar performance. However, the present results are in stark contrast to this prediction. The differential performance between the visual and auditory versions was robust, reaching significance for both the threshold and accuracy data. One explanation for the superior performance on the visual A-PSAT is that participants were more accustomed to performing calculations with digits that were presented visually rather than aurally. In fact, from the time we are first taught basic mathematical operations, the stimuli are visually presented. Support for this explanation is provided by Hiscock, Caroselli, and Kimball (1998) who reported more correct responses for visually presented Arabic numerals compared to number words. Hiscock et al. concluded that performance is enhanced in the visual modality due to familiarity with this format. Following this line of reasoning, it may be that participants' A-PSAT performance is better in the visual, rather than the auditory modality, because of familiarity with visually presented digits.

Another possible explanation for the superior visual performance on the A-PSAT is that an interference effect occurs for the auditory version as a result of processing multiple sources of information along a single channel. For example, Bateman (2000) has argued that it is much harder to articulate a number while listening for the next number than it is to articulate a number while watching for another. The auditory version requires a vocal response (output) while simultaneously processing a vocal stimulus (input). Overlap between the input-output occurring within the same modality is a plausible source of interference, requiring more cognitive effort to sustain “freedom from distraction”. As a result of the increased effort and susceptibility to distraction, latencies are attenuated in the auditory compared to the visual version of the A-PSAT. Based on this finding it is likely that the auditory version of the A-PSAT is also capturing a distraction factor that is not present in the visual version.

Simple and complex responses were also examined as they relate to A-PSAT performance. Findings indicated that there were no significant differences in performance as a result of the two number lists: Results were virtually equivalent for the easy compared to the complex number list. Although this result seems counterintuitive, given that sums greater than 10 are more difficult to process, it may be an artifact of the complex number list. Any significant performance differences between complex and simple number lists was confounded by the inclusion of simple sums in the complex number list. Including simple sums within the complex number list may have averaged out performance to resemble performance on the simple number list (Royen, 2001).

Due to the significant practice effect obtained in Experiment 3, it was of interest to determine whether significant practice effects would also occur on subsequent administrations

of this test. Some researchers propose that practice effects are minimal and short-lived while others claim they are robust and long lasting. For example, Gronwall (1977) claims that practice effects on the PASAT are limited to only the first and second administration. Stuss et al. (1987) support Gronwall's results by reporting significant improvement between the first and second sessions. However, Stuss et al. failed to extend their observations over two testing administrations. In contrast, Feinstein (1994) examined the effects of practice on the PASAT beyond two administrations and reported significant improvement in performance over eight testing sessions. But Feinstein's results are also fraught with interpretative problems. He reported PASAT performance based on number of errors, but the nature of errors was not clearly defined. Thus, despite the literature on practice effects, the issue surrounding PASAT performance over several testing intervals remains unresolved. This is an important issue to address, particularly as it relates to the newly developed A-PSAT.

EXPERIMENT 4 (a)

The Effect of Multiple Sessions on Practice

Introduction

Experiment 3 showed a significant improvement in A-PSAT performance over 2 sessions. However, it was unknown whether the effects of practice obtained in Experiment 3 were due to the effects of recency or strategy. That is, the practice effects that were obtained may have been the result of the short interval (20 mins) between test sessions, or due to participants having developed a strategic approach during the first session that enhanced their performance on the second session. Therefore, one research issue is to examine how subsequent testing sessions would impact on performance. To this end, Experiment 4 (a)

incorporated a multiple testing format which involved four testing sessions, and extended the delay interval between sessions from 20 minutes to one week. It was expected that any obtained practice effects would be most pronounced between the first and second administration, and that the impact of the increase in delay would be minimal. Thus, the prediction supports a strategy effect rather than a recency effect. This prediction was based on the logic that participants developed strategies during session 1 that could withstand time intervals exceeding 20 minutes. For this reason, it was expected that the effect of strategy would be more powerful than the effect of time.

There is also a need for a direct comparison of prolonged practice effects among the A-PSAT, reaction time tests and standard neuropsychological tests. Seldom have these tests been investigated together over several intervals. Experiment 4 (a) also incorporated the three measures of reaction time into the test battery to assess the simple, choice, and semantic RT tests over time. It was expected that the more complex effects associated with the A-PSAT and the semantic RT test would result in practice effects, but the simpler RT tests would not. In addition, three standard neuropsychological tests of attention were included in each of the four sessions. In short, Experiment 4 (a) represents a broad assessment of the impact of practice on performance on various test measures using four weekly intervals.

METHOD

Participants

Twenty undergraduate students (age 18-22) were tested 4 times at weekly intervals. Participants were randomly chosen from a pool of Psychology students at Carleton University and received course credit for their participation. All participants had normal or corrected to

normal vision and were native English speakers.

Procedure

Two groups were formed to compare the effects of presentation modality (visual, auditory) over repeated administrations. Half of the participants ($N=10$) received the visual version of the A-PSAT, and the other half ($N=10$) received the auditory version. Because no differential effects of number list (simple, complex) were observed in Experiment 3, all 20 participants received the simple number list. However, for this experiment the RT tests consisted of 50 trials rather than the 30 trials used in the three prior experiments. This was implemented to observe if an increase in the number of trials would have any differential effect on performance.

All 20 participants were administered three computerized RT tests (Simple, Choice, Semantic), followed by the three neuropsychological tests (Digits Span, Trails A and B, and Symbol Digit), followed by either the visual or the auditory version of the A-PSAT. The final test was the Computerized Addition Test. Participants were tested over 4 weeks with each session occurring approximately 1 week apart. The four sessions for each participant were conducted at approximately the same time of day.

RESULTS

Mean age, years of education and number of males and females for each group is presented in Table 6. Pairwise comparisons using a MANOVA confirmed that groups were equated for age and education.

Table 6

Demographic information for A-PSAT groups by age, years of education, and gender

A-PSAT group	<u>Age</u>		<u>Years of education</u>		<u>Gender</u>		
	M	SD	M	SD	F	M	N
Auditory	21	1.7	14	1.1	6	3	= 9
Visual	23	7.8	14	1.4	5	4	= 9
Total	22	4.7	14	1.2	11	7	= 18

Reaction time tests

A repeated measures ANOVA was used to determine if there were any overall differences among the three RT tests across the four testing sessions. The average median latencies for each of the three tests from the four testing sessions is shown in Figure 14.

The main effect of Test was significant ($F [2,54] = 144.03, p < .001$) with latencies increasing as the processing load increased from Simple ($M = 277$ ms), to Choice ($M = 486$ ms), to Semantic ($M = 638$ ms). This result supports the initial hypothesis that increased cognitive loads would result in increased RT, depending on the amount of information required to process. The main effect of Sessions was not significant. However, the Session x Test interaction was significant, $F (6, 162) = 2.90, p < .01$. Simple pairwise comparisons revealed that this interaction was due to significant increased latency scores on both the Simple and Choice RT tests over the four sessions, while the Semantic test resulted in decreased latencies, particularly between session 1 and session 2 ($M = 660$ ms and 636 ms, respectively).

Figure 14. Three RT tests over four sessions collapsed across groups.

Within-session performance. To determine if there were any within-session practice effects on each of the three RT tests, each test was further analyzed by dividing trials into 5 separate 10-trial blocks. The average median for each block was analyzed over the four sessions. All analyses used a repeated measures ANOVA with a "block" described as the group of 10 trial medians. Block data for each of the three tests are plotted in Figure 15.

Performance and summary scores are shown in Table 1 (Appendix D).

Simple RT. On the Simple RT test there was a significant main effect of Session ($F_{[3,54]} = 12.67, p < .001$) such that latencies tended to progressively increase from session 1 through session 4: Session 1 (261 ms), Session 2 (273 ms), Session 3 (284 ms), Session 4 (291 ms). These results indicate a reverse practice effect. There was also a significant effect of Block such that within session latencies tended to vary over the 5 blocks, $F(4, 72) = 8.90, p < .001$. However, simple comparisons revealed that this effect was due to a minimal difference

between blocks 3 and 4, with block 4 showing a 15 ms increase in latency relative to block 4. Over the first 3 blocks there was very little within session change ($M = 276$ ms, $M = 278$ ms, $M = 272$ ms, respectively). The Block x Session interaction was not significant.

Choice RT. On the Choice RT test there was a significant main effect of Session ($F [3, 54] = 5.81, p < .002$) with a progressive increase in latencies from session 1 through session 4: Session 1 (456 ms), Session 2 (479 ms), Session 3 (493 ms), Session 4 (515 ms). These results also indicate a reverse practice effect. The Block effect was also significant, $F (4, 72) = 6.09, p < .001$. Simple comparisons revealed that this effect was due to a difference between blocks 4 and 5, with block 5 showing a 26 ms increase in latency relative to block 4. However, further investigation again revealed very little within session variability over the first 3 blocks ($M = 470$ ms, $M = 499$ ms, $M = 488$ ms, respectively). The Block x Session interaction was not significant.

Semantic RT. On the Semantic RT the Session effect was not significant. Moreover, the trend on this test was in the opposite direction to that of the other two RT tests. This trend indicates that participants' performance improved over the 4 sessions, particularly between session 1 (660 ms) and session 2 (636 ms), but exploratory simple comparisons revealed that this difference was not significant. The Block effect and the Block x Session were not significant.

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 Insert Figure 15 about here

Figure 15. Within-session latencies over four sessions for RT tests.

A-PSAT

Threshold data. The A-PSAT scores were analyzed using a repeated measures ANOVA on the average of the median threshold scores for modality (visual, auditory) from each of the four sessions. As seen in Figure 16, the Modality effect was significant ($F [1, 16] = 6.68, p < .05$), and indicated that the visual version ($M = 890$ ms) resulted in better performance compared to the auditory version ($M = 1179$ ms). There was also a significant Session effect with threshold scores progressively decreasing from the first through the fourth day on both visual and auditory test versions, Session: $F (3, 48) = 53.20, p < .001$. Multiple comparisons revealed significant decreases in thresholds for each session, with the greatest decrease occurring between sessions 1 and 2 for both the visual (224 ms) and the auditory (256 ms) modalities. This finding is in contrast to the RT tests, as threshold scores on the A-PSAT showed a significant practice effect. The Modality x Session interaction was not significant.

Reliability estimates were also obtained over the four sessions and ranged from .95 to .74. Again, this result indicates that a distinction should be made between test stability and performance stability.

Figure 16. Threshold scores for two A-PSAT groups over four sessions.

Within-session performance. To examine the practice effects, performance on the A-PSAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials. The average of the median ISI for each block was analyzed across testing sessions. All analyses used a repeated measures ANOVA. Block data for each version (visual, auditory) were analyzed separately and plotted in Figures 17 and 18.

Visual. Results indicated a main effect of Session ($F [3, 24] = 25.39, p < .001$) with ISIs progressively decreasing over the four sessions. There was a main effect of Block, $F (7, 56) = 139.29, p < .001$. Pairwise comparisons indicated that the Block effect was due to shorter ISIs in the last four blocks (last 100 trials) compared to the first four blocks (first 100 trials). The Session x Block interaction was also significant, $F (21, 168) = 5.10, p < .001$. Pairwise comparisons revealed that the source of this interaction was due to a faster decline on blocks 1 through 4 (trials 25 to 100) on sessions 2 through 4 compared to baseline. This progressive effect illustrates the effect of practice on performance.

Auditory. Results indicated a main effect of Session ($F [3, 24] = 27.17, p < .001$) with ISIs progressively decreasing over the four sessions. There was a main effect of Block, $F (7, 56) = 45.44, p < .001$. Pairwise comparisons indicated that the Block effect was due to shorter ISIs in the last four blocks (last 100 trials) compared to the first four blocks (first 100 trials). The Session x Block interaction was significant, $F (21, 168) = 4.03, p < .001$. Pairwise comparisons revealed that the source of this interaction was due to a faster decline on blocks 1 through 4 (trials 25 to 100) on sessions 2 through 4 compared to baseline, which replicates the visual data reported above and illustrates the effect of practice on performance.

Figure 17. Visual A-PSAT within-session performance.

Figure 18. Auditory A-PSAT within-session performance.

Threshold trial number. To determine if thresholds occurred earlier within a session due to repeated testing, the trial numbers at which threshold was achieved over the four sessions were analyzed. A repeated measures ANOVA revealed no significant effects of Session, Modality, or their interaction. Trial numbers ranged between 153 and 167. Again, the trial at which threshold was achieved was prior to the last trial (trial 200) thereby confirming that a sufficient number of trials had been administered.

Accuracy data. The total number of correct responses were analyzed using a repeated measures ANOVA across modality (visual, auditory) from each of the four sessions. Figure 19 shows the number of correct responses over the four sessions. The main effect of Modality was significant ($F [1, 16] = 5.73, p < .03$) indicating that participants produced more correct responses when numbers were presented visually ($M = 134$) compared to aurally ($M = 127$). The main effect of Session was significant indicating that participants had more total correct responses as number of sessions increased, $F (3, 48) = 23.55, p < .001$. This pattern of response was the same across both modalities as confirmed by the absence of a significant Session x Modality interaction.

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Insert Figure 19 about here
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Figure 19. Total number correct responses for two A-PSAT groups over four sessions.

Neuropsychological tests. A repeated measures ANOVA was performed on each of the three neuropsychological tests over the four sessions. As shown in Figure 20, each of the neuropsychological tests show a progressive practice effect such that performance tends to improve over each of the four testing sessions. However, inspection of these data indicate that the greatest gains in performance occurred between session 1 and 2 for most tests.

Digit Span. Digit Span Forward resulted in a lack of significant effects over the four testing sessions. Digit Backward showed a main effect of Session ($F(3, 54) = 7.62, p < .001$)

with a greater mean increase in total score on session 4 compared to sessions 1 and 2. There were no other significant effects.

Trails A and B. Trails A showed a main effect of Session, $F(3, 54) = 6.39, p < .001$. Pairwise comparisons revealed a progressive increase in latencies over each of the four sessions with the greatest increase between sessions 1 and 2.

Trails B showed a main effect of Session, $F(3, 54) = 14.98, p < .001$. Pairwise comparisons revealed a progressive increase in latencies over each of the four sessions with the greatest increase between sessions 1 and 2.

Symbol Digit. Symbol Digit also revealed a significant increase in the number of correct responses over the four sessions, $F(3, 54) = 34.53, p < .001$. Pairwise comparisons revealed a significant and progressive increase in number correct responses over each of the four sessions.

Computerized Addition Test. The Addition Test showed no significant effects over the four sessions for either the latency or the accuracy data.

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Insert Figure 20 about here
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Figure 20. Neuropsychological tests over four weekly sessions.

Correlational analyses. Pearson correlations were conducted to determine the relation among A-PSAT threshold scores, the addition test, and the three neuropsychological tests. Tables 2-5 (Appendix D) provides correlations for each test. Separate correlations were performed for each of the four weekly sessions to determine if the relations changed over each session. Of particular interest is the virtual absence of any significant relations between the neuropsychological tests of attention with the A-PSAT threshold scores. This finding supports the notion that the A-PSAT measures something different than the traditional neuropsychological tests; namely a processing-speed component that is not captured in most traditional measures of attention.

Summary. Performance is shown in Table 7 for the total score on each session to show practice /fatigue effects among the four sessions. Values representing five 10-trial blocks collapsed over the four testing sessions are also presented. Table 7 also shows that latencies for the simple and choice RT tests increase over the four testing sessions, indicating a boredom/fatigue effect as performance becomes poorer over the four testing sessions. In contrast, latencies for the semantic RT test decrease over the four testing sessions indicating a minimal practice effect with improved performance over each session. Although this practice effect is most pronounced between session 1 and session 2, the effect did not reach significance. All other tests show a progressive practice effect over the four sessions with the two A-PSAT tests showing the most pronounced effects between sessions 1 and 2.

Table 7
Summary Data for Practice Effects: Experiment 4(a) and 4(b)

TEST	SESSION				
	1	2	3	4	Delay
<i>CTIP Score (ms)</i>					
Simple reaction time	261	273	283	290	286
Choice reaction time	456	479	493	515	472
Semantic reaction time	660	636	630	625	606
<i>Adjusting PSAT Threshold (ms)</i>					
Visual	1168	944	762	684	746
Auditory	1453	1197	1064	1002	1123
<i>Neuropsychological Tests (# correct)</i>					
Digit Span Forward	7.7	8.6	9	9.2	8.8
Digit Span Backward	7.1	7.4	8.3	8.9	8.1
Trails A	22.5	19.6	18.5	16.4	16.5
Trails B	49.7	40.6	39.6	33.3	36.2
Symbol Digit	59.7	64.6	71.5	77.4	67.1
<i>Computerized Addition Test</i>	1341	1367	1368	1431	1308
10 Trial Block					
	1	2	3	4	5
<i>CTIP Score (ms)</i>					
Simple reaction time	276	278	272	285	284
Choice reaction time	470	498	489	479	505
Semantic reaction time	654	645	652	637	638

DISCUSSION

The purpose of this experiment was to determine how weekly testing would impact on performance on three reaction time tests, on the A-PSAT, and on three neuropsychological tests over four test sessions. Based on the data obtained, the most significant change in performance occurs on the A-PSAT, with most of the improvement occurring between the first and second session. While these data do indicate a practice effect between the first two sessions, this effect seems to asymptote quickly in subsequent retests. By session 3, scores are fairly consistent with little significant change occurring in later sessions. This finding indicates that the large practice effect that occurs between sessions 1 and 2 does not warrant using session 1 as a stable baseline condition.

Because there was no significant improvement in performance over weekly sessions for the three RT tests, performance on these tests is judged to be relatively resistant to practice. The two simpler reaction time tests are in marked contrast to the A-PSAT in that a boredom, or fatigue effect occurs, as demonstrated by the increases in scores on subsequent testing sessions for the simple and choice RT tests. The lack of significant improvement over the four sessions may be due to the fact that these tests are relatively easy, and therefore do not require that the participants develop complex strategies to improve their performance. This suggestion is credible given that the more complex semantic RT test does result in improved performance. Given the absence of practice effects on the simple and choice tests, it appears that the first session for each test provides a good baseline measure of information processing. Consequently, when a person returns for future testing a significant decrease in latency scores indicates that a significant change

in performance has occurred that is independent of practice effects. Also, as hypothesized, the three tests (simple, choice, complex) remain differentiated throughout the four test sessions according to their level of complexity. Response times are significantly different among the three tests, and show a consistent effect of complexity regardless of the testing session. Throughout the four sessions, participants' response times increase as the level of processing increases.

EXPERIMENT 4(b)

The Effect of an Extended (six- month) Delay Interval

Introduction

The one week delay in Experiment 4(a) is not typical of most retest situations because most retesting occurs at intervals that are longer than one week. In a typical clinical setting, clients are retested within three to six months, or longer, depending on the situation. For this reason, Experiment 4(b) was designed to assess the impact of a longer delay (six months) on performance. Furthermore, it was of primary interest to determine if performance would revert to the initial level of performance obtained in session 1, or if multiple test exposure would sustain performance levels over time. This was particularly important for the A-PSAT because participants' performance on this test was most affected by repeated administrations.

Given that the impact of practice was greatest between session 1 and 2, with subsequent testing sessions showing minimal gains in performance, it was predicted that returning participants would perform at a level similar to that shown on session 4, with no further gains. This prediction was based on the observation that lower anxiety levels and

development of test strategy contributed to most of the performance gains in session 2.

Therefore, it was postulated that participants' familiarity and test strategy would sustain performance level over time.

METHOD

Participants

Participants from Experiment 4(a) were telephoned approximately six months following their last session and asked to return for a follow-up test. Thirteen undergraduate students agreed to participate in the present experiment, for which they received course credit.

Procedure

The procedure was identical to Experiment 4(a) except that participants were only tested once. The order of tests followed the same sequence with the three RT tests (simple, choice, semantic) administered first, followed by the three neuropsychological tests (Digit Span, Trails A and B, Symbol Digit), followed by the A-PSAT (auditory or visual) and the addition test. Participants were tested using the same version of the A-PSAT they received in Experiment 4(a). This resulted in 7 participants in Group (Visual) and 6 participants in Group (Auditory).

RESULTS

Reaction time tests

A univariate ANOVA was used to determine if there were any overall differences in latency scores among the three RT tests in the six-month delay condition. The Test effect was significant, $F(2, 36) = 112.19, p < .001$. Pairwise comparisons indicated that all three means were significantly different among the Simple (286 ms), Choice (472 ms), and

Semantic(606 ms) RT tests. It was expected that these latency differences would emerge, thereby reflecting the preservation of differences in test complexity over time without being compromised by practice.

The average median latencies for 13 participants on each of the three tests over five testing sessions are shown in Figure 21. These data were re-analyzed using a repeated measures ANOVA. The main effect of Test was significant, $F(2, 36) = 115.34, p < .001$. As before, latencies increased as the processing load increased from Simple (280 ms) to Choice (487 ms) to Semantic (637 ms). The main effect of Session and the Session x Test interaction were not significant.

Figure 21. Three RT tests over four sessions and a 6-month delay.

Because the primary purpose of this latter session was to determine how a prolonged delay would impact on performance, a repeated measures ANOVA was next conducted between the final session from Experiment 4(a) (session 4) and the six-month delay condition to determine if any residual effects of practice would remain over an extended period of time. Results indicated a significant effect of Test ($F [2,36] = 91.79, p < .001$), again showing that latencies increased as test complexity increased. The Session effect was also significant indicating that latencies decreased in the six-month delay condition compared to session 4 for all three RT tests ($F [1,36] = 5.39, p < .03$) as confirmed by pairwise comparisons. The Test x Session effect was not significant.

Within-session performance. To determine if there were any within-session effects on the three RT tests, each was further analyzed by dividing trials into separate blocks. As in Experiment 4 (a), this division resulted in 5 blocks for each test. The average of the median latencies for each block was used and analyzed across the two testing sessions. All analyses used a repeated measures ANOVA with "Block" as the between factor. Performance and summary scores are shown in Table 1 (Appendix D).

Simple RT. Performance was analyzed between session 4 and the six-month delay session. A repeated measures ANOVA was used to assess performance within and between sessions using 5 blocks, each composed of 10 trials. There were no significant main effects of Session, Block, or interactions to report.

Choice RT. Performance was analyzed between session 4 and six-month delay session. A repeated measures ANOVA was used to assess performance within and between sessions using 5 blocks, each composed of 10 trials. There was a main effect of Session ($F [1, 12] = 6.37, p < .05$) indicating that latencies decreased on the six-month

delay session relative to session 4, as shown in Table 2. The Block effect was not significant and there were no other significant effects or interactions.

Semantic RT. Performance was analyzed between session 4 and the six-month delay session. A repeated measures ANOVA was used to assess performance within and between sessions using 5 blocks, each composed of 10 trials. The Block effect was not significant and there were no other significant effects or interactions.

A-PSAT

Threshold data. The A-PSAT scores were analyzed using a repeated measures ANOVA on the average medians for threshold scores between modality (visual, auditory) across the final session from Experiment 4(a) (session 4) and the six-month delay condition. As shown in Figure 22, results indicated a main effect of Modality ($F [1, 11] = 6.35, p < .03$) and Session, $F (1, 11) = 6.70, p < .03$. Inspection of the main effects revealed higher threshold scores were produced in the six-month delay session compared to session 4, and shorter threshold scores were produced as a result of the visual compared to the auditory A-PSAT presentation. The Session x Modality interaction was not significant and indicates that results were similar across sessions for both visual and auditory presentations. There were no other significant effects or interactions. The obtained reliability estimate between session 4 and the six-month delay session ($r = .95$) shows that the high reliability of the A-PSAT is sustained over a longer period of time.

In contrast to the RT data, the A-PSAT scores are slightly increased in the six-month delay session relative to the fourth session. A post hoc analysis was conducted to compare means between the delay session and the four weekly sessions. It was of interest to ascertain at what level the participants were performing relative to the four weekly

sessions. Pairwise comparisons showed that performance on the six-month delay session ($M = 912$) had not significantly changed from session 3 ($M = 913$), but remained significantly different from session 1 only. Finding that participants' performance at six months was still showing the benefits gained during session 1 indicates the powerful effects of practice that were developed during this initial testing session. This finding was similar across modalities.

Figure 22. A-PSAT threshold scores over four sessions and a 6-month delay

Within-session performance. To examine the within-session effects on the six-month delay session relative to session 4, performance on the A-PSAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials (see Figures 23 and 24). The average of the median ISI values for each block was analyzed using a repeated measures ANOVA with a "Block" defined as median scores for

25 trials. Block data for each version (visual, auditory) were analyzed separately.

Threshold performance and summary scores are shown in Table 1 (Appendix D).

Visual. For the visual version, results indicated a main effect of Block, $F(7, 42) = 100.91, p < .001$. Pairwise comparisons revealed that the Block effect was primarily due to a sharper decrease in ISIs over the first four blocks compared to the last four blocks. Performance remained fairly consistent throughout blocks 5 to 8. The Block x Session interaction was not significant. No further effects were obtained in the six-month delay session.

Figure 23. Visual A-PSAT within-session performance: Session 4 and a 6-month delay.

Figure 24. Auditory A-PSAT within-session performance: Session 4 and a 6-month delay.

Auditory. For the auditory version, results indicated a main effect of Block, $F(7, 35) = 20.41, p < .001$. Pairwise comparisons again revealed that the Block effect was primarily due to a sharper decrease in ISIs over the first four blocks compared to the last four blocks. Performance remained fairly consistent throughout blocks 4 to 8. The Block x Session interaction was not significant. No further effects were obtained in the six-month delay session.

Threshold trial number. To determine if thresholds occurred earlier within the six-month delay session compared to session 4, the trial numbers at which threshold was achieved over these two sessions were analyzed. A repeated measures ANOVA revealed no significant effects of Session, Modality, or their interaction. Trial numbers ranged between 140-153. Again, the trial at which threshold was achieved was prior to the last

trial (trial 200) thereby confirming that a sufficient number of trials had been administered.

Accuracy data. The total number of correct responses was analyzed using a repeated measures ANOVA for session 4 and the six-month delay session between modalities (visual, auditory). Although there were no significant effects to report, there was a marginal effect of Modality ($F [1,11] = 4.57, p = .056$) indicating the superior accuracy of response on the visual compared to the auditory version.

Neuropsychological tests. A repeated measures ANOVA was performed on each of the three neuropsychological tests between session 4 and the six-month delay session. Results for all 4 sessions and the six-month delay are shown in Figure 25.

Digit Span. Digit Forward resulted in a lack of significant effects. Digit Backward resulted in a main effect of Session ($F [1, 12] = 5.80, p < .05$) with a mean increase (+1) in the total score in the six-month delay compared to session 4.

Trails A and B. Both Trails A and B resulted in a lack of significant effects.

Symbol Digit. Symbol Digit revealed a significant Session effect with a mean score decrease in the six-month delay compared to session 4, $F (1,12) = 12.54, p < .01$.

Computerized Addition Test. The Addition Test did not result in any significant effects or interactions on either the latency or the accuracy data.

Correlational analysis. Pearson correlations were conducted to determine the relation among A-PSAT threshold scores, addition, and the three neuropsychological tests at testing six-months later. Table 6 (Appendix D) provides correlations for each test. Again, there were no significant relations between the neuropsychological tests of attention with the A-PSAT threshold scores.

Figure 25. Neuropsychological tests over four weekly sessions and a 6-month delay.

DISCUSSION

While the latencies for the simple and choice RT tests tended to increase across four weekly test sessions, it is noteworthy that latencies decreased (e.g., performance improved) in the six-month delay (5th) session. This finding makes sense given that the increased latencies among sessions 1 through 4 were probably due to boredom with the test. Given that six months had elapsed since participants were last tested, it is not surprising that they approached the test with some renewed interest, clearly evident in the decreased variability in test scores at six months (see Appendix D).

In contrast to the RT data, the A-PSAT data showed the opposite trend with poorer performance between session 4 and the six-month delay. When one considers the relative difference in complexity between these two tests, this result is not unexpected. If boredom accompanies a relatively simple test, then it makes sense that alertness and strategy facilitate performance on a difficult test. Therefore, the effect of time is probably different for a simple versus a complex test, especially when the test is administered repeatedly over a one-month interval. Following a six-month delay, however, boredom on simple tests has been replaced by renewed interest, while practice and strategy effects on complex tests have partially deteriorated.

It was important to find that although significant, ISIs and threshold scores increased only slightly between session 4 and the six-month delay session, and remained practically unchanged. It was also important to find that performance at six months continues to show the benefits gained during session 1. These findings support the initial hypothesis that the greatest gain in performance would occur during the first two sessions, and that the effects of experience obtained in session 1 would be maintained in subsequent

sessions.

The consistently superior performance obtained from participants receiving the visual compared to the auditory version of the A-PSAT in Experiments 4 (a) and (b) has replicated the few, previous findings reported in the literature (e.g., Diamond et al., 1997; Hiscock et al., 1998). The lack of a modality interaction also indicates parallel effects for the auditory and visual versions of the A-PSAT.

Although the three RT tests showed some changes in performance over sessions, there was very little change in performance within the five blocks for any of the tests. For this reason Experiment 5 will only use three blocks of ten trials. This decision was based on the fact that a reduction in the time required to administer a test is beneficial to both the participant and the researcher. The resulting 30 trials provide sufficient data to determine performance, while providing a more economical and clinically feasible testing time. In addition, Experiment 5 employed only the auditory version of the A-PSAT because this is the more conventional version. Moreover, because the auditory version is experienced by participants as more difficult than the visual version, and requires more cognitive effort, it was chosen as a better indicator of cognitive speed and capacity.

EXPERIMENT 5

The Effect of Standard Testing and Dual Baselines

Introduction

The results for Experiments 3 and 4 have important implications for using the A-PSAT in any clinical situation that requires the repeated administration of a test to determine the degree to which a person has recovered from TBI or to evaluate the clinical

efficacy of some type of therapeutic intervention (e.g., drug trials). In situations such as these, the score on the second administration is compared to that obtained when the test was originally given. This first test is referred to as the baseline condition. The person's clinical status is generally considered to have improved when the second test score is greater than the baseline score. However, such a conclusion contains the implicit assumption that a favorable change in scores is not due to other factors. In the present context, the "other factor" is practice. Given the results of Experiments 3 and 4, if the A-PSAT had been administered twice to a TBI patient, a substantial increase in performance would be expected on the second administration solely on the basis of practice. Any interpretation of the person's clinical status would have to take this pronounced practice effect into consideration. Thus, it is obvious that the failure to take into consideration practice effects with the A-PSAT would result in the false impression that the person's cognitive condition had improved.

There are several reasons why the practice effects are so pronounced with the A-PSAT but not with the RT tests. One obvious reason is that the A-PSAT is a much more difficult and complex test. Due to the complexity of the A-PSAT, participants need to develop some type of strategy for performing on this test. It is likely that a person requires time and practice to develop the most effective way to handle this type of test. Consequently, effective strategies are probably not fully developed until after the initial, baseline administration has been completed. Although improved test scores on the second administration may be due to recall of items used in the testing task, it is unlikely that the specific test elements of the A-PSAT are remembered (e.g., such as words on a memory

task). Rather, a more plausible explanation is that procedural knowledge of the test demands and strategies for effective performance are retained, thereby enhancing subsequent performance.

A second factor contributing to improved scores is the heightened emotional state that the A-PSAT induces. During the initial baseline performance, participants typically experience anxiety and frustration. However, the novelty of the test is diminished with repeated exposure, thereby reducing anxiety effects associated with the testing process. As a result, participants are more comfortable and better able to concentrate during repeated testing.

Regardless of the specific reasons that underlie practice effects, the critical issue is how to take practice effects into consideration when evaluating a person's clinical status. In experimental situations the obvious solution is to use a control group that receives the same number of test administrations and then "factor out" the effects of practice from the overall treatment effects. However, this is not a viable alternative in the clinical environment where the progress of individual patients is tracked. One solution to eliminate practice effects is the use of alternate test forms. This approach is typically used in memory tests where learning the specific material (e.g., a list of 15 words) at baseline facilitates performance on the second administration. Improvements in performance due to the retention of specific information at baseline can be overcome by using an alternate test form on the second administration that contains different material (e.g., a different list of 15 words). However, using an alternate form (e.g., a different list of numbers) is not applicable with the A-PSAT because it is highly unlikely that improved performance is

due to the person remembering the specific number list used in the baseline administration. Consequently, some other type of procedure for controlling practice effects must be used, such as employing a baseline measure that already contains the effects of practice.

This approach accepts the fact that repeated administrations of the A-PSAT produce practice effects. This approach also acknowledges that interpretive problems arise when retest scores that contain practice effects are compared to baseline scores that do not contain practice effects, and that such interpretative problems would be greatly reduced if the retest scores were compared to baseline scores that already reflect the effects of practice. This type of baseline measure provides a more adequate standard of comparison because most, if not all, of the effects due to practice have already occurred. As such, subsequent administrations of the test would not be expected to show additional practice effects. A simple example illustrates this approach. The scores on 4 administrations of the A-PSAT are as follows: 1550, 1200, 1140, 1100. In this example, the score on the first administration is not an adequate baseline against which to compare any of the other scores. However, the score on the second administration does provide a relatively stable baseline, because it is not appreciably different from the scores on either the third or fourth administration (i.e., 1140 and 1100). Using the second administration (1200) as a baseline score is appropriate because most of the effects of practice have already occurred, and subsequent administrations of the A-PSAT would not be expected to produce any substantial improvement in performance. Thus, if session 2 (score of 1200) had been used as the baseline score with a clinical patient, any substantial changes on the

third and fourth administrations of the A-PSAT could then be adequately attributed to true improvement in the person's cognitive status. As such, the term "dual baseline" is typically used to describe this type of procedure in which more than one baseline is administered prior to "treatment".

Although the results from previous experiments suggest that the second assessment represents a relatively stable measure of performance, the length of the interval between the first and second testing sessions may also be important. The importance of when the second session occurs addresses the concern that a dual baseline procedure will be accepted in a clinical environment if it is practical and convenient. In most cases, this means that the second administration should occur during the patient's initial visit and does not require a second appointment a short time later (e.g., 1 day or 1 week). Thus, the timing of the second administration is critical.

In view of the above, the primary question in Experiment 5 concerned the appropriateness of using a 20-minute, test-retest procedure within the same testing session to obtain a baseline measure, and to evaluate the stability of this baseline over a three month period. Consequently, two groups were tested three times. The difference between the groups was the duration of time between the first and second administration. Group (20 mins) was tested 20 minutes after the initial administration and then at three months. Group (1-week) was tested one week after the initial administration and then again at three months. If the two groups having the 20-minute and one-week delay interval continued to improve at testing three months later, then the second assessment is not a stable measure. However, if both groups showed the same benefit in performance at three months, then the

second assessment is a stable measure and provides an accurate index of performance.

The performance of these two groups was also compared against a third group (Group 3 mths) was tested three months after the initial administration, which represented the procedure used in a typical clinical testing situation where individuals are tested once, and then required to return some three to six months later for subsequent testing.

The design of Experiment 5 also permitted examining how the length of the interval between the first and second assessment affects performance on the A-PSAT on the second assessment. Some investigators report changes in performance on measures of attention and new learning across relatively short time intervals such as 1-2 weeks (e.g., McCaffrey, Ortega, Orsillio, Nelles, & Haase, 1992). Others report changes in performance on measures of executive function that remain over a 12-month interval (e.g., Basso, Bornstein, & Lang, 1999). Hence, the degree to which practice differentially influences performance over short and long intervals remains uncertain. By comparing only the scores from the second test session, the effects of three different delay intervals (20 minutes, one week and three months) can be determined. If all groups showed similar performance on session 2, then performance benefits gained during session 1 remain stable up to a three-month interval.

In summary, Experiment 5 was designed to determine how obtaining dual assessments (compared to a single baseline measure) could facilitate interpreting scores obtained three months later. In addition, the interval between testing was manipulated by using either a 20- minute, a one-week, or a three month interval between session 1 and 2. Diagram 2 illustrates the design used for groups.

Diagram 2. Experimental design for Experiment 5.

GROUP	SESSION		
	1	2	3
Group 20 mins	Session 1	20 minutes later	3 months later
Group 1 week	Session 1	1 week later	3 months later
Group 3 months	Session 1	3 months later	N/A

METHOD

Participants

Thirty-eight undergraduate students (ages 18-22) were randomly chosen from a pool of Psychology students at Carleton University. All participants had normal or corrected to normal vision and were native English speakers.

Procedure

Participants were randomly assigned to one of three groups. Group (20 mins) and Group (3 mths) were composed of 13 participants and Group (1 week) was composed of 12 participants due to the failure of one person to return for testing. Group (20 mins) was tested twice using a 20- minute interval between testing sessions, and then tested once three months later. Group (1 week) was tested once during the initial session, again one week later, and a third time three months later. Group (3 months) was tested once during the initial session, and again three months later. All groups were administered the three RT tests (simple, choice, semantic), followed by the three neuropsychological tests (Digit Span, Trails A and B, Symbol Digit), and the auditory A-PSAT. The order of testing for each session was identical to the three previous studies, with the exception that Group (20- mins) was administered the entire test battery twice during the first session.

RESULTS

Mean age, years of education, and number of males and females for each group is presented in Table 8. Pairwise comparisons using a MANOVA confirmed that groups were equated for age and education.

Table 8

Demographic information for groups by age, years of education, and gender

Group	<u>Age</u>		<u>Years of education</u>		<u>Gender</u>		
	M	SD	M	SD	F	M	N
20 mins	19.7	1.5	13	.27	9	4	= 13
1 week	19.5	1.1	13	.50	9	4	= 12
3 months	20.5	2.0	13	.49	5	8	= 13
Total	19.9	1.5	13	.42	23	16	= 38

Equating Groups. To ensure that any obtained effects were not due to random error in group selection, a univariate ANOVA was conducted on RT latencies at session 1 using Groups as the between factor. Results indicated that there were no differences among groups. Levene's test of homogeneity also confirmed that variance was equal across the three groups. However, close inspection revealed that Group (1 week) tended to be slower (not significantly) than the other two groups on all RT tests (see Summary data in Table 1, Appendix E). Therefore, it was expected that Group (1 week) may continue to produce longer RT latencies, relative to the other two groups, if performance remained consistent among groups.

Experimental Questions

There were three major issues addressed in Experiment 5. As such, all subsequent analyses were structured around three questions as follows:

- 1). Does session 2 provide an acceptable baseline measure?
- 2). Does the duration between session 1 and 2 affect performance on session 2?
- 3). How does an intervening session affect performance?

Question 1. Does session 2 provide an acceptable baseline measure?Reaction time tests

To determine if session 2 provides an acceptable baseline, a repeated measures ANOVA was conducted on the average of the median latencies between Group (20 minutes) and Group (1 week) over all three sessions (see Figure 26). Results confirmed a significant effect of Test ($F [2, 69] = 189.76, p < .001$) and a significant effect of Group, $F (1, 69) = 8.18, p < .05$. The Session x Test effect was significant ($F [4, 138] = 3.03, p < .02$). The Session effect and the Group x Session interaction were not significant, and there were no other significant effects or interactions.

Pairwise comparisons using a Bonferroni correction adjustment again reveals the Test effect was due to increased latencies as test complexity increased from simple, to choice, to semantic. The Session x Test interaction was due to longer latencies for the SRT and CRT over sessions, but shorter latencies for the Semantic RT test, particularly between session 1 and session 2. This indicates the absence of practice effects for the two simpler RT tests, and improved scores for the more complex semantic test. Further inspection of the Group effect indicated that Group (1 week) produced overall longer latencies compared to Group

(20 mins) that were especially pronounced in Session 3. Moreover, inspection of these data shows longer latencies for Group (1 week) throughout all three sessions. In addition to the absence of a statistically significant Group x Session interaction, further inspection also indicates differences that are not clinically meaningful.

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Insert Figure 26 about here
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Within-session performance. To determine if there was any within-session practice effects on the three RT tests, each was further analyzed by dividing the 30 trials into three 10-trial blocks. The average median for each block was analyzed for the two groups over three sessions, with a "Block" described as the group of 10 trial medians for each test. Block data for each of the three tests is plotted in Figure 27. Performance and summary scores are shown in Tables 2- 4 (Appendix E).

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Insert Figure 27 about here
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Figure 26. Group (20 mins) and Group (1 week) over three RT testing sessions.

Simple RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance latencies between Group (20 mins) and Group (3 mths) over all three testing sessions. There was a main effect of Group ($F [1, 23] = 4.01, p < .025$) with longer latencies occurring for Group (1 week) compared to Group (20 mins) over all three sessions. The Session effect and the Session x Group interaction were not significant, which indicated that performance was not moderated by session or by the length of the interval between testing. The Block effect was not significant.

Choice RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance latencies between Group (20 mins) and Group (1 week) over all three testing sessions. There was a main effect of Group ($F [1, 23] = 4.60, p < .05$) with longer latencies occurring for Group (1 week) compared to Group (20 mins) over all three sessions. The Session effect and the Session x Group interaction were not significant, which again indicated that performance was not moderated by session or by the length of the interval between testing. The Block effect was not significant.

Semantic RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance latencies between Group (20 mins) and Group (1 week) over all three testing sessions. There was a main effect of Block, $F (2, 92) = 11.15, p < .001$. Pairwise comparisons showed that this Block effect was due to longer latencies in block 1 compared to blocks 2 and 3. There were no other main effects or interactions, which again indicated that performance was not moderated by the length of interval between testing.

Figure 27. Within-session latencies for Group (20 mins) and Group (1 week) over three sessions

A-PASAT

Threshold data. The A-PASAT scores were analyzed using a repeated measures ANOVA on the average median threshold scores for Group (20 mins) and Group (1 week) over the three sessions (Figure 28). Results showed a main effect of Session, $F(2, 46) = 28.93$, $p < .001$. The Group effect and the Group x Session interaction were not significant. Pairwise comparisons showed that the Session effect was due to practice effects between sessions 1 and 2. In contrast, performance on sessions 2 and 3 was similar. These findings confirm that the second session provides a good baseline measure of performance, and also confirm that the intervening session had the same impact on performance at three months, regardless of whether the intervening session occurred 20 minutes or 1 week following the initial testing in session 1.

Figure 28. A-PASAT threshold scores for Group (20 mins) and Group (1 week) over three sessions.

Within-session performance. To examine the within-session performance of the two groups over three sessions, the A-PASAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials. The average of the median ISI for each block was analyzed using a repeated measures ANOVA with Groups as the between factor. Performance and summary scores for each group are shown in Table 1 (Appendix E). Results showed a main effect of Session, $F(2, 40) = 37.04, p < .001$. Pairwise comparisons showed a significant difference between session 1 and 2 only. There was also a main effect of Block, $F(7, 140) = 41.82, p < .001$. Pairwise comparisons showed that this effect was due to a steeper decline over the first four blocks compared to the final four blocks. The Session by Block effect was significant, $F(14, 280) = 7.29, p < .001$. Pairwise comparisons showed that this was due to shorter ISIs over all blocks in sessions 2 and 3 compared to session 1. Figure 29 shows that practice effects occurred during session 1 to benefit performance on both sessions 2 and 3 equivalently. In fact, inspection of Figure 29 clearly shows the similar performance on sessions 2 and 3, as well as the same initial decrease in ISIs over the first 4 blocks that is not evident in session 1. This shows that in addition to shorter ISIs, Sessions 2 and 3 showed the same increase in efficient processing compared to session 1. The Group effect was not significant, which confirmed that the length of the delay interval did not affect subsequent performance. There were no other significant effects or interactions.

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Insert Figure 29 about here

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Figure 29. Comparison of A-PASAT block data over three sessions collapsed over Group (20 mins) and Group (1 week).

Threshold trial number. To determine if thresholds occurred earlier within a session, the trial numbers at which threshold was achieved for the groups over three sessions were analyzed. A repeated measures ANOVA revealed no significant effects of Session, Group, or their interaction. Trial numbers ranged between 129-156. The trial at which threshold was achieved was prior to the last trial (trial 200), thereby confirming that a sufficient number of trials had been administered.

Accuracy data. The total number of correct responses was analyzed using a repeated measures ANOVA for Group (20 mins) and Group (1 week) over all 3 sessions. Results showed a significant effect of Session ($F [2,46] = 19.60, p < .001$) due to a mean increase of 8 correct responses between sessions 1 and 2. Sessions 2 and 3 produced identical accuracy rates ($M = 122$). The Group effect and the Session x Group interaction were not significant. This finding replicates the threshold data and shows that an intervening session had no effect on accuracy of performance when participants were tested three months later.

Neuropsychological tests

A repeated measures ANOVA was conducted on each of the three neuropsychological tests for Group (20 mins) and Group (1 week) for the three sessions. Summary data are shown in Table 1 (Appendix E). Results for each test are shown in Figure 30. The individual plots are collapsed across groups due to their equivalent performance in each session.

Digit Span. On both Digit Forward and Backward, the Group and Session effect were not significant and there were no significant interactions, indicating equivalent performance among groups over the three sessions.

Trails A and B. Trails A showed a significant effect of Session ($F [2, 46] = 25.17, p < .001$) with decreased latencies (-7 sec) in session 2 compared to session 1. Performance on sessions 2 and 3 was equivalent. The Group effect was not significant and there were no significant interactions.

Trails B showed a significant effect of Session ($F [2, 46] = 4.72, p < .02$) with decreased latencies (-12 sec) in session 2 compared to session 1. The Group effect was not significant indicating equivalent performance among groups, and there were no significant interactions.

Symbol Digit. Symbol Digit revealed a significant Session effect with an increase (+11) in the mean number correct responses in session 2 compared to session 1, $F (2, 46) = 33.34, p < .001$. The Group effect was not significant, indicating equivalent performance among groups, and there were no significant interactions.

Computerized Addition Test. The Addition Test showed no significant effects or interactions for the latency or accuracy data.

Figure 30. Neuropsychological tests over three sessions.

Question 2. Does the interval duration between session 1 and 2 affect performance on session 2?

Reaction time tests

A repeated measures ANOVA was next conducted to determine if there were any overall differences in performance latencies among the three RT tests between sessions 1 and 2 for all three groups. This would show if the second session was equivalent among the three groups, despite their different delay intervals (e.g., 20 mins, one week, three months) between session 1 and 2. Results indicated a significant effect of Test, $F(2, 105) = 264.77$, $p < .001$. This Test effect replicates the previous experiments to indicate that latencies increase as test complexity increases from simple, to choice, to semantic as seen in both Figures 31 and 32. Figure 31 also shows that the Group effect was not significant, with equivalent latencies among the three groups. This finding indicates that RT test performance was not moderated by the length of interval between sessions 1 and 2. The Session effect was not significant indicating that overall latencies between session 1 and 2 were equivalent. However, the Session x Test interaction was significant, $F(2, 105) = 4.17$, $p < .02$. Simple pairwise comparisons again indicated equivalent latencies on both the Simple and Choice RT tests over sessions, while the Semantic test resulted in significant and progressively decreased latencies between session 1 and 2 as evident in Figures 31 and 32. This practice effect on the Semantic test was equivalent among all groups as indicated by the absence of a Test x Group interaction. There were no other significant effects or interactions.

Simple RT

Choice RT

Semantic RT

Figure 31. Comparison of three RT tests between session 1 (Baseline) and session 2 for three groups.

Figure 32. Three RT tests over sessions 1 and 2 collapsed across three groups.

Within-session performance. To determine if there were any within-session practice effects on the three RT tests, each was further analyzed by dividing the 30 trials into three 10-trial blocks. The average median for each block was analyzed for all groups over sessions 1 and 2, with a "Block" described as the group of 10 trial medians for each test. Block data for each of the three tests are shown in Tables 2 - 4 (Appendix E).

Simple RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance latencies between sessions 1 and 2 for all three groups. There were no significant effects or interactions to report for sessions or block latencies.

Choice RT. A repeated measures ANOVA was conducted to determine if there were

any overall differences in performance latencies between sessions 1 and 2 for all three groups. There were no significant effects or interactions to report for the between-session latencies. There was a main effect of Block, $F(2, 70) = 7.45, p < .001$. Pairwise comparisons showed longer latencies on blocks 2 and 3 relative to block 1. This finding indicates a reverse within-session practice effect possibly due to boredom or fatigue.

Semantic RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance latencies between sessions 1 and 2 for all three groups. Results indicated a main effect of Session ($F[1, 35] = 7.24, p < .01$) with decreased latencies on session 2 compared to session 1. There was a main effect of Block, $F(2, 70) = 5.55, p < .01$. Pairwise comparisons revealed that the Block effect was due to shorter latencies in blocks 2 and 3 compared to block 1. This Block effect is in the opposite direction to that found above with the CRT test in that latencies have decreased over blocks to indicate a within-session practice effect. This finding indicates within-session practice effects that were equivalent among groups and sessions, as confirmed by the absence of any other significant effects or interactions.

A-PASAT

Threshold data. The A-PASAT scores were next analyzed using a repeated measures ANOVA on the average median threshold scores for sessions 1 and 2 among the three groups. As shown in Figure 33, there was a Session effect to indicate a significant and progressive improvement in performance (decrease in threshold scores) between session 1 and session 2, $F(1, 35) = 62.14, p < .001$. The Group effect and the Group x Session interaction were not significant. This indicated that the second session was equivalent among the three groups, despite their different delay interval between session 1 and 2. Thus, the

experience gained in session 1 was maintained in session 2 regardless of whether the interval between them was 20 minutes, 1 week, or three months. Again, this illustrates the robustness of the effects developed in session 1, and further substantiates session 2 as a stable baseline measure for performance.

Figure 33. Comparison of three A-PASAT groups between session 1 and session 2.

Within-session performance. To examine the practice effects, performance on the A-PASAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials. The average of the median ISI for each block was analyzed for all groups over sessions 1 and 2. Block data for sessions are plotted in Figure 34. Overall performance and error summary scores are shown in Table 1 (Appendix E).

The A-PASAT block scores were analyzed using a repeated measures ANOVA on the average threshold between sessions 1 and 2 among the three groups. Results indicated a main effect of Session ($F [1, 35] = 52.84, p < .001$) with overall shorter ISIs (-300 ms) occurring on session 2 compared to session 1. The Block effect was also significant, $F (7,$

245) = 61.46, $p < .01$. Pairwise comparisons revealed that this effect was due to shorter ISIs occurring in the last four blocks (last 100 trials) compared to the first four blocks (first 100 trials). The Session x Block interaction was significant, $F(7, 245) = 12.70$, $p < .001$.

Pairwise comparisons revealed that the interaction was due to block scores decreasing at a faster rate in session 2 compared to session 1, which indicates that participants became more efficient in session 2. The Group effect was not significant and there were no other significant interactions.

Figure 34. Comparison of A-PASAT block data for three groups between session 1 and 2.

Threshold trial number. To determine if thresholds occurred earlier within a session, the trial numbers at which threshold was achieved over the two sessions were analyzed. A repeated measures ANOVA revealed no significant effects of Session, Group, or their interaction. Trial numbers ranged between 132-152. The trial at which threshold was

achieved was prior to the last trial (trial 200), thereby confirming that a sufficient number of trials had been administered.

Accuracy data. A repeated measures ANOVA was conducted for all groups between sessions 1 and 2. Results showed a significant effect of Session ($F [1, 35] = 56.91, p < .001$) due to a mean increase of 9 correct responses in session 2. There were no other main effects or interactions. This supports the results obtained from the threshold and ISI data that determined session 2 as the best baseline measure.

Neuropsychological tests

A repeated measures ANOVA was conducted on each of the three neuropsychological tests for all groups between session 1 and session 2. Results for each test are shown in Figure 35. Summary data are shown in Table 1 (Appendix E). The plots in Figure 35 are collapsed across groups due to their equivalent performance in each session.

Digit Span. On Digit Forward, the Group and Session effect were not significant and there were no significant interactions, indicating equivalent performance among groups between session 1 and session 2. On Digit Backward, there was a main effect of Session, $F (1, 35) = 9.49, p < .01$. However, inspection of these data again indicates virtually no differences between sessions, with a mean increase (+1) in the total score in session 2 compared to session 1. There were no other significant effects or interactions indicating equivalent performance among groups.

Trails A and B. Trails A showed a significant effect of Session ($F [1, 35] = 34.71, p < .001$) with decreased latencies (-8 sec) in session 2 compared to session 1. The Group effect was not significant and there were no significant interactions.

Trails B showed a significant effect of Session ($F [1, 35] = 10.81, p < .01$) with

decreased latencies (-14 sec) in session 2 compared to session 1. The Group effect was not significant indicating equivalent performance among groups, and there were no significant interactions.

Symbol Digit. Symbol Digit revealed a significant Session effect with an increase (+ 9 ms) in the mean number correct responses in session 2 compared to session 1, $F(1, 35) = 75.52, p < .001$. The Group effect was not significant indicating equivalent performance among groups, and there were no significant interactions.

Computerized Addition Test. The Addition Test showed no significant effects or interactions for the latency or accuracy data.

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Insert Figure 35 about here
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Figure 35. Neuropsychological tests for session 1 and session 2 collapsed across groups.

Question 3. How does an intervening session between session 1 and 2 affect performance?

Reaction time tests

A repeated measures ANOVA was next conducted to determine if there were any differences among all three groups in the average median latencies between session 1 and testing three months later. If the intervening session administered to Group (20 mins) and Group (1 week) contributed to practice effects over and above that obtained in session 1, then differences should emerge among the three groups when tested at three months. In contrast, a lack of benefit from an intervening session would produce no differences among the three groups when tested at three months. An absence of differences between Group (3 months) with Group (20 mins) and Group (1 week) would further substantiate using session 2 as a stable baseline measure of performance.

Figure 36 shows the main effect of Test ($F(2, 105) = 263.86, p < .001$) and Group, $F(2, 105) = 4.67, p < .02$. Pairwise comparisons confirmed that Group (1 week) was significantly slower (-52 ms) than Group (20 mins). The lack of any difference in pairwise comparisons with Group (3 months) indicates that an intervening session between session 1 and testing three months later did not significantly affect performance.

The Session x Test interaction was significant, $F(2, 105) = 4.82, p < .01$. Pairwise comparisons revealed that this interaction was due to a significant decrease in latencies at three months compared to session 1 for the semantic test only, also shown in Figure 36. The Group x Test interaction was not significant, and there were no other significant effects or interactions.

Figure 36. Three RT tests between session 1 and three months later for three groups.

Within-session performance. To determine if there were any within-session practice effects on the three RT tests, each was further analyzed by dividing the 30 trials into three 10-trial blocks. The average median for each block was analyzed for all groups between session 1 and testing three months later, with a "Block" described as the group of 10 trial medians for each test. Block performance and summary scores are plotted in Figure 37 and shown in Tables 2- 4 (Appendix E).

Simple RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance on the average of the median latencies between session 1 and testing three months later. There were no significant effects or interactions to report for either session or block latencies.

Choice RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance on the average of the median latencies between session 1 and testing three months later. There were no significant effects or interactions to report for either session or block latencies.

Semantic RT. A repeated measures ANOVA was conducted to determine if there were any overall differences in performance on the average of the median latencies between session 1 and testing three months later. The Session effect indicated shorter latencies for session 2 compared to session 1, $F(1, 35) = 5.92, p < .02$. There was also a main effect of Block, $F(2, 70) = 11.43, p < .001$. Pairwise comparisons again revealed that the Block effect was due to shorter latencies in Blocks 2 and 3 relative to Block 1. These results show practice effects for both within and between sessions for the semantic test.

Figure 37. Within-session latencies between session 1 and three months later.

A-PASAT

Threshold data A repeated measures ANOVA was conducted among all three groups to determine if there were any overall differences in performance on the average threshold scores between session 1 and testing three months later. Figure 38 shows the significant effect of Session, $F(1,35) = 65.22, p < .001$. This effect was due to decreased latencies at three months compared to session 1. The Group effect and the Group x Session interaction were not significant. These results confirm that an intervening session administered either 20 minutes or one week following session 1 had no impact on testing administered three months later.

Figure 38. A-PASAT threshold scores between session 1 and three months later.

Within-session performance. To examine practice effects, performance on the A-PASAT was further analyzed by dividing the 200 trials into 8 separate blocks, with a block composed of 25 trials. The average of the median ISI for each block was analyzed for all groups over session 1 and testing three months later, with a "Block" described as the group of 25 trial medians for each test. Block data for sessions is plotted in Figure 39.

Performance and summary scores are shown in Table 1 (Appendix E).

A repeated measures ANOVA indicated a main effect of Session ($F [1, 35] = 69.62, p < .001$) with overall shorter ISIs (-337 ms) occurring at the three month session compared to session 1. The Block effect was significant, $F (7, 245) = 81.61, p < .01$. Pairwise comparisons revealed that this effect was again due to shorter ISIs occurring in the last four blocks (last 100 trials) compared to the first four blocks (first 100 trials). The Session x Block interaction was also significant, $F (7, 245) = 16.55, p < .001$. This interaction was again due to block ISI values decreasing at a faster rate during the three months session

compared to session 1. The Group effect was not significant and there were no other significant interactions. These results confirm that an intervening session administered either 20 minutes or one week following session 1 had no impact on testing administered three months later.

Figure 39. A-PASAT block data for three groups between session 1 and three months later.

Threshold trial number. A repeated measures ANOVA revealed no significant effects of Group, Session, or interaction with threshold trial number, consistent with all of the experiments conducted within the present study. Furthermore, the trial numbers at which threshold was achieved ranged between 143-150. Thus, threshold was achieved prior to the final trial, and confirms a sufficient number of trials were presented to participants.

Accuracy data. A repeated measures ANOVA was conducted to determine if there were any differences in the total number of correct responses between session 1 and testing three months later. Results showed a significant effect of Session ($F [1, 35] = 36.45, p <$

.001), due to a mean increase of 9 in the number of correct responses three months later.

There were no other main effects or interactions. Again, results replicated the latency and threshold data by showing no effect of delay interval between session 1 and 2.

Neuropsychological tests

A repeated measures ANOVA was conducted to determine if there were any overall differences in performance on each of the three neuropsychological tests between session 1 and testing three months later. Results for each test are shown in Figure 40. The plots are again collapsed across groups due to their equivalent performance in each session.

Digit Span. On Digit Forward the Group and Session effects were not significant and there were no significant interactions, indicating equivalent performance among groups between session 1 and testing three months later. On Digit Backward there was a main effect of Session ($F [1, 35] = 16.62, p < .01$) although comparisons indicated a mean increase of 1 correct response between session 1 and testing three months later. The Group effect was not significant indicating equivalent performance across groups. There were no other significant effects or interactions.

Trails A and B. Trails A showed a significant effect of Session ($F [1, 35] = 55.72, p < .001$) with decreased latencies (-9 sec) at testing three months later compared to session 1. The Group effect was not significant and there were no significant interactions. Trails B showed a significant effect of Session ($F [1, 35] = 14.02, p < .01$) with decreased latencies (-15 sec) at testing three months later compared to session 1. The Group effect was not significant and there were no significant interactions.

Symbol Digit. Symbol Digit revealed a significant Session effect ($F [1, 35] = 52.27, p < .001$) with an increase in the mean number of correct responses on testing at three months

compared to session 1. The Group effect was not significant and there were no significant interactions.

Computerized Addition Test. The Addition Test showed no significant effects or interactions for the latency or accuracy data.

Correlational analyses. Pearson correlations were conducted to determine the relation among A-PASAT threshold scores, addition, and the three neuropsychological tests over each of the test sessions (see Tables 5-12, Appendix E). Consistent with the previous experiments within the present research, there were low to moderate relations between the neuropsychological tests of attention with the A-PASAT threshold scores.

Reliability coefficients. Reliability estimates were obtained for the PASAT over the various sessions and intervals. Coefficients (Pearson r) were similar for all groups and ranged from .83 between sessions 1 and 2 (all groups) to .77 between sessions 2 and 3 (Group 20 mins and Group 3 mths). Again, the reliability coefficient obtained between session 1 and 2 ($r = .83$) shows the high test stability despite differences in the interval between the two sessions and the influence of practice on performance for the three groups. However, finding practice effects that were especially pronounced between sessions 1 and 2 confirms that a distinction is necessary between test reliability and performance stability.

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Insert Figure 40 about here
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Figure 40. Neuropsychological tests for session 1 and three months later collapsed across groups.

DISCUSSION

Experiment 5 was guided by three research questions: Question 1 concerned the reliability of session 2 as a stable measure of performance against which subsequent sessions could be compared. Results obtained using the A-PASAT were consistent in showing that most practice effects occurred during the first session with minimal gains in performance over subsequent sessions. In contrast, results obtained using the three RT tests showed that both the simple and choice RT tests were resilient to the effects of practice over repeated sessions. However, the semantic RT test did show the effects of practice which, similar to the A-PASAT, were most marked between the first two sessions.

The second question concerned the timing of session 2. Specifically, this question addressed whether variations in length of the interval between session 1 and 2 would affect performance on session 2. The absence of a Group effect between session 1 and subsequent sessions indicates that the performance of all groups was equivalent, regardless of the time that had elapsed between sessions. More importantly, the absence of a Group x Session interaction indicates that the length of the interval between session 1 and 2 did not impact on performance. This finding suggests that healthy individuals will perform at similar levels on a second test administration whether the delay interval between the two sessions is 20 minutes, 1 week, or three months. Thus, prior exposure to these newly computerized tests appears to be unaffected by the effects of time, at least within the three month period presently explored.

The final question concerned the impact that an intervening session would have on performance when it occurred between session 1 and testing at three months. It was important to determine the robustness, or "lifespan", of the strategy effects that were

developed in session 1 in order to place additional confidence in the stability of performance obtained in session 2. If strategy effects are fully developed by the end of session 1, then an intervening session should provide no further benefit on performance at three months.

Moreover, a lack of difference between performance on session 2 and session 3 is a good indicator that session 1 mediates subsequent performance, and substantiates the prediction that session 2 provides the most stable measure of performance. Results confirmed that an intervening session did not result in improved scores when participants were tested three months later. Thus, the impact of session 1 mediated performance on subsequent testing with no additional gains derived from the intervening session. This finding indicates that the gains in performance scores that were evident in session 2 can be regarded as the best approximation of the maximum gain that one could expect to find on a retest. This is because all of the influences of practice are maximized. In contrast, the absence of practice effects on the RT tests indicates the lack of motivation that tends to accompany the negative effects of fatigue or boredom. Loss of motivation would tend to attenuate the retest scores and, consequently, would show no further gain in subsequent sessions that are closely spaced. Moreover, results obtained in Experiment 4 (b) indicated that a prolonged delay between sessions may result in participants' renewed interest, as evident in the slight, (nonsignificant) decrease in performance scores following a delay interval of six months. However, despite the slight decrease at six months, the overall results confirm the resilience of the RT tests to the effects of practice.

Gronwall (1974) indicated that most practice effects on the A-PASAT occurred during the first and second administration. However, the present results extend Gronwall's observation by showing that practice effects are maximized between the first two sessions

regardless of whether the second administration occurred 20 minutes or one week following the initial administration. The robustness of the effects attributable to prior exposure in session 1 suggests that session 2 provides a stable baseline measure against which to gauge subsequent performance. These results have relevance in a clinical situation, where one needs to differentiate between real change due to recovery of function, and change that occurs simply as a result of experience. Because the second session has maximized the effects of practice, it would be feasible to administer two assessments and to use the second as a baseline measure. Accordingly, this method may provide a more stable and reliable estimate of baseline performance.

The neuropsychological tests of attention also show practice effects that are most apparent between session 1 and session 2. However, there was no relation with the A-PASAT and the RT tests as shown by the low correlations, which suggests that the new tests are measuring components of capacity and speed not captured by traditional tests. These findings, together with the previous findings, are discussed in more detail in the general discussion which follows.

GENERAL DISCUSSION

The current study was conducted to investigate the effects of TBI, age, and practice on three newly developed RT tests and the Adjusting A-PSAT, which is a titrated, computerized version of the PASAT. This research incorporated a hierarchical design with tasks varied along a continuum of complexity. Overall task complexity was defined by the degree to which the task requires a higher level of concentration and attentional control. This variable was manipulated according to the level of choice involved in performing the task, and the degree to which the task required the participant to use cognitive abilities. The

physical requirements of the tasks were similar across tests. Three reaction time tests were used: Simple (SRT), Choice (CRT), and Semantic RT. These tests were used to differentiate the effects of slowing on automatic and controlled attentional processes due to TBI.

A new computerized version of the PASAT was also used which measures a threshold of response based on speed of information processing (Tombaugh, 1999). The traditional PASAT is a neuropsychological instrument used by clinicians and researchers to measure attention and information processing, to evaluate cognitive impairments, and to track changes in performance. The Adjusting-PSAT used in the present study is a modified computer version that measures speed of information-processing using a temporal threshold instead of accuracy rates. This test was examined in a series of experiments to determine the effects of TBI, age, and modality of presentation (visual, auditory) on speed of information-processing. One goal was to examine if the newly developed A-PSAT would differentiate TBI patients from controls, and to determine if this distinction could be made according to the degree of severity.

Due to the finding that prior exposure to a test may result in improved performance, practice effects associated with the new tests were also examined using repeated sessions. The duration of the interval between test sessions was also manipulated to examine the impact that various delay intervals would have on performance. To facilitate a discussion of the factors examined in the present study, each will be presented separately.

TBI

Experiment 1 was designed to provide a cursory view of the impact that TBI would have on information processing as measured by the newly developed RT tests and A-

PASAT. It was predicted that the different levels of test complexity would help to identify any differential effects that TBI had on processing speed. Results showed that performance was significantly slower for the Severe TBI group compared to the Mild and Control groups on the Semantic RT test. However, differences between the Mild TBI group and the Control group did not reach significance.

The current results are in agreement with previous research showing that RT is slowed in severely injured TBI patients (Bleiberg et al., 1997; Collins & Long, 1996; Segalowitz et al., 1997; Stuss et al., 1989, 1994). These results also support previous research with TBI individuals that suggest that the speed at which an injured person responds is decreased in direct proportion to the amount of information that must be processed before the response is made (Sohlberg & Matter, 1989). They also corroborate the findings of Demand, Vanier, Lambert, and Provost (1992) who concluded that TBI patients are not impaired on tasks that involve automatic processes, but are impaired on tasks that involve controlled processes. Relative to this, Salthouse (1988, 1991, 1996, 2001) and van Zomeren and Brouwer (1994) have proposed that the time required for controlled processes, as estimated with RT measures, gives a direct estimation of attentional capacity. This is well illustrated in the present experiment where the performance of TBI patients indicated no evidence of a deficit on simple tasks (SRT, CRT), but their performance did show evidence of a deficit on the complex task (Semantic RT).

In addition to the finding that latency scores are sensitive to the effects of TBI, large variability in performance has been reported in the TBI literature as an indicator of impairment (e.g., Segalowitz, Dywan, & Unsal, 1997). The present results show overall larger deviations compared to the Mild and Control groups, but deviation scores are

consistent across trial blocks. This observation attests to previous claims that although TBI patients perform poorly compared to controls by responding more slowly, their performance is stable over time and does not deteriorate as the task progresses (e.g., Brouwer, 1985; van Zomeren et al., 1984, 1987). The failure to obtain a significant Group x Block effect in the present RT data supports this prior research by showing that TBI patients are able to sustain attention, because impairment is only indicated if performance deteriorates in the latter part of the task.

One aspect that requires clarification is the failure to find any group differences on the CRT test. Both early and recent research findings have reported group differences between TBI and control groups on this measure. For example, Norman and Svahn (1961) and Miller (1970) identified longer latencies for TBI groups on a CRT test using a visual stimulus. Gronwall and Sampson (1974) also used a visual CRT and found longer latencies for 12 MHI patients following trauma. In addition, Schneider and Schiffman (1977) and van Zomeren and Deelman (1978) reported that a CRT task discriminated severe from MHI patients better than a SRT task. Furthermore, van Zomeren and Deelman reported that their RT tasks discriminated among subgroups according to severity of injury. Later, Ponsford and Kinsella (1992) tested very severe TBI patients using a SRT and CRT test and found that TBI patients were significantly slower than controls on the CRT. Patients were tested in the first year after injury, some in the acute phase and some in the chronic stage of recovery. A meta-analysis conducted by Raskin, Matter, and Tweeten (1998) reported that the tests which showed the greatest impairment in 148 patients with MHI were tests involving complex attention which included CRT tests. These studies have found that CRT is more sensitive to the effects of TBI than SRT.

Further inspection of the studies cited above provide insight into the possible reasons that the present study did not obtain a significant effect on the CRT test. Some of these reasons include differences across studies in: the complexity of the CRT test employed, the level of severity of the TBI samples, the nature of the injury, sample size, and the time that had elapsed since injury. For example, van Zomeren and Deelman's (1978) sample was composed of 57 young brain-injured males and findings were based on a follow-up study covering two years. Due to the nature of practice effects over repeated sessions, these results may also reflect differences in practice effects among the various tests as a function of injury, rather than differences in injury per se. Also, their study only included young males and may not generalize to an older sample.

Ponsford and Kinsella's (1992) sample was composed of very severe TBI patients who were admitted to a rehabilitation program, and their CRT test involved four-choices. Furthermore, these patients were tested in the first year after injury, some in the acute phase and some in the chronic stage of recovery. Using very severe patients in the acute phase of recovery would most likely result in impaired performance on a CRT task, especially when the response involves four choices. Other than increasing the number of stimulus-response alternatives, CRT complexity can also be manipulated by decreasing the stimulus-response compatibility so that the response is not directly indicated by the spatial location of the stimulus. Thus, if the complexity of the CRT test is varied, it may be possible to better differentiate among TBI subgroups. This assumption is based on prior results that show that the CRT is a better task than SRT in discriminating between control and TBI groups.

The ability to find significant group differences on the CRT may also depend on the type of injury sustained. For example, Roman et al. (1991) concluded that the sensitivity of

the PASAT to TBI may be best in samples where the injury involved subcortical or white matter damage. In addition, previous research (for a complete review see van Zomeren, 1981) that reports group differences on CRT measures have tested the prolonged effects of head injury according to the level of severity over time. Moreover, previous research shows more impairment for persons having injuries of greater severity with almost full recovery occurring two years following injury.

Results from the A-PASAT also showed that this task was sensitive to the effects of TBI. Both speed and accuracy were measured in the present study to assess the efficiency of controlled processing and the effects of increasing processing load (Schneider & Schifffrin, 1977; Ponsford & Kinsella, 1997). Higher thresholds of response, as measured by longer ISIs, were particularly marked for persons having sustained a severe brain injury when compared to persons having sustained a mild brain injury, and a healthy control group. Moreover, thresholds for the Severe TBI group occurred within the first 100 trials compared to the Mild and Control group which occurred within the last 100 trials. Overall, these results support previous findings that simultaneously monitoring and responding to multiple pieces of information is difficult for persons having sustained a head injury (Morse & Montgomery, 1992; Ponsford & Kinsella, 1992; van Zomeren et al., 1984; Whyte, 1992, 1996). This difficulty is probably related to a reduction in processing capacity when the cognitive processes that must be executed to perform a task are limited. As a task progresses, most normal functioning individuals develop strategies that result from their ability to allocate attention by alternating or by time-sharing processing resources. Based on this ability, strategies are constructed to facilitate performance. However, this ability is limited in individuals who have sustained a TBI, resulting in slower processing as shown by

the high threshold measure.

In addition to slower responses, the Severe TBI group also produced more incorrect responses compared to the Mild and Control groups on the A-PASAT. This finding indicates an inability of the severely injured group to develop a repertoire that would facilitate performance on the A-PASAT. Because the A-PASAT procedure increases the ISI by 20 ms whenever a response is incorrect, the accuracy data help to explain the increase in ISIs within the session. As the task progressed, ISIs increased, rather than decreased, as a result of the difficulty in processing multiple sources of information. The significant Block x Group interaction obtained shows that ISIs for the Severe TBI group increased over trial blocks, while both the Mild TBI and the Control groups showed a progressive decrease in ISIs over trial blocks, with a steeper decline over the first 4 compared to the final 4 blocks. Despite the different pattern of response for the Severe TBI group, Figure 4 shows that the longer ISIs produced by this group do not indicate a dramatic decrease in performance over trials. Rather, the distribution of performance is fairly consistent over blocks with responses showing a gradual and steady, but not steep, decrease in performance. These results are in contrast to those observed with the RT tests that showed no deleterious effect of performance over trials blocks.

The A-PASAT accuracy results are somewhat contradictory to widely held assumptions regarding the attentional deficits of TBI patients as reported by Miller (1970), van Zomeren (1981), Brouwer and van Wolfelaar (1985), Stuss et al.(1985), and Parasuraman, Mutter, and Molloy (1991) who showed reduced speed of processing but no significant reductions in accuracy or performance compared to controls. However, the A-PASAT accuracy data reflect how changes in processing time can exceed the processing

capacity of severely injured persons, so that speed and accuracy are linked in the response. Since it is the individual who sets the pace on the A-PASAT through accuracy of response, the present results extend those obtained with the traditional PASAT that uses accuracy as the primary index of performance. However, because accuracy also affects the length of the ISI in the A-PASAT, it is clear from the threshold data that the critical factor for assessing capacity is speed of responding.

The results of the neuropsychological tests of attention (Trails A and B, Symbol Digit) showed significance for impaired performance only for the Severe TBI group. However, no group differences were observed for Digit Span. Furthermore, a comparison of the neuropsychological test results with both the CTIP and the A-PASAT scores show no relation. Correlations were low for all RT tests as well as for the A-PASAT threshold scores with each of the neuropsychological tests of attention, except Trails B which shared a moderate relation with the A-PASAT. As previously indicated, this finding instills confidence in the newly developed tests as indicators of capacity and processing-speed. It is clear that caution should be exercised in interpreting the neuropsychological test performance of TBI patients, being careful to distinguish speed of performance from quality of performance.

Overall, the results from the RT tasks and the A-PASAT can be explained within the two-process model of Schneider and Shiffrin (1977). This model describes automatic processing as an effortless process, whereas controlled processing is described as involving cognitive effort, and is therefore more vulnerable to reductions in processing speed and capacity. The present results showed that TBI patients performed better on the SRT and CRT tasks which are fairly automatic, or less demanding, compared to the Semantic test and the A-

PASAT which require more deliberate and controlled allocation of attention for adequate performance. The implication derived from Experiment 1 is that increases in the task demands exceeded the available resources of the severe TBI group who were unable to process complex information. This implication is primarily based on finding that an increase in task demands dramatically reduced the speed of controlled cognitive processing for the severe TBI group. Thus, the present findings extend previous research showing that slowness in controlled information-processing can explain most of the attention deficits observed after head-injury (Cicerone, 1996; Gentilini et al., 1989; Ponsford & Kinsella, 1992; van Zomeren & Brouwer, 1994).

Salthouse's processing-speed theory is also compatible with the present findings. Although primarily concerned with the effects of age, this processing-speed theory can also link deficits observed in TBI to a decline in processing speed and capacity that is shared by aging persons and those having sustained a head injury. Any theory that describes general slowing as central to successful performance would logically predict reductions in information processing for any group lacking the processing capacity required to perform a complex task, especially when performance is measured by response speed. Thus, theories of processing speed, whether concerned with aspects of controlled versus automatic processing or with general slowing, would predict the present results.

In this study, neither the RT tests nor the A-PASAT were able to significantly differentiate between the mild TBI and normal control groups. However, it has been shown that the majority of persons having sustained a mild head injury achieve normal scores on information-processing within 4 weeks of injury (Alexander, 1995; Binder, 1986; Fos et al., 2000; Gronwall, 1991; Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974; King, 1997;

Ponsford et al.,1996; Tombaugh,1999). Furthermore, these persons may be highly motivated to perform well, albeit with a later cost to the participant later (e.g., they may require additional sleep or several days rest to recover from the testing process). In fact Gronwall (1977) noted that "since patients are more impaired after a second concussion...normal scores are possible" (p. 372).

Another factor is that there are currently no objective measures to quantify the severity of TBI more accurately than the GSA, PTA, and LOC. Furthermore, the diffuse nature of the injury involved in MHI, and differences due to type of injury, makes it difficult to equate groups across research studies. As such, the behavioural consequences of mild TBI are variable, and cannot always be replicated across studies. Thus, the challenge for researchers remains to detect the presence of neurological deficits if and when any exist.

Age

The present study also addressed a potential problem in generalizing the obtained results to the general population, such as diminished performance with increasing age (Horton, 1992). This is well illustrated by the cautionary note provided by Gronwall that serial addition may not be suitable for children or adults over age 40. Gronwall and Wrightson (1975) state that performance on the PASAT in healthy adults "decreases with age, reflecting neuronal fall-out" (p. 997). However, despite the caution that age-effects can appear as early as age 35, no research was cited to document this assertion.

To investigate the possible effects of age, Experiment 2 involved recruiting individuals ranging from ages 18- 80 to determine how increases in age would affect performance on the newly developed RT tests and A-PASAT. Given that general slowing is central in the literature on aging, it was predicted that age would mediate performance, particularly as test complexity

and the demand for response speed increased. Thus, it was expected that the magnitude of age differences would increase as the processing requirements involved in the tasks increase. This prediction was based on the vast literature on aging that reports reductions in information processing as a function of age. As a result of processing reductions, older adults may be required to use all of their available processing capacity for performing a cognitive task

The results from Experiment 2 supported this prediction. Performance was significantly slower for the Older group compared to the Young group on the Semantic and CRT test, and the Test x Group interaction showed that performance was significantly slower for both the Older and Middle groups compared to the Young group on the Semantic RT test, indicating that conceptual processing differentiated among age groups. Results also showed performance that was significantly slower for the Older group compared to the Young group on the A-PASAT.

Taken together, the results from the Semantic RT and A-PASAT showed that performance was differentially slowed for the older adults on measures that involved controlled processes. This result is consistent with previous findings showing a strong association between executive/frontal decline in normal elderly populations and a reduction in processing speed (Craik & Salthouse, 1992; Reingold & Goshen-Gottsein, 1997; Sauzeon et al., 2000). Salthouse (2001) suggested that a major factor contributing to age differences in working memory, and in other controlled processes, is a reduction of information processing resources. The current finding that the magnitude of age differences increased with increases in the processing requirements involved in the task is congruent with Salthouse's theory. When processing is slow, the processes necessary for cognitive operations may not be completed due to limited time, or because all relevant information is not available as needed, resulting in a decline on operations that consume processing time. The effort that is required to perform

cognitive activities may exhaust the processing resources of older adults and affect successful encoding of activities. Empirical results, such as longer latencies for older compared to young adults on the semantic RT and higher thresholds (e.g., longer ISIs) on the A-PASAT are evidence of this latter aspect.

Salthouse (1992) has demonstrated that age-related variance in cognitive performance is markedly reduced when perceptual speed is statistically controlled. The current results therefore corroborate Salthouse's processing-speed theory concerning aspects of controlled versus automatic processing, in that complex or controlled operations are differentially affected compared to automatic, or less complex operations. As such, the present findings can be explained within a processing-speed framework. However, to properly assess processing speed, the present findings highlight the importance in choosing measures that will reflect compromised cognitive functioning. For example, a measure of processing speed should be fairly simple, so that most of the variance in performance can be attributed to how quickly one can execute the relevant operations, rather than to variations in the amount of knowledge or skill one must possess to perform the task, as seen in the addition skills of older adults.

The above cautionary note is evident in the present results obtained using the A-PASAT with an older population. The A-PASAT threshold scores indicated a trend toward higher thresholds as age increased, but these differences did not reach significance. These data first appeared to be contradictory to those obtained in older populations, such as Brittain et al. (1990) who found that age significantly affected PASAT test results. However, guided by Dreary et al.'s (1991) finding that the PASAT was related to numerical ability, this numerical aspect was investigated in Experiment 2 because it was noted throughout this research that the young participants often experienced difficulty in retrieving responses for the A-PASAT.

Further inspection of the data revealed that the younger and middle aged participants were less able than older participants to mentally add numbers, as confirmed by the young group's slower performance on the Computerized Addition Test. Appendix B clearly indicates that the Older group were highly variable on the A-PASAT, yet highly consistent on the Addition Test compared to the Young group. Correlational analyses showed no relation between the addition test and the A-PASAT for the Older group possibly due to a truncated range (high skill) on the addition test. In contrast, there was a moderate relation between these two variables for the Younger and Middle groups, reflecting more variability within each of these groups for both the addition test and the A-PASAT. Consequently, the age effects in processing-speed were potentially confounded by ability in addition. When the A-PASAT threshold scores were partialled out from the effects of addition using an ANCOVA, results indicated a significant effect of Group that was due to lower thresholds for the young compared to the older group. Therefore, the older group showed a performance advantage on the ability measure while the younger group showed a performance advantage on the processing-speed measure, and the initial hypothesis of decreased speed with advancing age was supported.

The present findings are contrary to the claims by Gronwall (1977) and Gronwall and colleagues (Gronwall & Sampson, 1974; Gronwall & Wrightson, 1981) who reported that the PASAT was only mildly related to arithmetic ability. The present findings support studies that weaken the validity of the PASAT as a measure of information processing by showing that it may measure other cognitive processes such as IQ, memory, and arithmetic ability (Dreary et al. 1991; Egan 1988; Roman et al., 1991; Sherman, Strauss, & Spellacy, 1996) which has implications for the construct validity of the PASAT as strictly a measure of information processing.

Another implication from the above "skill" finding is that, for some tasks, the slowing in the rate of information processing often associated with aging can be compensated for by a shift to a more efficient problem-solving strategy. Schaie (1989) suggested that older persons have gained associative strength between the correct answer and the problem so that eventually a strong number tie is established which facilitates direct retrieval. In contrast, younger persons lack the frequency of occurrence that occurs between problem and answer, and consequently, have not yet achieved the automaticity of direct retrieval in basic addition. Thus, from a developmental perspective, older persons have considerable experience in retrieving numbers compared to younger persons. In support of this suggestion, Greary and Wiley (1991) showed a performance advantage for an elderly group on the mental solution of simple addition problems and problem-solving strategies, while a young group showed an advantage for overall solution times. Findings such as these suggest that skill development in adulthood may involve using adaptive strategy choices.

Age-related effects may also be the result of cohort differences. Cohort differences would be attributable to the greater emphasis on rote memorization of basic mathematical operations during the elementary school years for the older cohorts, as reported by Schaie (1989). One might speculate that the reason for this change is pedagogical, such as the widespread use of calculators in the classroom. This perspective centers on differences in strategy choices rather than differences in strategy development of each cohort.

Two major issues in cognitive aging that are germane to the present study are 1) age-related differences in problem-solving and strategies, and 2) differences in the rate of information processing speed among various age groups. It appears that age differences probably depend on both the complexity of the task (e. g., Mitchell & Babcock, 1989;

Salthouse, 2000, 2001) and the level of task familiarity for the young and older age groups. The present finding that age mediated performance on the semantic RT test, as well as on the A-PASAT when numeric skill was controlled, supports this statement. The present findings also support the argument that decreases in the overall rate of information processing typically associated with aging can be compensated for by a shift to more efficient strategies, at least in domains in which older persons have considerable knowledge. Hence, the attainment of expert status may be a factor for consideration when assessing performance on tests that rely on a specific underlying skill, whether it is the result of level of practice or age per se.

Contrary to the A-PASAT, the CTIP was unrelated to numerical skill and measures of attention as evidenced in its lack of correlation with the addition test and the three neuropsychological tests. Failure to find a meaningful relation with these measures indicates that the CTIP is measuring a different dimension of attention, and attests to the suggestion that the CTIP provides a “pure” measure of speed of information processing, uncontaminated by other components of attention and other factors such as memory. This is an important finding given that speed of information processing is the functional component most affected by aging and TBI.

Practice

The final issue to be addressed in the current study relates to practice effects. Neuropsychologists working in either a clinical or research setting may be required to perform serial neuropsychological assessments in order to monitor the progression of a disease process, to evaluate the efficacy of a therapeutic agent, or to assess the impact of a rehabilitation program. An important factor in any type of serial assessment is the variance attributable to practice effects. Repeated administrations of the same assessment tool may lead to increments

in performance that are due to practice effects only, but changes in performance that are the result of recovery can only be ascertained when practice effects are controlled (Basso, Bornstein, & Lang, 1999; Collie et al., 2003; McCaffrey, Ortega, Orsillio, & Nelles, 1992; Schretlen et al., 2003).

Since there is previous evidence that the traditional PASAT is sensitive to practice effects (Feinstein, Brown, & Ron, 1994; Stuss, et al., 1989), it was likely that the A-PASAT would show a similar effect. However, it was also anticipated that the RT tests would not show a practice effect due to their relatively light task demands. Thus, the present study administered all tests over repeated sessions to gain insight into practice effects. The present study further assessed the effects of practice by administering the tests at varying intervals. This was to examine the relation between spaced practice with respect to performance. It is possible that the nature of the task being practiced, the timing of the delay interval between sessions, or an interaction of these two variables may moderate the relation between task and performance. The impact that practice would exert on the A-PASAT was initially explored in Experiment 3. The impact that practice and length of delay between sessions would exert on the CTIP, A-PASAT and three neuropsychological tests was explored in Experiments 4 and 5.

Experiment 3 was a preliminary study primarily designed to determine whether the effects of practice would be observed on the new computerized A-PASAT. Modality of presentation (visual, auditory) was also examined by using two versions of this new test. Two sessions were conducted using two groups (visual, auditory) of neurologically intact participants with a 20 minute delay between sessions. Results showed that performance on both the visual and auditory version of the A-PASAT was equally affected by practice with improved scores on session 2.

These results support Gronwall (1974) who stated that practice effects are associated with the traditional PASAT. She also stated that most of the practice effects for the PASAT occur during the first and second administration. This contention has been challenged by researchers such as Stuss et al. (1987) and Feinstein (1994). For example, Feinstein (1994) examined practice effects on the PASAT beyond two administrations and reported significant improvement in performance over eight testing sessions. However these results were based on number of errors, which were not even clearly defined. Moreover, Stuss, et al. did not use more than two sessions. Thus, the issue surrounding PASAT performance beyond two sessions remains unclear and was further explored in Experiment 4 and 5. In addition to administering tests over several sessions, the delay interval between each session was varied using a 1 week interval over each of four sessions in Experiment 4 (a). Experiment 4 (b) tested these same participants six months later. Experiment 5 compared how various delay intervals would affect performance by using delays of 20 minutes, 1 week, or 3 months with three separate groups.

The results obtained in Experiments 3 and 4 indicate that most practice effects on the A-PASAT occurred during the second administration of the test. These results are in agreement with Gronwall's (1974) observation discussed above, and provide testimony to her claim that most of the practice effects for the PASAT occur during the first and second administration. Furthermore, this was shown regardless of whether the second administration occurred 20 minutes or one week following the initial administration, showing the robustness of the effects attributable to the experience gained in session 1. This finding suggests that session 2 represents a stable baseline measure against which subsequent performance can be compared. These results indicate that in a clinical situation it may be feasible to administer two assessments and to use the second as a baseline measure. That is, on the second assessment,

practice effects are maximized so that any subsequent changes in performance primarily reflect recovery. Accordingly, this method may provide a more stable and reliable estimate of baseline performance than is currently used, and will help to diminish the potential confound of practice.

The data obtained in Experiment 4 also replicate those obtained in Experiment 3 by showing parallel effects of practice regardless of whether the test was presented in the visual or auditory modality. This finding extends previous research (e.g., Bateman, 1997; Feinstein et al., 1994; Fos et al., 2000; Hiscock et al., 1998) and suggests the possibility that threshold measures obtained using the visual and auditory may assess different processes. Several researchers (Bateman, 1997; Feinstein, et al., 1994; Fos et al., 2000), as well as participants, have indicated that there is a problem in attending to a verbal stimulus (input) while simultaneously producing a verbal response (output). Most likely there is a conflict between the stimulus and the response when using the auditory presentation because both the input and output are verbal. This interference effect would result from the aural articulation "masking" the aural presentation of the numbers. This effect would be especially marked as the length of the ISI became shorter. In contrast, the visual presentation requires that the participant attends to a visual input while producing a verbal output. Thus, processing information along two different channels may facilitate performance on the visual version of the A-PASAT. In agreement with other researchers, the present findings suggest that interference is reduced on the visual compared to auditory PASAT.

Experiment 5 was primarily designed to determine the stability of session 2 as the best baseline measure of performance. To this end, this particular experiment was guided by three research questions: Question 1 addressed the stability of session 2 as the best performance measure against which to gauge subsequent performance. This question was approached by

comparing changes in performance between sessions 1 and 2 to changes in performance on session 3. Question 2 addressed whether variations in the timing of the interval between session 1 and 2 would affect performance on session 2. This question was approached by manipulating the length of the interval using either 20 minutes, 1 week or 3 months between sessions. Question 3 addressed the impact that an intervening session would have on performance when it occurred between session 1 and testing three months later. This final question was approached by interposing session 2 between session 1 and a testing session three months later. If performance had stabilized on session 2, then there should be no further performance advantage observed for this group when tested at three months. In this way, the stability of session 2 was ascertained.

For question 1, results consistently showed that practice effects on the A-PASAT occurred during the first session, with minimal gains in performance over subsequent sessions. In contrast, results consistently showed that both the simple and choice RT tests were resilient to the effects of practice over repeated sessions, but the semantic test was not. However, similar to the A-PASAT, the practice effects observed on the semantic test were most marked between the first two sessions.

For question 2, the absence of a Group and Group x Session effect between session 1 and subsequent sessions indicates that the performance was similar for the three groups, regardless of the time that had elapsed between sessions. This finding suggests that normally functioning individuals will show similar performance on a second test administration whether the delay interval between the two sessions is 20 minutes, 1 week, or three months. Thus, repeated exposure to these newly developed tests appears to be unaffected by the length of the delay interval, at least within the three month period presently explored.

For question 3, the failure to find a difference between session 2 and 3 suggests that strategy effects are fully developed by the end of session 1 with no further benefit gained from an intervening session beyond that already observed in session 2. Moreover, a lack of difference between performance on session 2 and session 3 is a good indicator that session 1 mediates subsequent performance, and substantiates the initial prediction that session 2 would provide the most stable measure of performance. This finding is important as it shows the robustness of the effects developed in session 1, and places additional confidence in the stability of performance obtained in session 2.

Finding that prior exposure to the A-PASAT mediated subsequent performance has important implications for stability of performance when compared to the reliability estimates reported in this research. The reliability of the A-PASAT was evaluated to measure its stability over repeated sessions. Correlation coefficients were obtained for the A-PASAT scores in Experiments 3 through 5 and showed reliability estimates that were consistently high throughout each experiment. Nonetheless, while the reliability coefficient provides an estimate of the stability of the test measure over time, it reflects the relative ranking of participants' performance between two assessments, but nothing about the impact of practice on changes in participants' scores. Consequently, the same test-retest coefficient could be obtained on several occasions even though the change in mean performance is markedly different. The present findings confirm that the psychometric properties of a test are not informative about the systematic changes in performance that result from practice effects.

In contrast to the practice effects observed on the A-PASAT, two of the RT tests (simple, choice) were unaffected by the effects of practice, confirming that the scores obtained on the

first administration of these tests are reliable indicators of performance stability. In contrast, the semantic RT test did show improved performance over the first two sessions, but like the A-PASAT, this improvement was limited to the first two sessions with little change occurring over subsequent sessions. This finding substantiates McCaffrey et al.'s (1992) claim that instruments having a speeded component, require an infrequently practiced response, or that require a conceptualized response, are likely to result in significant practice effects.

Practice effects were also obtained for the three neuropsychological tests, but these were also limited to the first two sessions regardless of the delay that had elapsed between sessions. However, correlations with the A-PASAT and CTIP were very low which indicates that the new tests are measuring components of attention not captured by traditional tests. Again, the multi-dimensional nature of attention and the population being tested should both be taken into account during neuropsychological assessment. Therefore, the task should be congruent with the deficit being tested. Based on the present research, tests that assess conceptual processing and have a speed component are suitable for detecting processing deficits in TBI and aging populations.

Due to the extremely stable performance within sessions, as well as over repeated sessions, the CTIP provides a viable alternative to tests that are sensitive to the effects of practice over repeated sessions. Another important characteristic of the CTIP is the lack of anxiety or frustration experienced by those participating in the tests. In fact, most persons enjoyed the tests and approached them with a sense of challenge, similar to a game. Despite the finding that the CTIP is unaffected by extraneous factors such as practice and skill in numerical or verbal ability, it is still sensitive to decrements in performance as indicated by the longer

latencies for both the severe TBI group in Experiment 1 and the older age group in Experiment 2. Because the simple and choice tests are resilient to practice effects, any gains in performance over time can be more confidently attributed to recovery than current tests. Furthermore, because the semantic test is susceptible to practice effects, failure of improved performance may flag a possible decline in function. As such, using all three tests as a complete battery can provide a comprehensive overview of a person's cognitive status over time. Based on the qualities described, the CTIP provides an effective measure of speed of information-processing that should be seriously considered in clinical and research settings.

Summary. The current findings show that the sensitivity of RT tests to performance deficits depends on the complexity of the information to be processed. Three RT tests were developed based on research which shows that a progressive increase in cognitive load negatively impacts on performance. The results obtained from Experiments 1 and 2 showed a differential impairment of processing between persons having sustained a severe brain injury compared to a healthy control group, as well as between an older group compared to two younger groups. To this end, as tests increased in complexity (simple, choice, semantic) a progressive separation was obtained between healthy controls and TBI patients. Furthermore, this separation also differentiated young from older adults. As predicted, latencies were consistently longer as RT test complexity increased (simple, choice, semantic), a finding that was consistent throughout all the experiments conducted, and across all groups. Most relevant to the present research, however, was obtaining the significant Group x Test interaction when age and TBI were the factors of interest, and finding this same interaction when the duration of interval between tests was the factor of interest. Specifically, the semantic RT test resulted in

longer latencies as a function of TBI and age. Thus, the interaction reflects the differential effect of processing when it occurs at a higher cognitive level.

There were no significant differences found among groups on the two simpler RT tests that assessed either basic response latencies (SRT) or a choice between two alternatives (CRT). This finding supports the central hypothesis of slowed processing for those individuals whose attentional capacity and control may be compromised only on tasks that require either substantial cognitive resources, or self-initiated processes. These findings are also in agreement with the literature which provides evidence that TBI and normal aging are often associated with inefficiencies in conceptual and controlled processing. Thus, the aging process and the effects of TBI on information processing may be viewed as a decline in accessing a high level of elaboration that requires more attentional resources. This assumption is supported by the observation that middle-age and older adults performed as well as young adults on tasks that involved fewer attentional resources.

The present results suggest that limitations in memory processing in both TBI patients and older adults may only be evident on tasks requiring controlled processing. For example, perhaps constraints may be found in memory processes if the task induces time pressure and requires categorizing words according to semantic organization in long-term memory. Increasing task complexity, or switching the category exemplars required to perform a comparison task, should affect response latency according to a capacity deficit hypothesis. In support of this assumption, Timmeran and Brouwer (1999) have suggested that mental slowness after TBI is a result of global slowing of associative strength between nodes, possibly as a result of diffuse axonal injury or structural loss of axonal tissue.

Practice effects were most pronounced on the more complex tests (i.e., A-PASAT, semantic RT) and concur with Collie et al.'s (2003) finding of marked improvement in performance between the first two sessions, with smaller improvements observed on subsequent sessions. Overall, the results from the RT tasks and the A-PASAT show that tasks requiring automatic processing are less vulnerable to the effects of practice than tasks requiring controlled processing. The present results showed that, compared to the Semantic test and the A-PASAT, which require controlled allocation of attention, the Simple and Choice RT tests were unaffected by practice. The observed practice effects are in stark contrast to the high reliability estimates obtained throughout the test sessions, and highlight the importance in making the distinction between psychometric reliability and performance stability. The implication is that when the task involves processing complex information, practice effects are a consideration, especially when a speed component is involved. This implication is primarily based on the finding that task complexity moderated a decrease in response time with repeated exposure. Furthermore, increasing the test-retest interval had no impact on performance by showing similar effects of test complexity and practice for all intervals.

FUTURE RESEARCH

Aging and Practice Effects

The improved performance of young adults in a test-retest situation probably reflects the effects of practice. However, the normal process of aging may require special considerations in the evaluation of practice effects. Decline in intellectual functioning may begin around age 50 in a non-patient population (Albert, Duffy, & Nasser, 1987). Albert et al. (1987) reported a decline in performance between the ages of 30 and 50 on memory tests, particularly on tests

involving delayed recall. Albert et al. also observed that changes in performance were accompanied by changes in the benefits of practice. Ryan, Paolo, and Brungardt (1992) also noted that changes in the magnitude of practice effects for older adults were not as reliable, or robust, as those for younger adults. Shatz (1981) reported that the practice effects of older adults on the WAIS may be half that observed in middle-aged adults. In fact, sometimes, the effects of practice are even nonexistent in older adults according to Shultz. Middle-aged adults may show an increase of 5 IQ points on a retest of the WAIS compared to older adults who show an increase of only 2 points. Similarly, Mitrushina and Shatz (1991) reported that 66-75 year old adults were less likely than 57-65 year-old adults to show test-retest improvement on a battery of neuropsychological tests. Moreover, adults of 75 years and older were not likely to benefit at all from repeated test exposure. Mitrushina and Shatz suggested that it is possible that consistent test-retest scores in older adults may be the result of cognitive decline that is offset by the effects of practice. Therefore, in healthy, young adults, cognitive abilities tend to remain relatively stable compared to older adults. If this is true, then there are important implications for the assessment of younger and older adults (and children). Thus, one avenue for future research is to evaluate the magnitude of change of various age groups over time using the newly developed tests examined in this study. Another area of interest would be to ascertain whether the aging process, or TBI, results in a differential practice effect as the result of various delay intervals among sessions. While there are age-corrected norms available for many neuropsychological tests, consideration should be given to obtaining age-corrected norms for practice effects.

Finally, before either the CTIP and the A-PSAT can be used clinically, it must be

discerned whether other modulating variables are affecting the patient that could be negatively impacting on performance. Variables such as anxiety, depression, and chronic pain may also be present in subgroups affected by TBI, and, as such, these must be accounted for so that the injury per se is responsible for any performance decrements observed in TBI patients. Furthermore, the specific role of IQ has not been adequately established for these measures and provides another avenue for future research.

Change Scores

The present research was limited to group performance due to small sample sizes, which placed restrictions on computing change scores associated with repeated test administrations that indicate real change, or as a source of normative data. While statistical analyses of group means can indicate a significant change in test scores from baseline testing to subsequent testing sessions, they do not indicate if such a change is meaningful. Furthermore, in a clinical setting, the focus of significant change is on the individual, not the group. The magnitude of clinical change is central to monitoring recovery over time, and, as such, requires clinical significance as much as statistical significance. To this end, it is critical to differentiate normal cognitive functioning from pathological or normal age-associated decline. Furthermore, because the central question concerns the degree to which an individual is affected, any clinical interpretation of a change should be based on information about the changes that occur over time for a cognitively-intact individual.

Although norms are available for most tests for assessing individuals at Time 1, norms for change over time are virtually nonexistent (McSweeney, Naugle, Chelune, & Luders, 1993). The few tests that do provide information about stability over time, such as The Mini-Mental

State Exam (MMSE), rely on test-retest reliability coefficients. The principal method for determining reliability is to evaluate the relation between the rank-order of scores from Test 1 to Test 2 by conducting a correlation analysis. However, the coefficients are usually derived from test-retest intervals which are very brief, and produce reliability estimates falling between .80 and .95 (Tombaugh & McIntyre, 1992). Furthermore, such estimates have no relevance in a clinical setting because the test-retest intervals used to monitor recovery are usually longer. Longer intervals produce less reliable scores, such that after a 1 to 2 year interval between testing sessions, coefficients less than .50 have been reported (Mitrushina & Shatz, 1991). Another factor that contributes to lower reliability estimates is regression toward the mean. This refers to the observed tendency for high scores on Test 1 to decline at retest, and for low scores on Test 1 to increase at retest. Thus, scores at both the high and low end of the mean tend to regress, or fall, toward the mean score.

Another limitation of reliability estimates is that while they are a good index of test stability, they do not control for practice effects. Practice effects, as noted earlier, can significantly improve performance due to experience with the test, so the underlying cognitive construct is not accurately assessed. Thus, any interpretation of change in cognitive status over time should consider the effect of prior experience on current performance. Other factors that can influence cognitive functioning include demographic variables such as age, education, and sex. Because these factors can impact on test performance, each factor should be considered in determining changes in performance over time.

Traditionally, changes in performance have been derived from calculating a significant change between scores on Time 1 and Time 2. There are several methods used to determine this change: (1) repeated measures ANOVA, (2) difference scores, and (3) percent change.

Repeated measures ANOVA directly compares scores between test 1 and test 2 to determine how the amount of change varies among different groups. This method requires a control group to compare the percent of change from baseline to retest. A Group x Session interaction will indicate any differences obtained between the control and the experimental groups. Difference scores are calculated by subtracting test 1 from retest (retest- test 1) with a negative difference score indicating a decline at retest. Percent change is calculated by using $(\frac{\text{retest} - \text{test 1}}{\text{test 1}} \times 100)$. A percent score of less than 100% indicates a decrease in performance at retest. Again, these methods are primarily useful for group comparisons but are not particularly useful for estimating the amount of change that would occur for individual participants. Consequently, within a clinical context, there are no indices by which to determine whether or not a change in an individual's performance is significant.

The standard statistical approaches to changes in performance ignore test-retest reliability measures, regression toward the mean, and practice effects. As such, researchers in the last decade have developed various methods for creating reliable change indices. Reliable change indices describe the base rate range of change on a test while taking random fluctuation across time (measurement error) into account (e. g., Basso, Bornstein, & Lang, 1999). The primary purpose of the RCI is to provide a confidence interval that is derived from a distribution of change scores. For example, the RCI developed by Jacobson and Traux (1991) determines a significant change score based on the numeric difference between baseline and retest scores using a normative sample (see Appendix F for a complete summary).

Variability

Reaction time tests have consistently shown that one of the most salient results of head injury is slowness in processing information. While overall slowness is well documented, there

is another aspect of performance after having sustained a head injury that requires further consideration. This aspect involves whether or not head-injured individuals show a change in performance within and across experimental sessions that is different than the change in performance observed in normal controls. Often referred to as consistency in performance, changes in performance over time can be reflected by increases in group variability as measured by the standard deviation, or by increases in individual, or within-subject variability, as measured by the coefficient of variation (see Appendix G).

Although increased intrasubject variability in the head injured patient has been observed in several studies, this finding lacks consistent replication. One factor that may contribute to the failure to replicate changes in variability is differences in the severity of the various head injured groups across studies. Some TBI patients show higher intrasubject variability compared to controls when tested immediately following the injury, but this difference is not observed 6 weeks following the injury (Stuss, Pogue, Buckle, & Bondar, 1994). Another issue concerns the fact that most researchers measure variability as it relates to mean performance, but because RTs are slower in head injured individuals, the observed increase in SDs is merely a result of their overall slowness in performance. "Increases in variability seem to be proportional to increases in mean reaction time" (van Zomeren & Brouwer, 1987, p.409). According to van Zomeren and Brouwer, if RTs are slowed by 50%, the SD should also increase by 50% because calculation of the SD is based on RT. However, despite the lack of replication in intrasubject variability, TBI patients still remain significantly slower than controls. Such a finding suggests that there is a dissociation between variability and speed of response that requires further investigation.

Inconsistency of performance has traditionally been considered to be the result of random

error, but in studies involving clinical populations the issue of variability is one that should not be overlooked. Because variability reflects consistency of performance, it may serve as an index of cognitive stability. Thus, in order to gain insight into recovery of function, an analysis of change and stability in response patterns over time may serve as a valid indicator of change in cognitive status. To determine whether changes in test-retest performance are due to normal fluctuations in random variability (error), practice, or real cognitive change it is necessary to construct a range of scores that define confidence intervals. Confidence intervals are established by knowing how much change "normally" occurs in a cognitively- intact individual. To this end, future longitudinal research could analyze test scores to be interpreted within a range of scores that reflect normal, or, expected changes in performance.

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Appendix A

Table 1

Summary Data for TBI and Control Groups: Experiment 1

TEST	GROUP		
	Control	Mild TBI	Severe TBI
<u>CTIP Score (ms) (SD)</u>			
Simple reaction time	320 (39)	308 (37)	421 (224)
Choice reaction time	537 (104)	531 (93)	770 (480)
Semantic reaction time	801 (158)	831 (219)	1200 (690)
<u>Adjusting PASAT</u> <u>Threshold (ms) (SD)</u>	1531 (313)	1600 (259)	1967 (497)
<u>Neuropsychological</u> <u>Tests</u> <u>(percentiles) (SD)</u>			
Digit Span	58 (29)	60 (30)	34 (25)
Trails A	57 (27)	55 (23)	28 (25)
Trails B	65 (31)	64 (31)	18 (32)
Symbol Digit	55 (27)	66 (22)	29 (27)

Table 2

Summary Data for Within-Session Latencies on Testing: Experiment 1 - Effects of TBI

<i>CTIP Tests</i>		10 Trial Blocks		
		1	2	3
	Group	ms (SD)	ms (SD)	ms (SD)
Simple	Mild TBI	306 (39)	316 (44)	306 (33)
	Severe TBI	420 (242)	440 (266)	412 (183)
	Control	317 (45)	329 (44)	323 (40)
Choice	Mild TBI	535 (109)	526 (87)	546 (94)
	Severe TBI	727 (435)	810 (559)	796 (458)
	Control	540 (119)	555 (113)	554 (109)
Semantic	Mild TBI	964 (286)	812 (247)	817 (221)
	Severe TBI	1277 (729)	1234 (752)	1302 (718)
	Control	786 (192)	927 (180)	788 (151)

Table 3

Correlations among A-PASAT threshold scores, RT tests, and neuropsychological tests of attention: Experiment 1 - Mild TBI Group

Measure	A-PASAT	Digit Span	Trails A	Trails B	Sym Dig
SRT	-.01	.01	-.62	-.62	-.59
CRT	-.21	.01	-.53	-.65	.36
Semantic RT	.47	.01	.14	-.16	.09
Digit Span	-.09				
Trails A	.47	.61			
Trails B	-.08	.84**	.64*		
Sym Dig	-.01	.21	-.03	.53	

* Significant at $p < .05$

** Significant at $p < .01$

Table 4

Correlations among A-PASAT threshold scores, RT tests, and neuropsychological tests of attention: Experiment 1 - Severe TBI Group

Measure	A-PASAT	Digit Span	Trails A	Trails B	Sym Dig
SRT	.40	-.10	-.27	-.34	-.35
CRT	.31	-.26	-.16	-.26	-.34
Semantic RT	.30	.09	-.19	-.27	-.39
Digit Span	-.41				
Trails A	-.48	-.04			
Trails B	-.62**	.25	.82**		
Sym Dig	-.88	.20	.83**	.92**	

* Significant at $p < .05$

** Significant at $p < .01$

Table 5

Correlations among A-PSAT threshold scores, RT tests and neuropsychological tests of attention: Experiment 1 - Control Group

Measure	A-PASAT	Digit Span	Trails A	Trails B	Sym Dig
SRT	.50	-.15	.25	-.05	-.17
CRT	.66**	-.29	-.15	-.27	-.04
Semantic RT	.47	-.22	-.13	-.22	-.08
Digit Span	-.18				
Trails A	-.05	.71**			
Trails B	-.44	.68**	.45		
Sym Dig	-.27	-.09	.08	.31	

* Significant at $p < .05$

** Significant at $p < .01$

Appendix B

Table 1

Summary Data for Age Effects: Experiment 2

TEST	GROUP		
	Young	Middle	Older
<i>CTIP Score (ms) (SD)</i>			
Simple reaction time	303 (42)	329 (53)	309 (33)
Choice reaction time	502 (70)	554 (113)	581 (97)
Semantic reaction time	716 (118)	911 (250)	948 (251)
<i>Adjusting PASAT Threshold (ms) (SD)</i>	1607 (354)	1653 (389)	1776 (423)
<i>Neuropsychological Tests</i>			
Digit Span Forward (# correct)	8.3 (1.9)	9.7 (2.4)	9.2 (2.5)
Digit Span Backward (# correct)	5.40 (1.90)	7.3 (3.10)	7.1 (2.30)
Trails A (secs)	27 (8.20)	26 (7.25)	34 (9.40)
Trails B (secs)	58 (22.20)	62 (21.40)	84 (34.70)
Symbol Digit (# correct)	60 (7.90)	50.45 (13.80)	46.45 (8.10)
<i>Computerized Addition Test (ms) (SD)</i>	1464 (204)	1179 (106)	1062 (84)

Table 2

Summary Data for Within-Session Latencies: Experiment 2 - Age Effects

<i>CTIP Tests</i>		10 Trial Blocks		
		1	2	3
	Group	ms (SD)	ms (SD)	ms (SD)
Simple	Young	304 (61)	313 (44)	303 (37)
	Middle	335 (53)	339 (52)	335 (56)
	Older	314 (35)	308 (36)	308 (45)
Choice	Young	496 (75)	531 (76)	504 (87)
	Middle	557 (123)	570 (140)	557 (105)
	Older	589 (106)	587 (98)	596 (111)
Semantic	Young	496 (23)	530 (24)	504 (23)
	Middle	557 (23)	570 (24)	557 (23)
	Older	589 (23)	587 (24)	596 (23)

Table 3

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 2 - Young Group

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.31	-.13	.06	.03	-.34	.12	-.17
CRT	.09	.26	.02	-.17	.15	.18	-.21
Semantic RT	.31	.39	.01	-.42	.39	.29	-.52*
Addition	.46*						
Digit Fwd	-.14	-.37					
Digit Bk	-.37	-.44*	.49*				
Trails A	.13	-.03	.11	.05			
Trails B	.47*	.31	-.34	-.27	.45*		
Sym Dig	-.60**	-.33	.10	.29	-.31	-.19	

* Significant at $p < .05$

** Significant at $p < .01$

Table 4

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 2 - Middle Group

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.42	.84	-.12	-.04	.24	.02	-.08
CRT	.26	.08	-.11	-.21	.27	.33	-.27
Semantic RT	.16	.07	-.11	-.26	.43	.67**	-.18
Addition	.47						
Digit Fwd	.09	.01					
Digit Bk	-.09	.32	.75**	-.41			
Trails A	.48*	.55	-.07				
Trails B	.29	.02	-.34	-.53*	.65**		
Sym Dig	-.30	-.31	-.61*	-.45*	-.09	-.09	

* Significant at $p < .05$

** Significant at $p < .01$

Table 5

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 2 - Older Group

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.30	.00	-.29	-.19	-.05	.27	-.43
CRT	.40	-.11	-.17	-.06	.43	.30	-.64**
Semantic RT	.47*	-.41	-.10	.14	.16	.23	-.54*
Addition	.17						
Digit Fwd	-.51*	-.38					
Digit Bk	-.35	-.42	.83**				
Trails A	.31	.41	-.02	.05			
Trails B	.60**	.44	-.29	-.16	.78**		
Sym Dig	-.51*	-.04	.34	.20	-.58**	-.69**	

* Significant at $p < .05$

** Significant at $p < .01$

Appendix C

Table 1

Summary Data for Preliminary Practice Effects: Experiment 3-A-PSAT Response Type by Modality

A-PSAT Version	Mean (ms)	Standard Deviation	Threshold Trial Number	N
<i>Best Time 1</i>				
Simple-Auditory	1515	258	158	15
Complex-Auditory	1572	395	169	15
Simple-Visual	1031	317	180	15
Complex-Visual	1301	417	159	15
<i>Best Time 2</i>				
Simple-Auditory	1237	260	164	15
Complex-Auditory	1220	398	175	15
Simple-Visual	727	227	171	15
Complex-Visual	988	304	167	15

Appendix D

Table 1

Summary Data for Practice Effects: Experiment 4(a) and 4(b)-1 week and 6 month delay

TEST	SESSION				
	1	2	3	4	Delay
<i>CTIP Score (ms) (SD)</i>					
Simple reaction time	261 (12)	273 (21)	283 (29)	290 (35)	286(19))
Choice reaction time	456 (48)	479 (69)	493 (65)	515 (92)	472 (58))
Semantic reaction time	660 (112)	636 (118)	630 (113)	625 (120)	606 (73))
<i>Adjusting PSAT Threshold (ms) (SD)</i>					
Visual	1168 (210)	944 (133)	762 (190)	684 (153)	746 (148)
Auditory	1453 (383)	1197 (361)	1064 (274)	1002 (255)	1123 (345)
<i>Neuropsychological Tests</i>					
Digit Span Forward (# correct) (SD)	7.7 (2.5)	8.6 (2.9)	9 (2.5)	9.2 (2.3)	8.8 (2.1)
Digit Span Backward (# correct) (SD)	7.1 (2.1)	7.4 (2.8)	8.3 (2.8)	8.9 (2.7)	8.1 (2.6)
Trails A (secs) (SD)	22.5 (4.6)	19.6 (4.9)	18.5 (8.7)	16.4 (5.8)	16.5 (3.3)
Trails B (secs) (SD)	49.7 (11.2)	40.6 (10.3)	39.6 (12.0)	33.3 (8.3)	36.2 (10.3)
Symbol Digit (# correct) (SD)	59.7 (9.6)	64.6 (10.9)	71.5 (13.8)	77.4 (14.4)	67.1 (15.4)
<i>Computerized Addition Test (ms) (SD)</i>	1341 (231)	1367 (223)	1368 (157)	1431 (158)	1308 (172)
<hr/>					
10 Trial Block					
	1	2	3	4	5
<u>CTIP Score (ms)</u>					
Simple reaction time	276	278	272	285	284
Choice reaction time	470	498	489	479	505
Semantic reaction time	654	645	652	637	638

Table 2

Correlations among A-PSAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 4 - Session 1

Measure	A-PSAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.21	.19	.48*	.38	-.19	.02	.27
CRT	.00	-.11	-.34	-.26	-.12	.06	.25
Semantic RT	.07	-.15	-.27	-.19	.20	.22	-.18
Addition	-.06						
Digit Fwd	.17	.46					
Digit Bk	-.21	.39	.30				
Trails A	.01	.08	-.14	-.22			
Trails B	.43	-.20	-.15	-.03	.34		
Sym Dig	.03	.24	.22	.39	-.66**	-.21	

* Significant at $p < .05$

** Significant at $p < .01$

Table 3

Correlations among A-PSAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 4 - Session 2

Measure	A-PSAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	-.26	-.44	-.04	-.05	-.56*	-.32	-.22
CRT	-.04	-.25	-.24	-.14	-.04	-.19	-.24
Semantic RT	.04	-.12	-.24	-.08	.05	-.10	-.22
Addition	.19						
Digit Fwd	-.32	-.23					
Digit Bk	-.14	-.13	.50*				
Trails A	-.14	-.59*	.14	.01			
Trails B	.52*	-.05	-.05	-.37	-.11		
Sym Dig	-.19	.08	.01	.26	-.17	-.06	

* Significant at $p < .05$

** Significant at $p < .01$

Table 4

Correlations among A-PSAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 4 - Session 3

Measure	A-PSAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	-.23	-.16	.08	-.08	.01	-.26	-.25
CRT	-.04	-.19	.04	.07	-.06	-.22	-.12
Semantic RT	.29	-.09	-.42	-.12	.19	.08	-.39
Addition	.16						
Digit Fwd	-.58*	-.08					
Digit Bk	-.16	-.06	.62**				
Trails A	-.07	.25	-.35	-.44			
Trails B	.44	.09	-.45	-.44	-.58**		
Sym Dig	-.28	-.24	.43	.38	-.57*	-.44	

* Significant at $p < .05$

** Significant at $p < .01$

Table 5

Correlations among A-PSAT threshold scores, RT Tests, addition, and neuropsychological tests of attention: Experiment 4 - Session 4

Measure	A-PSAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	-.17	.03	-.10	-.12	.16	-.05	-.44
CRT	.08	.21	-.33	-.16	.29	.19	-.54*
Semantic RT	.34	-.04	-.47*	-.05	.29	.19	-.27
Addition	.40						
Digit Fwd	-.43	.17					
Digit Bk	-.08	.24	-.49*				
Trails A	.26	.22	-.11	-.28			
Trails B	.17	.06	-.44	-.50*	.71**		
Sym Dig	-.27	-.14	.46*	-.27	.66**	-.54*	

* Significant at $p < .05$

** Significant at $p < .01$

Table 6

Correlations among A-PSAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 4 - Six-month delay session

Measure	A-PSAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	-.32	.04	-.08	-.26	.09	-.30	-.52
CRT	-.04	.05	-.68*	-.43	-.16	.03	.06
Semantic RT	.52	.07	-.35	-.38	.39	.83*	.01
Addition	.32						
Digit Fwd	-.37	-.16					
Digit Bk	-.42	-.01	.63*				
Trails A	.10	.32	-.06	-.10			
Trails B	.44	-.01	-.16	-.46	.55		
Sym Dig	-.52	-.32	.11	.22	-.11	-.01	

* Significant at $p < .05$

** Significant at $p < .01$

Appendix E

Table 1

Summary Data for Practice Effects: Experiment 5 - All Sessions

<u>CTIP Score (ms) (SD)</u>	<u>Group</u>	<u>Session</u>		
		1	2	3
Simple reaction time	20 minutes	293 (45)	295 (22)	279 (19)
	1 week	313 (51)	311 (31)	314 (20)
	3 mths	303 (46)	291 (27)	N/A
Choice reaction time	20 minutes	463 (41)	476 (75)	466 (64)
	1 week	508 (77)	514 (60)	537 (97)
	3 mths	476 (51)	476 (55)	N/A
Semantic reaction time	20 minutes	686 (94)	651 (87)	613 (81)
	1 week	727 (114)	696 (129)	710 (147)
	3 mths	714 (126)	664 (162)	N/A
<u>Adjusting PASAT</u> <u>Threshold (ms) (SD)</u>	20 minutes	1689 (391)	1395 (420)	1425 (380)
	1 week	1668 (433)	1330 (378)	1249 (326)
	3 mths	1555 (416)	1228 (217)	N/A
<u>Neuropsychological Tests</u>				
Digit Span Forward (# correct) (SD)	20 minutes	7.3 (1.5)	7.5 (2.0)	8.5 (2.1)
	1 week	8.2 (1.8)	8.2 (2.0)	8.1 (1.7)
	3 mths	8.4 (2.0)	8.8 (2.0)	N/A
Digit Span Backward (# correct) (SD)	20 minutes	5.4 (1.7)	5.7 (1.9)	6.0 (1.8)
	1 week	5.2 (2.0)	5.8 (2.0)	5.9 (2.1)
	3 mths	6.1 (1.5)	7.4 (1.8)	N/A
Trails A (secs) (SD)	20 minutes	24.5 (6.1)	17.2 (5.1)	17.8 (4.9)
	1 week	29.2 (9.0)	23.7 (7.9)	18.9 (3.6)
	3 mths	29.9 (10.5)	19.7 (4.6)	N/A
Trails B (secs) (SD)	20 minutes	62.4 (25.1)	46.9 (18.1)	44.9 (11.8)
	1 week	61.2 (16.0)	53.1 (14.0)	51.3 (17.6)
	3 mths	62.5 (18.8)	45.1 (10.9)	N/A
Symbol Digit (# correct) (SD)	20 minutes	61.0 (7.9)	74.1 (10.2)	69.9 (7.6)
	1 week	57.3 (8.3)	65.2 (8.7)	65.1 (9.6)
	3 mths	58.5 (10.1)	65.3 (8.5)	N/A
<u>Computerized Addition</u> <u>Test (ms) (SD)</u>	20 minutes	1431 (231)	1303 (214)	1370 (220)
	1 week	1439 (259)	1407 (244)	1420 (240)
	3 mths	1264 (214)	1341 (136)	1345 (220)

Table 2

Summary Data for Within-Session Latencies: Experiment 5 - Session 1

Session 1		10 Trial Blocks		
<i>CTIP Tests</i>		1	2	3
	Group	ms (SD)	ms (SD)	ms (SD)
Simple	20 minutes	287 (33)	297 (50)	289 (38)
	1 week	319 (75)	325 (51)	311 (44)
	3 months	294 (37)	308 (48)	309 (50)
Choice	20 minutes	463 (68)	472 (69)	454 (54)
	1 week	497 (68)	539 (76)	504 (89)
	3 months	470 (57)	494 (69)	502 (61)
Semantic	20 minutes	729 (157)	668 (96)	700 (116)
	1 week	774 (136)	715 (125)	735 (114)
	3 months	757 (150)	727 (132)	708 (136)

Table 3

Summary Data for Within-Session Latencies on Testing: Experiment 5 - Session 2

Session 2		10 Trial Blocks		
<u>CTIP Tests</u>		1	2	3
	Group	ms (SD)	ms (SD)	ms (SD)
Simple	20 minutes	293 (25)	300 (25)	295 (34)
	1 week	314 (42)	308 (27)	312 (25)
	3 months	297 (30)	299 (47)	271 (78)
Choice	20 minutes	463 (78)	503 (79)	487 (58)
	1 week	497 (58)	517 (56)	524 (60)
	3 months	450 (47)	467 (61)	501 (80)
Semantic	20 minutes	660 (98)	671 (113)	649 (97)
	1 week	734 (139)	700 (159)	681 (128)
	3 months	656 (195)	656 (148)	678 (157)

Table 4

Summary Data for Within-Session Latencies: Experiment 5 - Testing At Three Months

Three months		10 Trial Blocks		
<u>CTIP Tests</u>		1	2	3
	Group	ms (SD)	ms (SD)	ms (SD)
Simple	20 minutes	274 (20)	282 (23)	281 (25)
	1 week	315 (31)	319 (25)	314 (26)
	3 mths	297 (30)	299 (47)	271 (78)
Choice	20 minutes	475 (57)	492 (72)	449 (64)
	1 week	540 (126)	528 (86)	540 (85)
	3 mths	450 (47)	467 (61)	501 (80)
Semantic	20 minutes	654 (92)	608 (69)	617 (92)
	1 week	756 (182)	710 (150)	718 (147)
	3 mths	656 (195)	656 (148)	678 (157)

Table 5

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 5 - Group (20 mins) at Session 1

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.38	-.21.	-.14	-.16	.39	.01	-.30
CRT	-.01	-.22	-.10	-.43	.28	.36	.01
Semantic RT	.27	-.05	.15	-.30	.40	.10	.12
Addition	.05						
Digit Fwd	-.49	-.31					
Digit Bk	-.43	.04	.47				
Trails A	.41	-.19	-.02	-.08			
Trails B	.24	-.41	-.16	-.30	.51		
Sym Dig	-.57*	.39	.31	.33	-.32	-.15	

* Significant at $p < .05$

** Significant at $p < .01$

Table 6

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 5- Group (1 week) at Session 1

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.35	-.13	.16	.05	-.54	.17	-.06
CRT	.12	.35	-.10	-.01	.07	-.01	-.16
Semantic RT	.45	.73**	-.06	-.13	.36	.39	-.51
Addition	.62*						
Digit Fwd	-.04	-.37					
Digit Bk	-.40	-.38	.53				
Trails A	.04	.23	.20	.21			
Trails B	.61*	.64*	-.27	-.07	.29		
Sym Dig	-.66*	-.68*	.24	.37	-.20	-.37	

* Significant at $p < .05$

** Significant at $p < .01$

Table 7

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 5 - Group (3 months) at Session 1

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	-.09	-.46	-.17	-.01	.33	.17	-.49
CRT	.49	.12	-.16	-.23	.56	-.22	-.54
Semantic RT	.50	.32	.19	-.08	.01	-.55*	-.36
Addition	.65*						
Digit Fwd	-.02	-.07					
Digit Bk	-.41	-.50	.45				
Trails A	.56*	.27	-.22	-.23			
Trails B	-.28	-.16	.02	.38	.34		
Sym Dig	-.07	.35	.14	-.27	-.16	-.14	

* Significant at $p < .05$

** Significant at $p < .01$

Table 8

Correlations among A-PASAT threshold scores, addition, and neuropsychological tests of attention: Experiment 5 - Group (20 mins) at Session 2

Measure	A-PASAT	Addition	Digit Fwd	Digit Bk	Trails A	Trails B
Addition	.45					
Digit Fwd	.05	-.55				
Digit Bk	-.38	-.08	.40			
Trails A	.17	.63	-.15	-.30		
Trails B	.37	.31	-.20	-.19	.15	
Sym Dig	-.33	.64	-.20	.48	-.14	.02

* Significant at $p < .05$

** Significant at $p < .01$

Table 9

Correlations among A-PASAT threshold scores, addition, and neuropsychological tests of attention: Experiment 5- Group (1 week) at Session 2

Measure	A-PASAT	Addition	Digit Fwd	Digit Bk	Trails A	Trails B
Addition	.85**					
Digit Fwd	-.46	-.65*				
Digit Bk	-.53	-.54	.47			
Trails A	.64*	.66*	-.51	-.37		
Trails B	-.07	.22	-.01	-.44	-.12	
Sym Dig	-.68*	-.60	.36	.35	-.66*	-.25

* Significant at $p < .05$

** Significant at $p < .01$

Table 10

Correlations among A-PASAT threshold scores, RT tests, and neuropsychological tests of attention: Experiment 5 - Group (20 mins) at three months

Measure	A-PASAT	Digit Fwd	Digit Bk	Trails A	Trails B
SRT	.13	-.08	-.47	-.52	-.10
CRT	-.28	.35	-.29	.23	.15
Semantic RT	-.12	.17	-.13	.19	-.10
Digit Fwd	-.30				
Digit Bk	-.31	.42			
Trails A	.51	-.29	-.52		
Trails B	.50	.07	-.10	.50	
Sym Dig	-.34	.06	.28	-.32	-.63*

* Significant at $p < .05$

** Significant at $p < .01$

Table 11

Correlations among A-PASAT threshold scores, RT tests, addition, and neuropsychological tests of attention: Experiment 5 - Group (1 week) at three months

Measure	A-PASAT	Addition	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.16	-.26	.08	.09	-.06	-.29	.30
CRT	.37	-.65*	.08	-.01	.40	-.26	-.04
Semantic RT	.39	.23	.21	.42	.30	-.14	.01
Addition	.92						
Digit Fwd	-.22	-.33					
Digit Bk	-.44	-.51	.67*				
Trails A	.67*	.77	-.66*	-.54			
Trails B	-.13	.51	-.19	.26	.02		
Sym Dig	-.58*	-.98	.16	.63*	-.46	-.52	

* Significant at $p < .05$

** Significant at $p < .01$

Table 12

Correlations among A-PASAT threshold scores, RT tests, and neuropsychological tests of attention: Experiment 5 - Group (3 months) at three months

Measure	A-PASAT	Dig Fwd	Dig Bk	Trails A	Trails B	Sym Dig
SRT	.31	-.25	.22	-.22	.49	.30
CRT	.12	-.35	-.04	.14	.40	-.04
Semantic RT	.18	-.12	.16	-.03	.36	.01
Digit Fwd	-.37					
Digit Bk	-.40	.42				
Trails A	.18	.07	-.39			
Trails B	.13	-.64	-.27	.01		
Sym Dig	-.42	.21	.39	-.37	-.19	

* Significant at $p < .05$

** Significant at $p < .01$

Appendix F

Reliable Change Indices (RCI)

Reliable change indices describe the base rate range of change on a test with random fluctuation across time (measurement error) taken into account.

1. Difference scores. This method requires a control group to compare the percent of change from baseline to retest. A Group x Session interaction will indicate any differences obtained between the control and the experimental groups, so will only work if control group shows practice effects.
2. Standard Deviation Index. This method does not require a control or normative group. It is calculated using the difference between two testing sessions relative to the SD of session 1. An obtained score greater than 1 indicates a real change.

$$\frac{X_2 - X_1}{SD_1}$$

3. RCI (Jacobson and Traux (1991))

$$RCI = \frac{X_2 - X_1}{SE_{diff}}$$

$$SE_{diff} = \sqrt{2 (Se)^2}$$

$$Se = s_1 \sqrt{1 - r_{xx}}$$

Where X_1 and X_2 represent the baseline and retest scores respectively. SE_{diff} provides the spread of dispersion of change scores that would be expected to occur if there was no change between the 2 scores. Se is the standard error of measurement which uses the SD of the normative group at baseline and the test-retest reliability coefficient (r_{xx}).

An RCI exceeding ± 1.64 times the S_{diff} would be considered a chance occurrence as this corresponds to 5% in either end of a two-tailed distribution (± 1.64 SD units from the mean).

Hence, the RCI index can be used to determine the limits of individual change that are within or beyond normal fluctuation. A change score is considered significant if it lies outside the 90% confidence interval (95% one-tailed).

4. Dikmen, Heaton, Grant, and Temkin (1999) have used a variation of Jacobson & Traux's RCI by calculating the difference between T1 and T2 and dividing by the SD of these difference scores. This method does not take into consideration the test-retest reliability (error) but instead uses the SD of the difference scores to create the SD diff.

$$\frac{T2 - T1}{SD \text{ diff}}$$

The SD diff of the normative sample is multiplied by 1.64 to obtain the RCI.

5. Chelune, Naugle, Luders, Sedak, & Awad (1993) revised the original RCI to take into account practice effects by incorporating a correction factor. This correction factor is derived by subtracting the difference between the two group means ($X2 - X1$) from an individual's difference score ($X2 - X1$), and then comparing this score to 1.64 times the SD of either the SD diff or the SE diff.

6. Standard Error of Prediction (SEP) Charter (1996) criticized the RCI method because the SE diff is based on the assumption that the SEM (standard error of measurement) between assessment is uncorrelated. But Charter argues that the SEM between baseline and retest has to be related because of practice effects. To control for this difficulty, he proposes using the Standard Error of Prediction (SEP)

$$SEP = SD y_2(1 - r_{y_1y_2}^2)$$

$SD y_2$ is the SD of scores at retest and $r_{y_1y_2}$ is the correlation between test scores across sessions.

The confidence interval is predicted by multiplying the SEP for the normative group by 1.64.

7. Regression Approach. McSweeney, Naugle, Chelune, & Luders (1993) recommend this method because it corrects for regression toward the mean and practice effects due to repeated testing. Unfortunately, the regression approach does not take into account the SEM, so it is necessary to use a z-score transformation to utilize the SEM. Conversion to z-scores also allows for direct comparisons among various test measures.

The basic regression procedure determines those factors that may impact on performance at follow-up in a control group, such as age, education, test-retest interval, and baseline score. Baseline score is entered first and then the remaining variables are entered using a stepwise procedure based on the partial correlation with the criterion variable. The level of entry or removal (PIN) is set at .15 at each step.

The equation is $Y = bX + C$.

Y is the predicted score based on b is the regression coefficient, X is the baseline score and C is the intercept (a constant).

Appendix G

Measures of Within-Subject Variability or Intra-Individual Variability

Intra-Individual Variability refers to the variance within a series of trials by one individual, and can be assessed using the statistical measures outlined below.

1. Individual Standard Deviations. This method compares the mean of the individual SDs of the patient and control groups.
2. Coefficient of Variation (CV). This method indicates response variability while controlling for speed (RT) differences by using each individual's SD divided by the group mean. In this way, the CV indicates the degree of individual differences within a group with differences in RT controlled. The formula is expressed $CV = SD/(\bar{x}RT) \times 100$, as a percent of the group mean. Thus, the larger the CV, the larger the dispersion relative to the mean.
3. Multiple Regression. This method obtains variability uncontaminated by RT through partialling out the absolute RT from the within-subject SD. In this way, the variance in SD is unconfounded by the variance due to RT (RT held constant). Another way is to use multiple regression to partial RT out of the SD and save the residuals (SD resid) and use these residual scores as the dependent variable (DV). Thus, SD resid refers to the residual variability in participants' response times unconfounded by the mean response speed.
4. Semi-interquartile Range. This method uses the ratio of the semi-interquartile range and the median RT (using half the difference between 75th and the 25th percentile $(Q75 - Q25)/2$). A very stable index as it is not affected by extreme values in both tails of the distribution curve. Because the median lies at Q2, if the distribution is normal then it will lie halfway between Q1 and Q3. If the distribution is skewed then the median will lie closer to either Q1 or Q3. Van Zomeren & Brouwer (1987) found that the average median and the

average Q for their patient group was 400 ms and 31 ms respectively, while for the patients these scores were 352 ms and 27 ms. The interquartile deviation was similar in both groups (8% of the median RT). In addition, these authors found that using the Q did not contribute any more to predicting group membership (TBI vs Control) than did using the medians alone (correlations between RT and group membership only increased from .55 to .56 using the Q).

A more sensitive measure may be to use the difference between the 10th and 90th percentile (uses the fastest 10% of median RT and slowest 10%). However, Van Zomeren & Brouwer (1987) found no differences between these measures.

Between-Subject Variability or Inter-Individual Variability

Inter-Individual Variability refers to differences in the variance within a series of trials between groups.

1. Standard Deviation. Calculate the standard deviation of each group to look at differences in overall variability between groups

2. Group Coefficient of Variation (CV). Calculate the group SD and divide by the group mean to hold RT constant.