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**The Effects of Modality of Presentation and Problem Type on the Adjusting
Paced Serial Addition Task**

Jodie L. Royan

**A thesis submitted to the Faculty of Graduate Studies and Research in partial
fulfillment of the requirements for the degree of Master of Arts in
Psychology**

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August 20 2001**

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**The undersigned recommend to the
Faculty of Graduate Studies and Research
Acceptance of the thesis:**

**"The Effects of Modality of Presentation and Problem Type
on the Adjusting Paced Serial Addition Task"**

submitted by

Jodie Royan

**in Partial fulfillment of the requirements for
the degree of Master of Arts**

Chair

Thesis Supervisor

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Abstract

The Adjusting Paced Serial Addition Task (APSAT) is a new, modified version of the original PSAT. The APSAT was administered both visually and aurally to determine if modality had an effect on performance. Also, two versions (restricted and unrestricted) consisting of different problem types were investigated to determine whether problem complexity had an effect on performance. The APSAT was administered along with several classic tests of attention and a math test to 60, non-head injured undergraduate psychology students. In this way, the relationship between APSAT performance, attention, and math ability could be examined. The main purpose of the study was to investigate whether the different APSAT versions measured different cognitive processes and to make recommendations for the future clinical use of this tool. Evidence suggested that the visual and auditory versions of the APSAT may tap into different cognitive processes and that math ability may have an effect on APSAT performance. Results revealed that: (1) auditory presentation of the APSAT may tap into more cognitive processes than visual presentation, (2) a combination of or individual use of either the APASAT or APVSAT may be clinically useful for head injury assessment, and (3) APSAT versions that include complex problem types should not be used clinically. Thus the restricted-APASAT and restricted-APVSAT are suggested for clinical use.

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Introduction

The purpose of the present study is to investigate the effects of several variables on a modified version of the Paced Serial Addition Task (PSAT) and to make recommendations for future clinical use of this measure. Literature on the traditional PSAT, first developed as the PASAT by Gronwall and Sampson (1974), will be discussed to provide a background for this new modified PSAT. However, the new version will not be compared to the traditional PSAT in the experimental design. Rather, the questions surrounding the nature of the PSAT will be applied to the modified version.

There are two versions of the PSAT: the Paced Auditory Serial Addition Task (PASAT) and the Paced Visual Serial Addition Task (PVSAT). The PSAT is the most widely used test of attention for assessing rates of information processing, particularly with head injured patients. The PSAT was developed as an experimental tool to examine the role of immediate memory and attention on a paced performance task (Corballis & Sampson, 1963; Sampson, 1956; Sampson, 1958 a & b; Sampson & MacNeilage, 1960). Later versions of the PSAT were adapted to clinically assess head injured patients (Gronwall, 1977; Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974). This adaptation involved aural rather than visual presentation and is referred to as the PASAT.

The main task of the PSAT is the serial addition of single digit numbers from 1 through 9. A series of digits are presented either visually or aurally and the participant must add the two most recent digits. For example, if the digits '3', '6', and '2' were presented, the participant would respond with the correct sums, which are '9' and then '8'. The participant must respond during the inter-stimulus intervals (ISIs) in order for a response to be correct.

Participants complete four trials, each consisting of a series of 61 digits with increasingly shorter ISIs (2.4 s, 2.0 s, 1.6 s, and 1.2 s). As the ISIs become shorter, the participant's information processing capacity is progressively challenged as he/she has less and less time to: (a) retain the last digit presented, (b) mentally add this to the next digit, and (c) inhibit the response from the previous sum from intruding on the current addition task.

Although the PSAT is considered a useful measure of information processing speed (Spreen & Strauss, 1991), there are some inherent problems with validity. That is, does the PSAT really measure what it is intended to measure, speed of information processing? Early literature on the PSAT suggested that individuals process information along a single channel that has limited resources (Gronwall & Sampson, 1974). Several studies also indicated that the PSAT yielded an index of the speed at which this information was processed along the channel (Crawford, Obonsawin, & Allan, 1998; Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974; Stuss, Stethem, & Poirier, 1987). However, later literature indicated that the PSAT might measure other cognitive processes in addition to speed of information processing (Diamond, DeLuca, Kim, & Kelley, 1997; Dieher & Heaton, 1998; Fos, Greve, South, Mathias, & Benefield, 2000; Hiscock, Caroselli, & Kimball, 1998; Madigan, DeLuca, Diamond, Tranmontano, & Averill, 2000).

One cognitive process that the PSAT may measure in addition to processing speed is working memory. This idea surfaced with the discovery that performance on the auditory version differed from that on the visual (Bateman, 1997; Diamond et al., 1997; Fos et al., 2000, Hiscock et al., 1998). In addition to potentially providing an index of working memory, there is a possibility that the PSAT may reflect math ability in addition to rate of information processing.

Before discussing these issues on the validity of the PSAT, a definition of what this tool purportedly measures (i.e., rate of information processing) will be provided.

Theories of attention

Attention can be described in terms of how it is measured. The most important point to remember when measuring attention is that attention can't really be conceived as a unitary process. Rather, there are several component processes of attention that can theoretically be teased apart with various neuropsychological measures. While component processes of attention are recognized (Mateer & Mapou, 1996; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991, van Zomeran & Brouwer, 1994), there is no evidence of one-to-one relationships between brain structure and attentional processes (van Zomeran & Brouwer, 1994). Even though there is no direct evidence of these relationships, van Zomeran and Brouwer (1994) point out that consistent relationships have been found between performance on cognitive tasks and specific neurologic patient characteristics. These cognitive tasks are often identified by the component of attention that they tap into. However, these different measures of attention tend to be inter-related

Arousal

Arousal, or alertness, can be viewed as one the most basic forms of attention. Alertness has been described as a subcortical process necessary for the operation of attentional systems (Gronwall, 1987). The measurement of alertness is two-fold. First, a 'phasic' or rapid change in level of alertness can be measured both electrophysiologically and behaviourally (vanZomeran & Brouwer, 1994). Phasic increases in alertness can be assessed by comparing an individual's reaction time to a stimulus with and without a warning signal (vanZomeran and Brouwer, 1994). The difference between the warned and un-warned reaction time (RT) gives an approximation of the time required to 'switch' levels of alertness (vanZomeran & Brouwer, 1994). A second form

of arousal can be measured through tonic changes in alertness. A tonic change is a more gradual change in level of alertness that can be measured over a period of time. Observation of an individual's daily behaviour may reveal reduced levels in tonic alertness (vanZomeran & Brouwer, 1994).

The study of head injured patients' levels of phasic and tonic alertness provides an opportunity to understand the connection between arousal and other attentional processes. For example, tonic changes in alertness do not appear to be reduced in head injured individuals whereas phasic levels of alertness do seem to be reduced in this population (Gronwall, 1987). Attentional problems in head injured populations may, in fact, be due to an increased effort, which appears as an increased tonic change in alertness, required to complete an attentional task. This increased effort may in turn be due to a *decreased* phasic change in alertness or a processing deficit (Gronwall, 1987). Thus, there may be a connection between a basic level of arousal and other attentional processes.

Sustained Attention

Sustained attention or vigilance is another attentional process measured in neurologically impaired populations. Vigilance can be defined as the ability to maintain a continuous level of alertness over time in the absence of distraction. In terms of measurement, vanZomeran and Brouwer (1994) describe sustained attention through a variety of tasks including vigilance and monitoring. In comparison to observational measures of tonic changes in alertness, vigilance tasks require a participant to focus on a particular task over time. Specifically, these tasks involve the detection of a low frequency signal over a long period of time.

A continuous performance task (CPT) is a vigilance task often used to measure sustained attention. For example, when viewing a series of letters presented on a computer screen, a

participant may be required to react only to the letter 'x'. Over a period of about one half hour, the number of errors would be measured to see if there was a decrease in signal detection.

Head injured groups usually have lower signal detection than controls on vigilance and monitoring tasks such as the CPT, yet both groups are often equivalent on maintaining their respective levels alertness over the duration of a task (vanZomeran and Brouwer, 1987). For example, Ponsford and Kinsella (1992) found that head injured individuals' RTs were significantly slower to visual stimuli than non-head injured individuals. However, their responses *over time* were not significantly different from non-head injured individuals. These findings correspond to Gronwall's (1987) earlier research where phasic arousal, or signal detection, was decreased with head injury, but tonic arousal, or levels of attention over time, was not.

Selective Attention

A third component of attention is selective attention. This type of process requires the ability to ignore a particular stimulus (distractor) while focusing on another stimulus (signal). As vanZomeran and Brouwer (1994) illustrate, selective or 'focused' attention can be assessed both visually and aurally. A dichotic listening task measures auditory selective attention through the simultaneous presentation of the target text to one ear and distractor text to the other ear (vanZomeran & Brouwer, 1994).

Visual focused attention can be assessed through a number of visual 'search' tasks. An example of a visual search task is the Letter Cancellation Task where certain letters must be canceled from horizontal rows of a variety of letters. A second visual search task is the Trail Making Test (TMT), B-form (vanZomeran & Brouwer, 1994). For the TMT-B, participants must connect circles containing numbers and letters in order as quickly as possible. This task

taxes selective attention because the participant must alternately switch from letter to number, thus the signal and distractor are constantly changing.

Another measure often used for the assessment of selective attention is the Stroop Color and Word Test (Stroop). The Stroop was originally designed to measure selective attention and cognitive flexibility (Spreen & Strauss, 1998). The key component of this task is to name the colour of ink of colour words as quickly as possible. Thus, a participant must suppress the name of the word (i.e., 'green', 'red'...) in order to name the appropriate coloured ink of a word. The decreased speed required to name colours due to suppressing the reading of colour words is called the 'Stroop effect'.

Research has revealed that severely head-injured patients tend to respond more slowly on the Stroop task than normal individuals, but not necessarily on the interference condition alone (Ponsford & Kinsella, 1992; Spreen & Strauss, 1998). In order to elicit the interference effect in mildly head injured individuals, a more challenging version of the Stroop is required (Spreen & Strauss, 1998). A modification that provides this challenge requires participants to switch between reading the word and naming the colour (Spreen & Strauss, 1998).

Information processing

A fourth type of attention often measured with neuropsychological tests is information processing. Another side of information processing, or *speed* of information processing is capacity. Weber (1990) defines capacity as the amount of information that a person can attend to within a given time. Other researchers have also referred to capacity in terms of time limits. For example, Broadbent (1958) defined capacity as "...the limiting quantity of information which can be transmitted through a given channel in a given time." Similarly, Gronwall and Sampson (1974) defined channel capacity as the amount of information that can be processed within finite

limits. The underlying theme of capacity theory is that there are a limited amount of resources available to process information. In terms of speed, the faster people can process information the more information they can obtain, and the larger their capacity.

A test of reaction time provides an index of just how fast an individual can process information and thus reflects their capacity for information. For example, if head injured individuals respond to a stimulus within 1000 ms and non-head injured individuals respond within 800 ms, it can be assumed that the non-head injured group can obtain more information because they react to information at a faster rate. That is, if they process information more quickly, then they have a larger capacity (vanZomeran & Brouwer, 1994). Head injured individuals have, in fact, demonstrated a longer RT or reduced information processing speed in comparison to non-head injured individuals (Gronwall & Sampson, 1974; Ponsford & Kinsella, 1992).

In addition to RT tasks, another type of task also provides an index of capacity. This task involves the presentation of a series of tasks to be completed within a time limit. Unlike RT tasks, this type of procedure sets limits within which the participant responds to stimuli. Thus, the *amount* of information an individual can process is assessed. The PSAT is a measure that provides this type of assessment by way of the time-constrained manipulation of several tasks. The PSAT tasks include: (a) retaining the most recently presented digit, (b) mentally adding this to the next digit, and (c) simultaneously inhibiting the response from the previous sum from intruding on the current addition task. A response is considered correct only if it is made within the time-constraint or ISI for a particular trial. Along with providing a time constraint, the PSAT 'pushes the system' with increasingly shorter ISIs to see just how fast an individual can process information. Therefore, by providing a series of tasks within an increasingly shorter time-

constraint, the PSAT score reflects how much information is acquired. Since the PSAT task requires the mental manipulation of several pieces of information, the PSAT score is also believed to reflect working memory, which can be described as a theoretical system that temporarily stores and manipulates information needed for essential cognitive processes such as learning and reasoning (Baddley, 1990).

An individual's PSAT score is calculated a number of ways. One type of score is the number of correct responses for each pacing trial and summed over all trials. Another index of processing speed is time per correct response for each trial. This measure is calculated by dividing the time taken to complete a trial by the number of correct responses in that trial. The average time per correct response can be used to compare participants on particular ISI trials (Gronwall, 1977). That is, the average time per correct response may not be useful to compare subjects across ISIs as some ISIs are often eliminated in some experimental designs (e.g. Chronicle & MacGregor, 1998; Egan, 1988; Feinstein et al., 1994; Ward, 1997).

Although Gronwall (1977) states that this type of scoring system is useful when researchers have used different numbers of trials per ISI, using the average time per correct response over all trials may not be useful. This is true as researchers often use different numbers of ISIs. That is, one experimenter may only use the 2.0 and 1.2 s ISI, while another may use the full range of ISIs.

Prior to discussing the benefits of PSAT scores and the question of whether the PSAT *only* measures of speed of information processing, a history on the development and use of this measure will be presented.

History of the PSAT

Sampson (1956) developed the PSAT in order to study the effects of pacing (i.e., the frequency of stimulus presentation) and duration (i.e., length of stimulus exposure) on performance. He studied the effects of pacing on performance by recording response times for the addition of visually presented digits. The auditory version of this task, the PASAT, draws upon the same procedure, but through a different modality.

Early Studies: Stimulus duration vs. pacing

Sampson (1956) originally manipulated the duration of stimuli by leaving the digits on for 0.4, 0.8, and 1.2 s and off for the same intervals. The pacing of stimuli was manipulated through different random combinations of the 'on-off' phases. These combinations allowed for the presentation of digits at 2.4, 2.0, 1.6, 1.2, and 0.8 s ISIs in random order. Sampson found that there was a significant decrease in the percentage of correct answers as the ISIs shortened from 2.4 s/digit to 0.8 s/digit. Interestingly, the number of omissions increased more than the number of incorrect answers with the increased pacing. This may have indicated that participants were not able to sum digits fast enough to attempt a response, be it correct or incorrect.

Sampson and MacNeilage (1960) examined the role of stimulus duration on the ability to rapidly sum visually presented digits. They found that a 0.4 s stimulus duration was ideal. In addition to this finding, the results from this and other studies on stimulus duration (Sampson, 1958) led to the conclusion that it was increased pacing, not stimulus duration, which was affecting performance on the paced serial addition task. Sampson and MacNeilage (1960) suggested that increased pacing affected performance because changes in pacing disturbed immediate memory. That is, as the pacing became increasingly faster, there was less time

available to retain digits through mnemonic or any other types of memory devices (Sampson & MacNeilage, 1960).

Today, the PSAT is considered to be more a test of one or more aspects of attention rather than immediate memory. This concept of measuring attention with the PSAT was first addressed by Sampson and MacNeilage (1960). They suggested that as long as the series of stimuli were homogeneous, or always digits, the paced task forced a constant attentional requirement on the participant. Furthermore, Sampson and MacNeilage (1960) proposed that variations in adding performance or less than perfect performance revealed a central process, immediate memory, that could be examined in addition to other peripheral processes.

If a paced serial addition task does indeed tap into a central process such as immediate memory, or short term memory (STM) as it is called today, then such a task may be useful in the assessment of individuals with deficits in STM. However, today the central process considered to be measured by the PSAT is speed of information processing rather than STM (Brittain, LaMarche, Reeder, Roth, & Boll, 1991; Crawford et al., 1998; Gronwall & Sampson, 1974; Levin et al., 1987; Roman, Edwall, Buchanan, & Patton, 1991; Stuss et al., 1987; Wiens, Fuller, & Crossen, 1997; Wingfield, Holdwick, Davis, & Hunter, 1999). However, current research suggests that different measures of attention, such as those for speed of information processing, sustained attention, focused attention etc. reflect a common cognitive process in addition to a discrete aspect of attention. Thus, the assertion that the PSAT primarily reflects processing speed is questionable. Expansion of this issue will be provided in the discussion section.

Attention and head injury

One of the most common results of a closed head injury (CHI) is diffuse axonal injury (DAI) (Alexander, 1995; Binder & Rattok, 1989; King, 1997; Weber, 1990). This injury results

in reduced speed of information processing due to the reduced transmission of information within the nervous system (Whyte, 1992). This reduced processing speed is consistently found across variable severities of head injury (Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974; Mateer & Mapou, 1996; Ponsford & Kinsella, 1992). Another common result of CHI is damage to the frontal lobes (King, 1997; Ponsford & Kinsella, 1992) that affects the ability to control the allocation of attentional resources (Whyte, 1992). Both of these types of injury can lead to deficits in attention in different ways. First, if processing speed is reduced, then the ability to attend to as much information at one time may be reduced (Weber, 1990). This may result in concentration problems because the ability to rapidly process information has been reduced (Weber, 1990). Second, a reduced ability to control attention may lead to deficits in dividing attention amongst incoming information (Mateer & Mapou, 1996; Weber, 1990). That is, the ability to rapidly process information may still be intact, but the ability to guide this rapid processing is not. As a result, head injured patients may have problems switching their attention from one source of information to another or may lose track of what they are saying, doing, or thinking (Weber, 1990).

Head injured patients often manifest a combination of both of the above types of deficits (Weber, 1990). These deficits in speed of processing and control of attention make up what Schneider and Schiffman (1977) call effortful or controlled processing. This type of processing may be the source of a variety of other symptoms such as memory and concentration problems. That is, the more automatic processes needed for over-learned tasks such as driving may remain intact; however, the ability to engage in more effortful activity such as driving while listening to the radio may be compromised.

There are a variety of measures available to assess the above deficits as described in previous sections. Amongst these, the PSAT is often selected to assess the underlying deficit of reduced processing speed. However, the PSAT may measure other cognitive functions such as working memory. If this is true, then reduced performance on the PSAT may reflect a deficit in another cognitive domain other than, or in addition to, processing speed. This, in turn, may have some important implications for rehabilitation.

The PSAT as a clinical tool

Gronwall and Sampson (1974) first used the PASAT as a clinical assessment tool to measure the extent of reduced speed of information processing in concussed patients. Gronwall and Sampson (1974) made one major change to Sampson's (1956) original version of this paced serial addition task. The modality of presentation was auditory rather than visual. The auditory method of presentation was most likely developed for convenience. A tape recorder was used to present the task to head injured patients. This device would have been much more convenient to transport to the patient than the original projection apparatus used by Sampson.

Besides modality of presentation, PASAT administration is similar to that of Sampson's PVSAT where the two most recent digits in a series of numbers are added. Random series of digits from 1 to 9 are presented orally via pre-recorded tape cassette in five sets of variable ISIs. Stimulus duration was maintained at an average 0.4 s/digit with ISIs increasing from 0.8 s to 2.4 s in 0.4 s increments for each set.

Gronwall and Sampson (1974) found that the PASAT was sensitive to deficits in information processing in concussed patients, as were symbolic choice reaction time tasks that required extra information processing in comparison to non-symbolic choice reaction time tasks. The non-symbolic choice RT task required participants to press a key on a pinball machine-like

apparatus at the base of an alley that the ball had entered. The symbolic task required participants to depress a numbered key according to which numbered alley the ball had entered. Two main findings from Gronwall and Sampson's (1974) studies were: (a) concussed patients performed significantly worse than controls on the PASAT, and (b) concussed patients performed significantly worse on symbolic choice reaction time tasks than controls.

Gronwall and Sampson's (1974) study was the first among many to demonstrate the value of the PASAT as a clinical tool (e.g., Diamond et al., 1997; Gronwall, 1977; Gronwall & Wrightson, 1974). For example, Gronwall (1977) demonstrated the PASAT's sensitivity to concussion. She investigated the PASAT as a measure of recovery from mild concussion that could be used as a potential guide to rehabilitation and return to work. Head injured individuals' PASAT performance was compared to performance of age-matched controls. If performance was below 1 SD of controls on an initial screening test, head injured participants were admitted to an occupational therapy program which included weekly retests on the PASAT. As their PASAT scores approached the 1 SD cut-off, patients were gradually re-integrated into their former work settings.

The results of Gronwall's (1977) research revealed recovery curves where PASAT performance improved over 60 days following injury for patients on the rehabilitation program. Based on the results of her study, Gronwall (1977) concluded that return to work difficulties experienced by head injured patients might have been related to a decreased ability to process information as rapidly as normal. Gronwall suggested that return to work could be guided by PASAT performance such that scores approaching the 'normal' range indicated a relative return to 'normal' speeds of information processing.

However, Gronwall (1977) did provide a note of caution with her interpretation. This caution was that 'normal' scores on the PASAT did not necessarily reflect fully recovered processing capacity. Yet, it is possible for an individual to function adequately in the work place with a lower than normal capacity. Thus, some additional means of assessing readiness to return to work may be required.

Another problem with Gronwall's (1977) interpretation is that the ability of the PASAT to *predict* eventual return to work is unknown. The direction of this cause-effect relationship remains unresolved. That is, does normal PASAT performance predict a readiness to return to work or does a successful return to work predict normal PASAT performance? As Gronwall (1977) explained, the PASAT can only be useful for guiding return to work when repeated testing, rather than a single administration, can be done throughout the recovery period.

In addition to Gronwall and colleagues' research, numerous other studies have demonstrated the sensitivity of the PASAT to reduced information processing in head injured populations (Gronwall & Wrightson, 1981; Leninger, Gramling, Farrell, Kreutzer, & Peck, 1990; Levin et al., 1987; McMillan & Gluckman, 1987; Ponsford & Kinsella, 1992; Stuss et al., 1985). Some studies have indicated that PASAT results also correlate with subjective complaints following head injury (Gronwall & Wrightson, 1974; O'Shaughnessy, Fowler, & Read, 1984; Roman, Edwall, Buchanan, & Patton, 1991).

For example, Gronwall and Wrightson (1974) demonstrated that PASAT performance was correlated with symptom reports in head injured patients in the weeks following injury. In short, those who recovered more slowly in terms of subjective reports of symptoms such as reduced concentration also recovered more slowly in terms of PASAT performance. Conversely,

scores on the PASAT of individuals not complaining of lingering symptoms returned to normal more quickly.

Recent modifications

A number of modifications to the original PASAT procedure have been made over the years since Gronwall and colleagues' initial research on the PASAT. For example, Levin et al. (1987) used 50 single digits in *different random sequences* for each of the four trials instead of the standard 61 digits in the same sequence for each trial (Brittain et al., 1991). The rationale for this modification was that different random digit sequences reduced practice effects due to repeated exposure to the same digits within one administration. However, this does not counteract practice effects due to repeated PASAT administrations. This topic will be discussed further in the next section.

There are two potential problems with Levin et al.'s modification. First, they did not compare performance on the first ISI trial between his and Gronwall's sequence of digits. A comparison of the two different sequences on the first ISI could have determined their equivalency. Second, there are no comparative studies of the original PASAT and Levin's modification. Comparative studies are needed to demonstrate that practice effects are reduced with different random digit sequences and with fewer digits per trial. In fact, the only data on Levin's modification other than Brittain et al's (1991) research comes from normative studies (Roman et al., 1991; Wiens et al., 1997).

Another modification of the standard PSAT procedure, the computerized PSAT, arose from the increasing convenience of the microcomputer. Wingenfeld et al. (1999) developed a computerized PASAT such that the digits are presented aurally via microcomputer speakers.

The participant's response and RT is recorded on the computer through an external microphone and hand scored at a later time during playback.

Wingenfeld et al. (1999) described some advantages of their computerized PASAT. First, several indices of performance can be obtained: number of correct responses/ISI trial, number of missed responses, number of errors, number of suppression failures (add the digit to the last sum uttered as opposed to the last digit heard), number of strings (three consecutive correct responses), and longest string (longest sequence of correct responses). Second, the computer records reaction time data. However, there are also some disadvantages.

One disadvantage of Wingenfeld et al.'s (1999) computerized PASAT is that the indices Wingenfeld lists must be calculated *manually* after the task has been administered. Since this is also the case with the non-computerized PSAT there is apparently only one advantage other than automatic RT recording. This advantage is that the tester does not have to manually enter the participant's response during PASAT administration.

A second disadvantage is that the soundboard, which records the reaction time of the participant's first utterance, may not reliably record the participant's response (Wingenfeld et al., 1999). That is, the soundboard could record the RT of a clearing of the throat or some other noise other than the response. In sum, while Wingenfeld et al.'s PASAT is a viable alternative to the standard PSAT procedure; the results should be interpreted with caution (Wingenfeld et al., 1999). Possible solutions to this problem are discussed in a later section.

As a further modification to the computerized PASAT procedure, many researchers have opted to present digits visually as opposed to aurally by microcomputer (Bateman, 1997; Diamond et al., 1997; Feinstein, Brown, & Ron, 1994; Fos et al., 2000; Hiscock et al., 1998). Most of these researchers, except for Feinstein et al. (1994), compared differences in

performance on the PASAT and the PVSAT. However, they did not use a computerized PASAT, rather, they compared the original taped PASAT to a computerized PVSAT. A potential conflict with these studies is that the auditory mode of presentation may actually tap into different cognitive processes such as interference as discussed in the next section under validity.

In summary, since Gronwall's development of the PASAT as a clinical tool, many modifications have been made. There is really no evidence to suggest that any particular version provides the most valid and efficient means of measuring speed of information processing. However, as discussed in the next section, there are several confounds with PSAT measurement. This is not surprising, as it seems unlikely that speed of information processing can be isolated from *all* other aspects of attention and *all* other cognitive processes.

Validity of the PSAT

Descriptive data of concussed and non-concussed PSAT performance for the original version of the PASAT were provided by Gronwall and Sampson. However, Gronwall and Sampson (1974) did not provide information on how performance is affected by other variables. Some variables that may confound the interpretation of PSAT performance include: practice effects, age, IQ, education, math ability, and mode of presentation.

Practice

There are two potential sources for practice effects on the PSAT. One originates from within a single PSAT administration. Another originates from repeated PSAT administrations. The results of practice effects can be detrimental to clinical assessment and to research results. On the other hand, some amount of practice is needed in order for the PSAT score to accurately

reflect cognitive ability. Thus, practice effects from both within and between PSAT administrations should be understood and accounted for.

The reason for potential within PSAT practice effects may be due to each trial containing the same 61 digits presented in the same sequence over all ISI trials (Brittain et al., 1991). Thus, a participant may become familiar with the sequence. As previously mentioned, Levin's modification may be a solution to this; however, there is no supporting evidence at this time.

Another reason for within PSAT practice may simply be due to increased familiarization with PSAT procedures across trials. In fact, when developing a children's version of the PASAT, Johnson, Roethig-Johnston, and Middleton (1988) discovered that the addition of one ISI trial (2.8 s) actually served as a further practice trial. That is, performance increased from the 2.8 to the 2.4 s trial rather than the usual decrease from a longer ISI to a shorter ISI trial. As a result, Johnson et al. (1988) removed the 2.8 s trial from their analysis. The implication of this study is that there is a need to practice the PSAT procedure prior to the actual administration. Without the opportunity to practice, a PSAT score may not accurately reflect information processing ability. In sum, with a chance to practice the PSAT, variables such as inexperience and anxiety associated with task novelty may not be as influential as without the opportunity to practice.

While within administration practice effects have been recognized, repeated administration is the most commonly acknowledged source for practice effects (Feinstein et al., 1994; Gronwall, 1987; Stuss et al., 1987 & 1988). The result of repeated PSAT testing is that performance may improve over time due to practice rather than to an improvement in information processing ability. This can be problematic if, according to improved PSAT

performance, a head injured individual appears to have recovered from a head injury when in fact he/she has only improved on the PSAT due to practice.

Gronwall (1977) addressed this issue of between administration practice as part of a study on return to work following head injury. Rather than comparing the head injured patients' PASAT scores across administrations, Gronwall compared their performance to that of a control group consisting of non-head injured individuals.

While procedures for counteracting the effects of practice exist, as discussed above, the issue of practice is currently unresolved. Some claim practice effects to be minimal and short-lived (Gronwall, 1977) while others claim they are significant and long lasting (Feinstein, 1994). Gronwall (1977) proposed that the major effects of practice occur between the first and second PASAT administration. Stuss et al. (1987 & 1988) also found significant improvement between first and second PASAT administrations. However, these researchers did not extend their investigation to see if practice effects continued beyond the second administration.

Feinstein et al. (1994) were the only group to study practice effects on the PASAT past two administrations. These investigators demonstrated that there was a significant improvement in performance over eight PASAT administrations. In fact, Feinstein et al. (1994) found ceiling effects in their results such that there were often no errors following the first or second PASAT administration.

There are a few problems when interpreting Feinstein et al.'s (1994) results. First, they only used 4.0 s and 2.0 s ISI trials. Since faster ISI trials are generally more sensitive to head injury, the data regarding the 4.0 s trial may not have much applicability. Second, PASAT performance was reported in terms of number of errors. This may explain why Feinstein et al. (1994) found ceiling effects in their results. Had Feinstein et al. (1994) reported performance in

terms of time per correct response they may not have encountered these ceiling effects. Also, using time per correct response would allow others to use their results for comparative purposes, at least for the 2.0 s ISI trial.

A third problem was that Feinstein et al. did not define what constituted an error. That is, were responses considered incorrect if the sum was mathematically incorrect, if the response was late, or both? Finally, Feinstein et al.'s study included two age ranges, from 25 to 33 and 41 to 57. The authors noted that the younger group appeared to improve more rapidly and across more administrations than the older group. However, due to a small sample size they were not able to separate the two groups for statistical analysis and results are based on both groups combined performance. Due to the interpretive problems with Feinstein et al.'s research, there is a need for more conclusive evidence for practice effects following a second PASAT administration.

In summary, the effects of practice on PSAT performance and the interpretation of an individual's information processing capabilities should be taken into account for both single and repeated PSAT administrations. One way this can be accomplished may be through the presentation of different randomized digit sequences across trials (Levin modification: Levin et al., 1987). Another method to counteract misinterpretation of PSAT performance is to provide an opportunity to practice the PSAT task prior to initiation of the actual procedure. Finally, for clinical interpretation of PSAT performance, head injured scores should be compared to non-head injured scores.

Age

In Gronwall and Sampson's (1974) original clinical trial with the PASAT, age was not an important factor as all participants were between the ages of 17 and 25. However, Gronwall (1977) subsequently cautioned the interpretation of PASAT results for patients older than 40.

Gronwall (1977) found that while the mean performance for an older, non-concussed group (41 to 55 years) was similar to that of younger groups (14 to 40 years), the older group had a larger SD than younger groups. While Gronwall (1977) does not provide an explanation for the older group's larger SD, the reason may be that these individuals were at various stages of decline in information processing ability.

To support the notion that speed of information processing ability declines with age, Gronwall (1989) found that a group of mildly concussed individuals in their 40's were significantly slower to recover than a group in their 20's. Also, Feinstein et al. (1994) suggested that younger participants perform more quickly and improve to a greater extent and over a longer period of time than older participants.

Further evidence for a relation between age and PASAT performance comes from a number of studies (Brittain et al., 1991; Crawford et al., 1998; Dieher & Heaton, 1998; Roman et al., 1991; Wiens, Fuller, & Crossen, 1997). Roman et al. (1991) provide norms stratified for age for the Levin version while others provide a description of the means and SDs for various age groups (Brittain et al., 1991; Crawford et al., 1998; Dieher & Heaton, 1998; Wiens et al., 1997).

The results from these studies should be used for the assessment of adults according to age range, particularly for those who have suffered a head injury. However, some of these data on age should be used with caution. For example, Dieher and Heaton (1998) included an extra 3.0 s ISI trial and excluded the 1.2 s ISI trial. Therefore, use of their means and SD's should only be used within these parameters.

IQ

Gronwall and Wrightson (1981) claimed that PASAT performance did not correlate significantly with general intelligence. Thus, based on their claim, PASAT performance can be

interpreted independently of intellect. However, Crawford et al. (1998) found that PASAT performance was correlated with the attention/concentration factor on the WAIS-R, and with overall IQ. Results from studies on Levin's version (Brittain et al, 1991; Wiens et al, 1997) of the PASAT also provide relatively large and significant correlations between IQ and PASAT performance.

On the other hand, Roman et al. (1991) demonstrated only a small, but significant, relationship between IQ and PASAT performance. One reason for this small correlation may be that they calculated an IQ estimate based on only two sub-tests of the WAIS-R, Block Design and Vocabulary. Had they determined a Full Scale IQ as prescribed by Wechsler, their results may have been more consistent with other studies where correlations were larger (e.g., Brittain et al., 1991; Crawford et al., 1998; Wiens et al., 1998).

With respect to head injured patients, the PSAT recovery curves for patients with lower and higher IQs may differ such that those with higher IQs appear to recover more rapidly than those with lower IQs (Gronwall, 1989). However, individuals of all IQ levels may actually recover to an identical level of performance. Thus, the data available on PSAT performance according to level of IQ can be important when assessing recovery from head injury. In other words, head injured patients' scores should be compared to those of non-head injured individuals at an equivalent level of intellect.

Education

With respect to education, there has not been as much research on possible confounds as there has been with respect to age and IQ. One reason for this may be that the samples most often used for non-clinical trials are university students who inevitably have similar levels of education. However, there is some data to support a correlation between level of education and

PASAT performance (Dieher & Heaton, 1998; Stuss et al., 1987). For instance, Stuss et al. (1987) looked at PASAT performance in a number of non-head injured individuals with years in education ranging from 8 years to 20 years across a variety of age ranges. The results from this study reported a significant and positive correlation between PSAT performance and level of education when age was controlled. In addition to age and IQ, level of education is yet another factor to consider when interpreting PSAT results.

Math ability

There is a body of evidence to suggest that PSAT performance should be interpreted according to mathematical ability in addition to speed of information processing (Chronicle & MacGregor, 1998; Crawford et al., 1998; Egan, 1988; Hiscock et al., 1998; Shermann, Strauss, & Spellacy, 1997). For example, Chronicle and MacGregor (1998) examined the relationship between PASAT performance and mathematical ability. The authors proposed that participants who were quicker to verify calculation correctness, determined by reaction times on a calculation verification task, would have higher PASAT scores. The calculation verification task required participants to respond by pressing YES or NO keys as quickly as possible to displayed calculations.

Chronicle and MacGregor (1998) did find a significant correlation between RT for calculation verification and PASAT performance. In addition, they also found significant contributions of mathematical attainment and self-rating of math ability to PSAT performance. While the results to appear to support their hypothesis, Chronicle and MacGregor (1998) point out that measuring mathematical performance in terms of number of correct verifications rather than RTs may be useful. That is, the calculation verification task may share some of the PSAT's

subtasks such as making rapid additions in order to process each trial, while a task of calculation accuracy may not (Chronicle & MacGreger, 1998).

In an attempt to provide convergent and divergent evidence for construct validity of the PASAT, Shermann et al. (1997) examined the unique contributions of attention and mathematical ability to PASAT performance. They examined the relationship between PASAT and tests of attention including the WAIS-R Arithmetic, Digit Symbol, and Digit Span subtests, to provide convergent evidence for the PASAT's construct validity as a test of attention. Correlations between PASAT and tests of mathematical ability including the Wide Range Achievement Test - Revised (WRAT-R) Arithmetic test were also examined to provide divergent evidence for construct validity of the PASAT. Shermann et al. (1997) found a significant unique contribution of the WRAT-R Arithmetic sub-test to PASAT performance. They also found that of all the attention tests they administered, only the WAIS-R Arithmetic sub-test (which measures both attention and mathematical ability) was a unique predictor of performance.

The coefficients for both the convergent and divergent evidence were similar with respect to math (i.e., WAIS-R Arithmetic and WRAT-R) where the higher the level of mathematical ability, the better the PASAT performance. Based on this evidence, Shermann et al. (1997) concluded that the PASAT might measure math in addition to attention, which does not demonstrate construct validity for the PASAT. Thus, PASAT results should not be interpreted if mathematical performance is poor (Shermann et al., 1997).

Considering the evidence cited above, it appears that mathematical ability plays a role in PSAT performance. However, correlations between the PSAT and other tests of mathematical ability do not explain *how* the PSAT itself may require a certain amount of mathematical skill only that it is *related* to other tests requiring mathematical skill.

Ward (1997) studied the role of mathematical ability in PASAT performance and provided an explanation of how this ability can inadvertently affect an individual's speed of information processing score. He explained that the underlying assumption of the PASAT's ability to index speed of information processing is that all adults retrieve addition facts *directly* from memory. Essentially, their performance for all sums on the PASAT whether simple (sums less than 10) or complex sums (greater than 10) is similar (Ward, 1997).

However, adults may actually solve addition problems with non-retrieval methods in addition to retrieval methods (LeFevre, Sadesky, & Bisanz, 1996). Research on mental arithmetic has shown that problems with sums greater than 10 require procedures other than direct retrieval and take longer to solve than problems with sums less than 10 (e.g. LeFevre et al., 1996). This difference in time to solve simple and complex additions is called the 'problem size effect'. What may underlie this effect are the procedures used to solve addition problems. For example, for problems with sums greater than 10, transformation procedures (e.g., through 10: " $7 + 5$ is really $7 + 3 + 2$ ") are used almost as frequently as direct retrieval (e.g., just 'remembering' or 'knowing' the solution) (LeFevre et al, 1996). However, for problems with sums less than 10, transformation is rarely used (LeFevre et al., 1996).

In their study, LeFevre et al. tested participants on simple addition problems and then on arithmetic fluency. Self-reports were used to classify the type of procedures the participants used to solve the problems. The procedures were classified as retrieval, counting, transformation, zero rule, or other. Results from this study indicated that retrieval procedures produced the shortest latencies and were used most frequently. Conversely, transformations produced the longest next to 'others' (e.g., guessing, memory aids, visualization...) and were

second in terms of frequency. In addition, it was found that latencies increased with problem size.

LeFevre et al. (1996) found that retrieval procedures were selected most often for problems with sums less than 10. For problems with sums greater than 10 the use of transformation procedures increased substantially. This makes sense given that latencies increased with problem size. If results from this study are applied to PSAT performance, it should follow that latencies on complex sums would be greater than those for the simple sums. The increased latencies on the complex sums could theoretically be due to the fact that non-retrieval procedures such as transformation or counting are being used in addition to retrieval procedures.

The role of mathematical ability fits into the problem size effect such that less skilled participants show larger problem size effects than more skilled individuals (e.g., LeFevre et al., 1996). According to LeFevre et al. highly skilled individuals used retrieval more often than those who were less skilled. In terms of PSAT performance, there may be an influence of mathematical ability on simple and complex sum performance. For example, if the PSAT procedure were reduced to a 'simpler' form such that sums never exceeded 10, then individuals with lower mathematical ability may have lower scores on the standard PSAT version than the simple version because of increased use of non-retrieval methods for the complex sums. Conversely, those with a greater mathematical skill may perform equally well on both versions since they tend to use retrieval procedures.

However, evidence for differential performance on simple and complex PSAT sums does not exist, yet, the potential to do so does exist. In fact, Johnson, Roethig-Johnston, and Middleton (1988) distinguished simple from complex sums when they developed the Children's

Paced Auditory Serial Addition Task (CHIPASAT). Johnson et al. (1988) used sums that never exceeded 10 as a more suitable PASAT for children as they have a lower level of math ability and would be less efficient at solving the larger sums. As with adult performance on the PASAT, children's performance on the CHIPASAT correlated with math ability.

Johnson et al. compared child PASAT performance to adult performance based on data from Gronwall's (1977) study. They noted that performance, trial for trial, was lower in children than in adults. However, this comparison was made with different PASAT versions, a restricted version for children that involved simple sums, and an unrestricted version for adults with both simple and complex sums. A more useful comparison may have been to contrast performance in children alone on the CHIPASAT and the PASAT. Similarly, it may be useful to compare adult performance on restricted and unrestricted PASAT versions.

Mode of presentation

A final variable that may be related to PSAT performance is the modality in which digits are presented. Originally, digits were presented visually (Sampson, 1958). Then presentation became auditory with the audiocassette version (Gronwall & Sampson, 1974). More recently, the PSAT has been re-adapted so digits can be presented visually on a computer screen (Bateman, 1997; Diamond et al., 1997; Feinstein et al., 1994; Fos et al., 2000; Hiscock et al., 1998). If PSAT performance reflects primarily the ability to rapidly process information, then auditory and verbal presentation should yield similar PSAT scores. However, as the following paragraphs illustrate, this is not the case. The implication of these findings will be discussed in more detail in later sections.

Feinstein et al. (1994) were one of the first groups to report differential performance on the PASAT and PVSAT. Their findings indicated that healthy adults made fewer errors on

visual as opposed to auditory presentation of the PSAT. The authors, who were examining the effects of practice on PSAT performance, used the 2.0 s and 4.0 s trials, 31 pairs of digits and different sets of random digits to prevent within session practice. Since they used only two relatively slow ISI trials, results from this study are not comparable with other PSAT studies.

Some of Feinstein et al.'s (1994) findings regarding superior performance on the PVSAT may be, in part, due to practice as this test was always administered after the PASAT. Thus, performance may have improved due to the participant's familiarity with the paced serial addition procedure on the first or second administration. However, there is other evidence to support differential performance on a visual version of the PSAT (Bateman, 1997; Diamond, DeLuca, Kim, & Kelley, 1997; Fos et al., 2000; Hiscock et al., 1998).

Bateman (1997) also found superior performance on a computerized PVSAT in comparison to a tape-recorded PASAT. For both versions, Bateman used 41 digits presented at 2.5, 2.0, 1.5, and 1.0 s per digit. As with all other PSAT versions, the digits ranged from 1 to 9, but; the sums never exceeded 10 as with the CHIPASAT. One advantage of Bateman's study was the provision of adequate practice, defined as achieving 9 out of 10 sums correct on the practice exercise, prior to commencing the PVSAT or PASAT.

In another investigation of modality effects with normal adults, Hiscock et al. (1998) found that performance on the PASAT decreased more rapidly across ISI trials than that on the PVSAT. In other words, the PASAT task became progressively more difficult than the PVSAT as the ISI decreased from 2.4 s to 1.2 s (Hiscock et al., 1998).

Hiscock et al. (1998) proposed that the vocal response might mask the next stimulus when presented aurally as with the PASAT. They suggested that this type of interference is 'peripheral' as opposed to 'central'. The 'central' process is in fact speed of information

processing. Thus, as a peripheral interference, modality is independent of capacity (Hiscock et al., 1998). This concept of central and peripheral processes as measured by the PASAT is similar to Sampson and Corbalis' (1963) original findings that the PSAT tapped into central cognitive processes such as immediate memory in addition to peripheral processes.

Like Sampson and Corbalis (1963), Hiscock et al. (1998) demonstrated that in addition to the central component of information processing there was also a peripheral component of modality. This is true because while the effect for modality was significant, the effect for increased ISI was greater (Hiscock et al., 1998). The implication of this is that a patient with poor PASAT performance may actually be susceptible to auditory-verbal interference in addition to decreased speed of information processing (Hiscock et al., 1998).

Hiscock et al.'s (1998) findings suggest that to determine the degree to which interference affects performance, an individual's PASAT performance should be compared to their performance on a visual version of the same task. However, if an auditory version of the PSAT does indeed measure interference, then this type of presentation would still be a viable test for assessing the effects of brain damage, be they reduced ability to cope with auditory-verbal interference, or reduced speed of information processing.

Diamond et al. (1997) were one of the few groups to compare the relative performance on the PVSAT to the PASAT in a clinical population. The clinical population of interest in their study was a group of Multiple Sclerosis (MS) patients. Some of the cognitive impairments associated with MS are similar to those with head injury such as impaired PSAT performance due to attention and concentration deficits (Diamond et al., 1997). Diamond et al. (1997) studied the performance of MS patients on Levin's version of the PASAT in comparison to that on the

PVSAT in an attempt to demonstrate that MS patients have deficits related specifically to auditory/verbal processes.

Results from Diamond et al.'s study indicated that PVSAT scores, calculated by the number correct over 4 trials, were generally higher than PASAT scores for both MS patients and controls. A comparison of controls and MS patients revealed that the MS group performed significantly worse than controls on both versions of the PSAT. Thus, the authors concluded that MS patients may have impairments in both visual *and* auditory modalities, contrary to their original hypothesis.

While the above studies do suggest differential performance on the PASAT and PVSAT, there is little data on the effect of modality of presentation on PSAT performance in a head injured population or on the construct validity of the PVSAT. Fos et al. (2000) were the only group to compare the PVSAT to the PASAT in head injured and normal groups. Similar to the previously mentioned studies, they found the PVSAT to be relatively easier than the PASAT for both head injured and control groups.

However, these researchers were unable to differentiate the head injured from the non-head injured group with neither the PASAT/PVSAT procedures nor any tests of attention including the TMT, Stroop Color Word Test, and Digit Span subtest of the WAIS-R. Fos et al. (2000) suggested the reasons for this were that: (a) a great deal of time had elapsed since injury (11 ± 8 years), and (b) the head injured group consisted of college students who may have been highly motivated to succeed at the test and thus appeared to perform at a normal level. However, the head injured group may have spent a considerable amount of effort in comparison the non-head injured group to achieve this.

In addition to Fos et al.'s cited reasons for a lack of differentiation, most of the patients had suffered only mild head injuries. The inclusion of moderate to severely head injured participants may have been useful since the PSAT is particularly frustrating for these groups (Spreen & Strauss, 1991) compared to mild head injured groups. Thus, an easier version of the PSAT would be particularly beneficial for these groups. Aside from these procedural problems, Fos et al. (2000) were able to demonstrate the construct validity of the PVSAT. They found that the PVSAT was significantly correlated to the PASAT, although the PVSAT was easier. Also, both the PVSAT and the PASAT demonstrated identical relations to other measures of attention.

As previously mentioned, a major implication from these studies is that the PASAT may not provide an index of speed of information processing alone. That is, some procedural aspect of the PASAT may allow this measure to tap into more than one cognitive process more so than the visual version. One suggestion is that the interference between auditory input and verbal output on the PASAT puts more demands on working memory than the PVSAT. This possibility will further discussed in later sections.

The 'Adjusting-PSAT' (APSAT)

The literature discussed so far has described how the PSAT has been developed and some of its advantages and disadvantages. An advantage of the PSAT is that it provides an index of speed of information processing that can be used to assess head injured patients. However, using the average speed of correct response may not be the ideal method for comparing head injured to non-head injured individuals, as it does not really define the speed at which information can be processed. In the following section, this problem will be expanded and a new version of the PSAT will be presented as a solution to this disadvantage of the PSAT.

Gronwall and Sampson (1974) suggest that capacity has finite limits. Essentially, everyone has their own personal limit as to *how fast* they can process information and *how much* information they can process. RT tasks provide a good index of just how fast the information being presented is acquired. Consequently, recording an individual's latency, or the time it takes to respond to a stimulus, can provide a measure for capacity (vanZomeran & Brouwer, 1994).

On the other hand, the amount of information processed can be described by the analogy of an adult reading while listening to music. If a third task such as participating in a conversation is added, then the adult's capacity may be overloaded and one of the tasks must be discontinued. That is, the information provided by one of these tasks, for example a passage from the book, is no longer being acquired. Since individuals have their own information processing limits, the amount of information that is acquired varies. The PSAT provides a way of indexing this side of information processing. The PSAT 'pushes' an individual's information processing resources by presenting three tasks at increasingly faster rates.

Ideally, a threshold or finite limit for information processing should be determined since the task at hand is to push the *limits* of capacity. However, this is where the PSAT is lacking. In fact, the current PSAT task and scoring system do not provide a means of accurate threshold calculation.

The current scoring system, usually average speed per correct response, erroneously gives the impression of an individual's speed of responding. However, this score more accurately reflects the number of correct responses within a particular ISI trial. The precise speed or ISI at which an individual can no longer process information is unknown. As an analogy, if an assembly line worker is required to simultaneously check a toy truck for defects, attach a plough, and carry on a conversation with his supervisor; at what conveyor belt speed

will he no longer be able to accomplish all of these tasks? If the number of defects he failed to notice over a certain period of time is examined, the speed at which the conveyor belt was moving when he was no longer able to complete all three tasks at once is still unknown.

One way to determine this threshold is to alternately increase and decrease the conveyor belt speed according to the worker's mistakes. That is, if a mistake is made the speed decreases and if the job is done correctly, the speed increases. In terms of the PSAT, if an incorrect response is made the ISI could be increased, or if the correct response is made the ISI could be decreased. The speed at which information can no longer be processed could be established as that ISI where there is an equal (50%) chance of a correct or incorrect response being made.

Tombaugh (1999) developed a system for measuring an individual's threshold with the new APSAT. The APSAT combines the usual increase in ISIs with a stair-step procedure to determine a threshold as described above. In short, each time a participant produces the incorrect sum the ISI increases and with a correct response the ISI decreases. A threshold can be calculated as that point where the speed of digit presentation surpasses the speed of information processing, in other words, when there is a 50/50 chance of a correct or incorrect response.

Summary

Advantages of the APSAT

Tombaugh (1999) suggests several advantages of the APSAT over the non-adjusting APSAT. First, it provides a threshold for comparing head injured to non-head injured individuals as discussed in the previous section. Second, if people 'cheat' on this task by skipping every other ISI, then their score will not be invalidated as with the non-adjusting PSAT. If individuals were to cheat on the non-adjusting PSAT they could potentially get 50% of the sums correct. This may not have much of an implication for the slower ISI (i.e., 2.4 s); however,

an individual may actually score above his/her potential for the faster ISIs. In short, if a head injured individual were to normally score 30% correct on the 1.6 s ISI, and he/she actually scored 50% correct, then his/her score would not be a valid index of their ability.

In comparison, individuals can't really 'perform' better by skipping every other ISI on the APSAT. That is, the threshold at which point they started to skip every other ISI would simply be maintained. Since a change in strategy usually occurs when information processing begins to break down, the threshold would provide a more valid index of capacity relative to the score provided by the non-adjusting PSAT.

The APSAT has a third advantage which provides a solution to the inaccuracy of soundboard recording. As previously discussed, Wingenfeld et al. (1999) encountered soundboard inaccuracy with their computerized PASAT. The solution to this problem is for the examiner to type the participant's uttered responses directly into the computer as soon as the response is uttered. This way the computer can simultaneously determine whether the response was correct or incorrect according to a pre-set list of correct responses and record RT. Furthermore, a response can be marked as late or on time according to the recorded RT.

A fourth benefit is that the APSAT may be less frustrating than the original PSAT. This is because the adjusting procedure does not force an individual into an ISI much beyond their capacity. That is, if an individual's maximum capacity is at the 1.6 s ISI, they will not be forced to go through an entire 1.4 or 1.2 s trial as they would with the original PSAT.

Purpose of Study

In light of the advantages of the APSAT over the non-adjusting PSAT the purpose of this study was to investigate the effect of several variables on the APSAT in order to make some recommendations for clinical use of this tool. Therefore, four variables were investigated: (1)

complexity of problem type, (2) modality, (3) math ability, and (4) attention factor. In addition to this research, future research with head injured individuals on the APSAT may prove this measure to be a viable alternative to the non-adjusting PSAT and may shed some light on what cognitive processes other than speed of information processing are indexed by these measures.

Variable # 1: Problem complexity

The relative contribution of problem difficulty or complexity was examined through the comparison of a restricted and unrestricted APSAT. A restricted version included the same type of digit set as that used for the CHIPASAT where sums greater than 10 are never required. An unrestricted version requires sums that range from 2 to 18. Thus, one of the aims of the present study was to examine the differences in thresholds for restricted and unrestricted versions of the APSAT. If there is no difference in performance between versions, then both the restricted and unrestricted versions may be equally useful for clinical assessment.

Variable #2: Modality

In addition to studying the effects of complexity, another aim of this study was to investigate whether modality of presentation made a difference to APSAT performance and if so, what this meant about the cognitive processes measured by this tool. Thus, the APSAT was being presented either aurally or visually. Modality of presentation was important because the participant's own oral response may interfere with the retention of the aurally presented stimuli more so than with the visually presented stimuli. If this is true, then the auditory version may measure interference in addition to information processing speed. While this may occur, measuring interference may actually be clinically useful for the assessment of head injured individuals.

In other words, auditory versions of the PSAT may provide, in part, an index of an individual's ability to handle interference in addition to providing an index of their speed of information processing. Thus, a head injured patient's performance may reflect one of or a combination of two things: a decreased speed of information processing and/or a reduced ability to handle auditory input/verbal output interference.

For the purpose of this experiment, auditory and visual APSAT thresholds were compared amongst undergraduate university students. If thresholds were found to be similar for both versions, then it was assumed that there may be no effects due to interference. However, if thresholds were higher for the auditory version then the theoretical 'interference effect' may be supported.

Variable #3: Math ability

Level of math ability may be responsible for differential performance depending on the APSAT version. With respect to complexity, if there was a lower threshold for restricted than for unrestricted, as predicted by the 'problem size effect' (e.g., LeFevre et al., 1996) then some other variable may be affecting information processing speed. This variable may be level of math ability, which may determine the type of procedure used to solve addition problems (LeFevre et al., 1996).

If there was an effect due to math on the APSAT, then there should be a correlation between math ability and APSAT performance. In addition, if the unrestricted APSAT was more difficult than the restricted APSAT due to the inclusion of complex sums, then math ability should have demonstrated a stronger relationship with unrestricted than restricted performance. With respect to modality, a correlation with math ability may or may not have been significant.

It was expected that participants would have the highest thresholds on the auditory and unrestricted version of the APSAT and the lowest thresholds on the visual and restricted version. Furthermore, it was predicted that math ability would correlate with APSAT performance and that there would be a stronger correlation between math and unrestricted APSAT performance than with math and restricted APSAT performance.

Variable #4: Attention factor

Since the APSAT is purported to measure speed of information processing, which is one aspect of attention, then this measure should correlate with other tests of attention. Thus, several classic tests of attention with well-established norms were administered. It was expected that there would be a correlation between APSAT performance and performance on the other measures of attention.

Method

Participants

The majority of participants were volunteers from the Introductory Psychology course at Carleton University. Participants received course credit for their participation. In addition, students from other undergraduate psychology courses were recruited. A medical health questionnaire (see Appendix A) was used to screen participants. Participants were excluded if they: (1) were diagnosed with a neurological, mood, or psychotic disorder, (2) had a history of substance abuse, (3) were currently using antidepressants, tranquilizers, or antipsychotics, or (4) had suffered a head injury.

Design

Sixty participants were randomly assigned to one of the following conditions:

- 1) Visual-Unrestricted APSAT

- 2) Visual-Restricted APSAT
- 3) Auditory-Unrestricted APSAT
- 4) Auditory-Restricted APSAT

A between groups design was chosen as the literature indicates practice to be strongly associated with repeated PSAT administration, particularly between first and second administrations (Gronwall, 1977; Stuss, et al., 1987 & 1988).

Materials and apparatus

APSAT: Each version of the APSAT was administered via computer. A series of digits from 1 to 9 were presented either visually by computer screen, or aurally by headphones. A mask to prevent after-image formation followed each of the visually presented digits. Aural digits were presented by a male human voice through a Windows PCM WAV file format. The numbers for both versions were preset and stored in a file. The ISI length was controlled by the 32-bit multimedia timer function of Windows 98. An unrestricted APSAT consisted of digit pairs whose sums ranged between 2 and 18 while the restricted version never required sums greater than 10.

Each administration began with a practice session of 12 trials. The ISI length between each digit remained constant at 3.0 s. Following the practice trial, a series of 200 real trials began with the presentation of a single-digit number followed by a 2.4 s interval. Following this interval, the next digit was presented and had to be added to the previously presented digit. The participant said the answer aloud and the experimenter typed the response into the computer using the numeric keypad. The ISI was adjusted with a titrated/stairstep procedure so that each correct response was followed by a 20 ms ISI increase and each incorrect response was followed by a 20 ms decrease. This procedure resulted in a 50% threshold.

Several different measures were collected from this task. These measures included: number of correct and incorrect responses and their mean latencies, number of missed responses, fastest ISI (threshold) and fastest ISI trial number. A response was considered incorrect if the sum was incorrect.

Neuropsychological tests: A number of classic tests of attention with well established norms were administered. These included:

- 1) Trail Making Test, Parts A and B (Reitan & Wolfson, 1985). On part A, the participant must join 25 numbers in order as rapidly as possible. On part B, 13 numbers and 12 letters must be joined in order starting with a number first, then a letter, in the same manner as for part A. The score for each part is the time to complete each task.
- 2) Symbol Digit Modalities Test (SDMT: Smith, 1982). Participants are required to pair numbers associated with 9 particular symbols according to a key. Ninety seconds is given to complete this task and the resulting score is the number of symbols correctly identified.
- 3) Digit Span (Subtest from the LAMB: Schmidt & Tombaugh, 1995). Participants must repeat a series of progressively longer digits in the same order for the first part, and in the reverse order for the second. Two trials are given for each number series. Digit span length is the number of digits that are recalled in the correct sequence for the longest series. Each correctly remembered series is given one point and the total number of points is recorded for both the forward and backward span.

Math Test: In order to examine the relationship between math ability, APSAT performance, and the interactions with complexity and modality, each participant's mathematical proficiency was measured with an addition test from the French Kit (French, Ekstron, & Price, 1963) (see Appendix B). The participants were instructed to solve the problems as quickly and

as accurately as they could. Part one consisted of a series of 9 practice problems that were to be solved as quickly as possible. Parts two and three required the participant to complete as many addition problems as they could out of 60 in two minutes. Scores derived from the addition test were the number addition problems solved correctly within two minutes on parts two and three of the test.

Procedure

The testing session took approximately one hour to complete. Participants were introduced to experimental procedures with the informed consent form (see Appendix C). Following this, the session began with the medical health questionnaire. In addition to their medical history, the participant's age, level of education, first language, and handedness were determined. Next, the addition test was administered. Following this, the APSAT task was completed. Then, the participants completed the neuropsychological tests in the same order as they were listed above. Finally, upon completion of the session, subjects were given a debriefing thanking them for their participation and describing the nature of the study in more detail (see Appendix D).

The test order remained constant across participants and the APSAT version was randomly determined for four participants at a time. In this way, each of the 4 APSAT versions was completed by 1/4 of the sample.

Results

The mean age and years of education for each APSAT group is presented in Table

1. In addition, the number of males and females for each group is indicated in the table.

Insert Table 1 about here

Effects of Modality and Complexity

Separate analyses were performed for each APSAT dependent variable. The following sections summarize the results. The first section looks at APSAT measures for unrestricted and restricted APSAT versions. The unrestricted APSAT was further analyzed to differentiate performance on simple sums (2– 10) from complex sums (11 – 18). Results related to this analysis are reported in the second and third sections.

Unrestricted vs restricted APSAT performance

Threshold: Since the APSAT is test of *speed* of information processing, threshold was chosen as the primary measure for analysis as it reflects the fastest *speed* at which information can be processed. A 2 (visual vs auditory) by 2 (restricted vs unrestricted) ANOVA was performed to determine if a difference existed in APSAT threshold due to modality and/or complexity. The analysis revealed only a significant main effect for modality: Modality, $F(1,56) = 29.6, p < .001$; Complexity, $F(1,56) = .40, p > .05$; Modality x Complexity, $F(1,56) = .00, p > .05$. Inspection of Figure 1 demonstrates that the modality effect was due to lower visual thresholds.

Table 1. Breakdown of APSAT groups by age, years of education, and gender

APSAT group	Age		Years of education		Gender	
	M	SD	M	SD	F	M
Auditory-restricted	23.6	4.7	13.6	1.2	8	7
Auditory-unrestricted	23.0	5.0	13.7	1.5	10	5
Visual-restricted	24.5	6.6	14.1	1.7	6	9
Visual-unrestricted	27.1	7.8	13.6	.91	6	9
Total	24.6	6.2	13.6	1.3	30	30

 Insert Figure 1 about here

Final time and threshold trial number: To determine if a sufficient number of trials had been used to provide an accurate threshold, a further analysis was conducted on the mean latency of the last response (i.e., final time) and on the trial number at which the threshold occurred. This was done as too few trials may underestimate an individual's potential threshold. In order to determine if a suitable number of trials were administered for this experiment, the relationships amongst final time, threshold, and trial number were examined.

First, if a sufficient number of trials were administered then the latency for the final ISI trial should be equal to or longer than that for the threshold ISI. Inspection of Figure 2 reveals that final ISI time was longer than the threshold within each group. An ANOVA, with final time and threshold as a within groups variable, confirmed a significant difference: Final Time vs Threshold, $F(1,56) = 80.7, p < .001$; Modality, $F(1,56) = 30.7, P < .001$; Complexity, $F(1,56) = .48, p > .05$; Modality x Complexity, $F(1,56) = .01, p > .05$; Modality x Final Time vs Threshold, $F(1,56) = 1.8, p > .05$; Complexity x Final Time vs Threshold, $F(1,56) = .4, p > .05$. A correlational analysis between final ISI and threshold provides further evidence that a sufficient number of trials were given. The two measures were highly and significantly correlated ($N = 60,60$) when modality was controlled for ($r = .97, p < .05$). Thus, regardless of APSAT version, final time was always longer than threshold as revealed by the above ANOVA and the difference was similar across groups as indicated by the positive correlation.

Figure 1. Threshold means for APSAT groups

 Insert Figure 2 about here

Second, if final time was related to threshold, then the same effect of modality and lack of effect of complexity should be found. The results do, in fact, indicate only a significant modality effect: Modality, $F(1,56) = 31.0, p < .001$; Complexity, $F(1,56) = .57, p > .05$; Modality x Complexity, $F(1,56) = .04, p > .05$. As Figure 3 demonstrates, final time for the visual group was lower than that for the auditory group. Figure 3 also reveals that, like threshold, there was not much difference between restricted and unrestricted versions and that there was also no interaction between modality and complexity.

 Insert Figure 3 about here

Third, if an adequate number of trials were given, then threshold trial numbers should be similar regardless of APSAT version. The results revealed that there were no significant effects of modality or complexity on threshold trial number which ranged between 157 and 179: Modality, $F(1,56) = .31, p > .05$; complexity, $F(1,56) = .48, p > .05$; Modality x Complexity, $F(1,56) = 3.2, p > .05$.

Number of correct responses: A 2 by 2 ANOVA was performed on the number of correct responses to provide further evidence for the effects of modality on APSAT performance. Similar to the results for threshold, the ANOVA on total number correct revealed a significant main effect for modality ($F(1,56) = 27.5, p < .001$). Figure 4

Figure 2. Threshold VS final time for APSAT groups

Figure 3. Final times for APSAT groups

indicates that visual groups had more correct responses than auditory groups. As seen in Figure 4, there was not much difference between restricted and unrestricted groups and there was no interaction between modality and complexity: Complexity, $F(1,56) = .32, p > .05$; Modality x Complexity, $F(1,56) = .11, p > .05$.

 Insert Figure 4 about here

Missed vs incorrect responses: According to past research on the traditional PSAT, there are generally more missed (no-answer) than incorrect responses. As Figure 5 reveals, there were more missed than incorrect responses for all groups in the present study as well. An ANOVA with number missed vs number incorrect as a within subject variable and with modality and complexity as between subject variables revealed a significant difference between number missed and incorrect responses as well as a significant interaction between number missed vs number incorrect and complexity: Modality, $F(1,56) = 32.1, p < .001$; Complexity, $F(1,56) = .32, p > .05$; Modality x Complexity, $F(1,56) = .11, p > .05$; Number missed vs number incorrect, $F(1,56) = 151.8, p < .001$; Number missed vs number incorrect vs x Modality, $F(1,56) = 1.66, p > .05$; Number missed vs number incorrect x Complexity, $F(1,56) = 5.7, p < .05$; Number missed vs number incorrect x Modality x Complexity, $F(1,56) = 1.9, p > .05$.

 Insert Figure 5 about here

Figure 4. Correct responses for APSAT groups

Figure 5. Missed vs incorrect responses for APSAT groups

Missed responses: Since there was an interaction between the within group variable and complexity, a further analysis was undertaken. For this analysis, the proportion of missed responses was calculated with respect to combined number of both missed and incorrect responses. That is, if 150 responses out of 200 possible responses were correct, then the remaining 50 would be the total number of 'non-correct' responses. If 30 of these responses were missed then 30/50 or 60% of the 'non-correct' responses were missed. Use of these proportions allowed for comparison across groups as not every group had the same number of non-correct responses.

As Figure 6 reveals, the complexity effect occurred with the APVSAT and not the APASAT (Modality, $F(1,56) = .05, p > .05$; Complexity, $F(1,56) = 6.7, p < .05$; Modality x Complexity, $F(1,56) = 3.1, p = .08$). This would explain the interaction between number of missed vs number incorrect and complexity seen in the previous analysis. Since thresholds were lowest on the restricted APVSAT, the ISI within which a response could be given was shorter than for the unrestricted APVSAT. As a result, more responses were not answered on the unrestricted version due to the relatively shorter period of time within which a response could be made.

 Insert Figure 6 about here

Correct latency: It was expected that response latencies would be shorter for the visual than for the auditory APSAT version since the analyses for threshold and number of correct responses revealed better APVSAT than APASAT performance. If visual latencies were found to be shorter than auditory latencies, then the effects of modality on

Figure 6. Proportions of missed responses for APSAT groups (see text for calculations)

APSAT performance would be further supported. As Figure 7 reveals, this type of result did in fact occur. There was only a significant main effect for modality: Modality, $F(1,56) = 39.7, p < .001$; Complexity, $F(1,56) = 3.6, p > .05$; Modality x Complexity, $F(1,56) = .39, p = .08$.

Insert Figure 7 about here

Unrestricted-simple vs unrestricted-complex APSAT performance

Contrary to earlier predictions, the above analyses revealed no significant difference between restricted and unrestricted APSAT versions on several APSAT measures. However, there was a consistent non-significant trend of better performance on the restricted APSAT for several measures. Thus, an investigation was undertaken to determine if the lack of a complexity effect was due to the fact that both simple and complex sums occurred within the unrestricted APSAT. To further investigate this matter, performance on the simple sums and the complex sums within unrestricted APSAT was analyzed separately. This produced a 'pure' simple and 'pure' complex condition where the complexity effect was more likely to be observed. All measures except threshold, threshold trial number, and final time were calculated. It was expected that performance on the unrestricted-complex sums would be lower than that for unrestricted-simple sums.

Correct responses: A one-way ANOVA, with correct responses as a within subject variable and modality as a between subject variable, was performed to determine if there was a difference in unrestricted-simple correct and unrestricted-complex correct

Figure 7. Correct RT for APSAT groups

responses and to further support the effects of modality. Analyses were performed on baseline adjusted scores (i.e., proportions of correct responses) as there was an unequal ratio of simple (126) to complex (74) sums. Thus, if a participant had 63 correct simple responses and 37 correct complex responses, then 50% of the total possible responses would have been correct for both simple ($63/126=.50$) and complex ($37/74=.50$).

The ANOVA revealed significant main effects for modality and complexity: Modality, $F(1,27) = 11.44, p < .001$; Complexity, $F(1,27) = 60.4, p < .001$; Modality x Complexity, $F(1,27) = 3.6, p > .05$. Figure 8 illustrates that there were proportionately more correct responses on the visual than on the auditory APSAT. Inspection of Figure 8 also reveals that there were proportionately more correct responses for the unrestricted-simple sums than for the unrestricted-complex sums.

Insert Figure 8 about here

Correct latency: Correct latency was analyzed to provide further support for the modality effect found throughout the analyses and for the complexity effect found for some measures in this analysis. Total correct reaction time had significant main effects of modality and complexity: Modality, $F(1,27) = 13.0, p < .01$; Complexity, $F(1,27) = 53.9, p < .001$; Modality x Complexity, $F(1,27) = .00, p > .05$. As Figure 9 illustrates, visual latencies are shorter than auditory latencies and latencies for unrestricted-simple sums are shorter than unrestricted-complex sums.

Figure 8. Proportions of correct responses for unrestricted-simple and unrestricted-complex APSAT groups (see text for calculations)

Insert Figure 9 about here

Restricted-simple vs unrestricted-simple APSAT performance

A comparison of unrestricted-simple performance and restricted-simple (i.e. restricted APSAT version) performance was undertaken to determine if the inclusion of complex sums in the unrestricted APSAT version had an effect on the simple sums. That is, are the two types of simple sum groups significantly different and does the effect of modality still exist?

Correct responses: If the inclusion of complex sums within the unrestricted APSAT made simple sums relatively easier in contrast, then the unrestricted-simple group should have a significantly higher proportion of correct responses than the restricted-simple group. Prior to the analysis, baseline adjusted measures were calculated for correct responses relative to total possible responses. For restricted-simple there were 200 possible responses and for unrestricted-simple there were 126 possible responses. Inspection of Figure 10 reveals that as with previous analyses, the visual group had proportionately more correct responses than the auditory group. Also, the unrestricted-simple group had proportionately more correct responses than the restricted-simple group as expected. These results are confirmed with significant main effects of modality and group: Modality, $F(1,55) = 12.7, p < .001$; Group, $F(1,55) = 11.3, p < .001$; Modality x Group, $F(1,55) = 2.0, p > .05$.

Figure 9. Correct RT for unrestricted-simple and unrestricted complex APSAT groups

Insert Figure 10 about here

Correct latency: Latencies for both simple groups were analyzed to determine if the effects of modality were consistent with past results and to examine if there were differences between simple groups. Correct RT had a significant main effect of modality: Modality, $F(1,55) = 40.1, p < .001$; Group, $F(1,55) = 1.8, p > .05$; Modality x Group, $F(1,55) = .53, p > .05$. Inspection of Figure 11 reveals that the auditory group had longer latencies than the visual group. However, unlike the findings for correct responses, there was no difference in correct latencies between simple groups.

Insert Figure 11 about here

Correlations and Multiple Regressions: APSAT Threshold, Math Scores, and Neuropsychological Measures of Attention

Correlations

Correlational analyses were performed to determine the relationships amongst APSAT threshold, math, and attention regardless of APSAT version. Next, since there was a significant modality effect, the same analyses were performed separately for visual and auditory versions. Table 2 gives test abbreviations used in Tables 3, 4, and 5.

Insert Table 2 about here

Figure 10. Proportions of correct responses for restricted-simple and unrestricted-simple APSAT groups (see text for calculations)

Figure 11. Correct RT for restricted-simple and unrestricted-simple APSAT groups

Table 2. Abbreviated test names

Abbreviation	Test name	Scoring
Math	French Kit	Total number correct for Parts 1 and 2
TMT-A	Trail Making Test – Part A	Time in seconds for completion
TMT-B	Trail Making Test – Part B	Time in seconds for completion
SDMT	Symbol Digit Modality Test	Number correct substitutions
Fwd score	Digit Span Forward (LAMB)	Total score (one point per correct response)
Bkwd score	Digit Span Backward (LAMB)	Total score (one point per correct response)

As Table 3 illustrates, there was a strong and significant negative correlation between math (score on French Kit) and APSAT threshold. There was a moderate correlation between APSAT threshold and TMT-A and a moderate negative correlation between threshold and SDMT and threshold and Digit Span backward. Of all the measures of attention, APSAT threshold was most highly correlated with the TMT-B.

Insert Table 3 about here

Table 4 reveals that there was a high and significant negative correlation between math and threshold for visual presentation. There was also a high and significant positive correlation between TMT-B and APVSAT threshold. Finally, there was a significant negative correlation between APVSAT threshold and SDMT and APVSAT threshold and Digit Span backward. As in the previous analysis, TMT-B had the highest correlation with APVSAT of all the measures of attention.

Insert Table 4 about here

As Table 5 illustrates, the correlation between math and threshold for auditory presentation was higher than that between math and visual presentation. The negative correlation between math and APASAT threshold was high and significant. The positive, significant correlation between TMT-B was similar in this analysis as in the previous analysis for visual presentation. Also, there was a significant negative correlation

Table 3. Correlations amongst APSAT threshold, math, and measures of attention

Measure	Threshold	Math	TMT-A	TMT-B	Dig Sym	Fwd score
Math	-.63***					
TMT-A	.33**	-.14				
TMT-B	.60***	-.41***	.31*			
SDMT	-.47***	.36**	-.11	-.39**		
Fwd score	-.13	.06	-.09	-.21	-.09	
Bkwd score	-.31**	.29*	.01	-.25	.06	.67***

*Significant at $p < .05$

** Significant at $p < .01$

***Significant at $p < .001$

Table 4. Correlations amongst APVSAT threshold, math, and measures of attention

Measure	Visual Threshold	Math	TMT-A	TMT-B	Dig Sym	Fwd score
Math	-.53**					
TMT-A	.20	-.09				
TMT-B	.56***	-.29	.18			
SDMT	-.54**	.36*	-.05	-.54**		
Fwd score	-.12	.01	-.06	-.10	-.16	
Bkwd score	-.41*	.26	-.02	-.18	.18	.59***

*Significant at $p < .05$

**Significant at $p < .01$

***Significant at $p < .001$

between APASAT threshold and SDMT and APASAT threshold and Digit Span backward. Finally, TMT-B had the strongest relation to APASAT threshold of all the measures of attention.

Insert Table 5 about here

Multiple regressions

In order to account for APSAT threshold variance, multiple regressions were performed with modality, complexity, math, and TMT-B. The math variable was chosen since it was highly and significantly correlated with APSAT performance. TMT-B was selected since it had the highest correlation with APSAT threshold of all the attentional measures. Only one attention measure was selected in order to reduce the number of variables entered into the regression.

Modality and complexity: Table 6 presents the unique proportions of variance accounted for by modality, complexity, math, and TMT-B for all the following regressions. Modality and the combination of modality and complexity accounted for a significant proportion of APSAT variance across all versions: Modality (34%), $F(1,58)=30.5, p < .001$; Modality + Complexity (35%), $F(1,58)=15.3, p < .001$. When regressed on restricted and unrestricted APSAT versions separately, modality accounted for significant proportions of variance in both cases but accounted for more restricted (43%) than unrestricted (29%) variance: Restricted, $F(1,27)=21.3, p < .001$; Unrestricted, $F(1,27)=9.7, p < .01$.

Table 5. Correlations amongst APASAT threshold, math, and measures of attention

Measure	Auditory Threshold	Math	TMT-A	TMT-B	Dig Sym	Fwd score
Math	-.74***					
TMT-A	.35	-.14				
TMT-B	.53**	-.43*	.34			
SDMT	-.36*	.30	-.10	-.24		
Fwd score	-.32	.18	-.15	-.37*	.003	
Bkwd score	-.37*	.34	.05	-.33	-.05	.79***

*Significant at $p < .05$

**Significant at $p < .01$

***Significant at $p < .001$

 Insert Table 6 about here

Math: Table 6 illustrates the proportions of variance accounted for by math when entered alone after modality and complexity. Five separate analyses were performed by regressing math after modality and complexity on: (1) All APSAT versions (total), (2) Restricted APSAT, (3) Unrestricted APSAT, (4) APVSAT (Visual), and (5) APASAT (Auditory). The results from these regressions are discussed below.

Math – total: Modality, complexity, and math score were used to predict APSAT threshold across all subjects. Since math was highly and significantly correlated with APSAT threshold, this analysis was performed to determine how much of the variability in APSAT performance, which was not accounted for by modality and complexity, could be accounted for by math ability. Results indicated that math ability accounted for 26% of APSAT threshold variance after modality and complexity: $F(1,55) = 34.8, p < .001$.

Math – unrestricted vs restricted groups: Even though the initial 2 x 2 ANOVA did not reveal a complexity effect, further analysis indicated that there is some type of a difference in performance due to the inclusion of complex sums within the unrestricted version. If solving complex sums requires greater math ability than solving simple sums, then math ability should account for more of the APSAT variance in the unrestricted group than in the restricted group. To further investigate the complexity effect, the previous analysis was conducted for both unrestricted and restricted groups. As Table 6 indicates, math ability accounts for more APSAT variance in unrestricted (33%) than

Table 6. Unique proportions of APSAT variance accounted for by Modality, Complexity, Math and TMT-B

Variable	Incremental R ²				
	Total	Restricted	Unrestricted	Visual	Auditory
Modality	.34***	.43***	.29**		
Complexity	.0046			.006	.001
Modality + Complexity	.35***				
Modality	.34***	.43***	.29**		
Complexity	.46			.006	.001
Math	.26***	.18**	.33***	.28***	.54***
Modality	.34***	.43***	.29**		
Complexity	.46			.006	.001
TMT-B	.18***	.025	.32***	.32***	.28**
Modality	.34***	.43***	.29**		
Complexity	.46			.006	.001
TMT-B	.18***	.025	.32***	.32***	.28**
Math	.15***	.16**	.13**	.15**	.36***
Modality	.34***	.43***	.29**		
Complexity	.46			.006	.001
Math	.26***	.18**	.33***	.28***	.54***
TMT-B	.062**	.008	.11**	.20**	.029

*Significant at $p < .05$ **Significant at $p < .01$ ***Significant at $p < .001$

restricted groups (18%). Both proportions of variance were significant: Unrestricted, $F(1,26)=21.1, p < .001$; Restricted, $F(1,26)=12.0, p < .05$.

Math-visual vs auditory groups: Since there was a modality effect, further analysis was undertaken to determine if math ability accounted for more auditory or visual APSAT variance. Since there was a higher correlation with math and the APASAT, it was expected that math would account for more APASAT variance. The analysis confirmed this expectation. Math ability accounted for more auditory (54%) than visual (28%) variance and both proportions were significant: Auditory, $F(1,26)=15.6, p < .001$; Visual, $F(1,27)=5.3, p < .01$.

TMT-B: The same analyses that were conducted for math ability were conducted for TMT-B as well. The resulting proportions of variances are presented in Table 6 and are discussed in the following paragraphs.

TMT-B – total: Since TMT-B was more highly correlated with APSAT threshold than the other measures of attention, it was expected that this attention variable would account for a significant proportion of APSAT variance regardless of APSAT version. As Table 6 illustrates, when modality, complexity, and TMT-B were used to predict APSAT threshold, 18 % of the variance was accounted for by TMT-B after modality and complexity. As predicted, this proportion of variance was found to be significant: $F(1,55)=21.5, p < .001$.

TMT-B – unrestricted vs restricted groups: The unrestricted APSAT may require more attentional resources than the restricted version due to the inclusion of complex sums. If this is true, then TMT-B performance may account for more APSAT threshold variance on the unrestricted than on the restricted version. Modality and complexity,

followed by TMT-B were regressed on APSAT threshold to determine if this was true.

As expected, TMT-B accounted for less restricted-APSAT variance (2.5%) than unrestricted- APSAT variance (32%): Restricted, $F(1,55) = 1.2, p > .05$; Unrestricted, $F(1,55) = 22.1, p < .001$.

TMT-B – visual vs auditory groups: TMT-B was regressed on the visual and auditory versions separately to determine whether this measure accounted for more variance in either modality. Since the correlation between TMT-B and APVSAT threshold was similar to that between TMT-B and APASAT threshold, the proportions of variance in each case were expected to be similar. As Table 6 illustrates, TMT-B accounted for similar proportions of APVSAT (32%) and APASAT (28%) variance, both were significant: Visual, $F(1,27) = 6.5, p < .01$; Auditory, $F(1,27) = 5.3, p < .01$.

Math and TMT-B: Both math and TMT-B were regressed on APSAT threshold to further investigate which variable accounted for more APSAT variability. First, TMT-B was entered first after modality and complexity followed by math. Then, the order between math and TMT-B was reversed. In each case the same analyses were performed as for those with math and TMT-B alone. The results are presented in Table 6 and discussed below.

Math and TMT-B – total: In this case, math accounted for 15% of APSAT variance after TMT-B, while TMT-B only accounted for 6.2% after math. Both variables accounted for significant proportions of variance: Math, $F(1,54) = 24.0, p < .001$; TMT-B, $F(1,54) = 9.6, p < .05$.

Math and TMT-B – restricted vs unrestricted groups: Previous analyses demonstrated that both math and TMT-B accounted for more unrestricted-APSAT

variance than restricted-variance. An analysis was performed on restricted and unrestricted APSAT versions to determine the differential relationships of math and TMT-B. First, math accounted for more restricted-APSAT variance when entered last (16%) than did TMT-B (.8%) and only math was significant: Math, $F(1,28) = 10.7, p < .05$; TMT-B, $F(1,26) = .57, p > .05$. However, both variables accounted for similar amounts of unrestricted-APSAT variance, and both were significant: Math (13%), $F(1,26) = 11.0, p < .05$; TMT-B (11%), $F(1,26) = 9.4, p < .05$. Thus, it appears that math and TMT-B account for similar amounts of unrestricted-APSAT variance.

Math and TMT-B – visual vs auditory groups: Since previous analyses indicated that math accounted for more auditory than visual variance, this was expected to be the same when math was entered after TMT-B. When TMT-B was entered after math, it was expected that more visual than auditory variance would be accounted for since math accounted for more auditory variance. That is, since a large amount of APSAT variance was already accounted for by math, not much variance was expected to be left over for TMT-B to account for. These results were confirmed by the regression analysis. First, math accounted for more APSAT variance with auditory presentation (36%) than with visual presentation (15%) and both proportions were significant: Auditory, $F(1,25) = 11.2, p < .001$; Visual, $F(1,26) = 8.0, p < .001$. Second, TMT-B accounted for more visual (20%) than auditory (2.9%) variance and only the visual variance was significant: $F(1,26) = 8.0, p < .001$.

Discussion

The results from the present study demonstrated that performance on the APSAT was primarily affected by the mode of presentation. Visual thresholds were lower than auditory thresholds. While the effects of modality were obvious, the effects of complexity were more subtle. That is, no difference in complexity was found between the restricted and unrestricted APSAT in the major analysis. However, a more detailed analysis suggested that the complex numbers (sums between 11 and 18) had a greater effect on performance than simple numbers (sums between 2 and 10). In addition to the results for modality and complexity, the present study also revealed that the effects of two moderator variables, attention and math, were related to APSAT performance. All of the results will be described in more detail in the following sections. The clinical implications of the results will also be discussed at the conclusion of the discussion.

Independent variables

Mode of presentation

The most consistent result found in the present study was superior APVSAT performance over APASAT performance. As predicted, visual thresholds were significantly lower than auditory thresholds. The effect of modality was further supported by the number of correct responses being significantly higher on the APVSAT and the latency for correct responses being significantly shorter for the APVSAT than for the APASAT. Furthermore, analyses on final time revealed shorter final ISIs for the APVSAT than for the APASAT. When the unrestricted-APSAT was further analyzed and when the unrestricted-simple and restricted-simple groups were compared,

significant modality effects were found for correct responses and latencies for correct responses.

Comparisons with traditional PSAT studies

The results for number of correct responses obtained in the current study are consistent with those found in past studies. For example, Bateman (1997) compared non-head injured participants on the traditional PVSAT and PASAT. He found that non-head injured participants had significantly more correct responses on a modified version of the original PVSAT than on the PASAT. One difference between the present study and Bateman's study is that Bateman only used simple sums where as both simple and complex sums were used in the current study. Like Bateman's results, the results from the current study demonstrated a modality effect for the restricted (simple) APSAT as well as for the unrestricted-simple and unrestricted-complex groups.

In another study, Fos and colleagues (2000) found that non-head injured and head injured patients had more correct responses on the traditional PVSAT than on the PASAT. Although these researchers attempted to differentiate head injured from non-head injured participants with PVSAT and PASAT scores, they were unable to do so. Their failure to detect head injured individuals was probably attributed to the fact that the average time since injury was 12 years and that the majority of the patient group had only sustained a mild head injury (i.e. length of loss of consciousness was 20 minutes or less). Thus, the participants may have had sufficient time to recover from their injuries, especially the mild-head injured patients.

Hiscock et al. (1998) compared non-head injured individuals' performance on the traditional PVSAT and the PASAT. They found that the decline in performance across

ISIs (2.4 s, 2.0 s, 1.6 s, 1.2 s) was more marked for the PASAT than for the PVSAT.

That is, as the ISIs became shorter there was a greater reduction of correct responses on the PASAT than on the PVSAT.

Further support for a modality effect comes from Feinstein et al. (1994) and Diamond et al. (1997). Feinstein et al. (1994) compared non-head injured participants on the traditional PVSAT and PASAT at 4 s and 2 s ISIs. Although no statistical analysis compared the PVSAT to the PASAT, inspection of the results indicated that fewer errors were made on the PVSAT than on the PASAT at the 2 s ISI. Performance on the PVSAT was not compared to that on the PASAT at the 4 s ISI as this ISI is considered too long to adequately assess speed of information processing. Unlike the above researchers, Diamond et al. (1997) used all ISI trials to compare Multiple Sclerosis patients to controls on the traditional PVSAT and PASAT. They found that that both Multiple Sclerosis patients and controls had more correct responses on the visual version.

Threshold

In addition to the studies on traditional PSAT measures, one study provides similar results to the current study in terms of threshold. This evidence comes from Madigan, DeLuca, Diamond, and Tramontano (2000). These researchers sought to examine the speed (threshold) and accuracy (correct responses) of information processing in moderate-to-severe head injured individuals on a modified PVSAT and PASAT procedure. The results from their study indicated that PVSAT thresholds were lower than PASAT thresholds for both the head injured and control group. In addition, it was found that the head injured group was disproportionately slower on the PASAT than the control group. Madigan et al. (2000) also found that when subjects were administered the PSAT

using threshold values, the accuracy of responding did not differ between groups. That is, although the head injured group took longer to process information, when given extra time they were just as *accurate* as controls.

As indicated above, the effect of modality of presentation on APSAT performance is very powerful. In the present study, a modality effect was reported for all measures: threshold, number of correct responses, correct response latency, and final time. In addition, all the comparisons of the traditional PVSAT to the PASAT revealed a significant modality effect. Even more convincing, a modality effect was found across a variety of samples. That is, head injured, non-head injured, and even Multiple Sclerosis samples all had superior performance on the APVSAT. This finding has some important clinical implications for head injured patients; however, prior to presenting these implications, some possible explanations for the modality effect will be presented.

Information processing in auditory and visual modalities – explanations for discrepancies

Early literature on the traditional PSAT suggested that individuals process information along a single channel which has limited resources (Gronwall & Sampson, 1974). Several studies also indicated that the PSAT provided an index of the speed at which this information was processed along the channel (Crawford et al., 1988; Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974; Stuss et al., 1987). If the PSAT only indexed the efficiency of a central processor, then both the PASAT and PVSAT should yield similar results. However, this is not the case in the present study. As results from this study and others have demonstrated, the visual and auditory versions of the APSAT and PSAT procedure reveal different results for both head injured and non-head injured individuals.

Differential performance on the visual and auditory APSAT seems to suggest that the two APSAT versions measured different processes. This view is consistent with those who believe that the traditional PASAT provides an index of more than just speed of information processing. For example, Madigan et al. (2000) suggested that numerous cognitive functions are involved in successful completion of the PASAT, including sustained attention and working memory. Other researchers also agree that the PASAT is a measure of working memory in addition to speed of information processing (e.g., Fos et al., 2000; Dieher et al., 1998). Diamond et al. (1997) further explained that working memory processes may underlie information processing mechanisms. Furthermore, Hiscock et al. (1998) proposed that since modality-specific factors may contribute to poor PASAT performance, then there may be a peripheral process involved in addition to some undifferentiated central process.

Another possibility is that the APASAT is susceptible to some type of cognitive effect that the APVSAT is not. Either way, differential processing appears to occur for each measure. In the following sections, some explanations for the differential effects of auditory and visual presentation of the APSAT will be discussed.

Familiarity with visually presented digits

One reason that the APVSAT thresholds were lower than APASAT thresholds may be that participants were more familiar with performing calculations of visually presented digits than with aurally presented ones. This makes sense given that computations are taught and generally performed visually. Some evidence to support this notion is provided by Hiscock et al. (1998). As part of a three-part study, these researchers investigated the difference in performance on the PVSAT when digits were

presented as either Arabic numerals or as number words. The expectation was that performance would be better with Arabic numerals as this format is more familiar than number words. Results indicated that there were indeed more correct responses for Arabic numeral presentation than for number word presentation. The researchers concluded that performance with numerals was better because of familiarity with this format.

The same conclusion may be true for visually presented numerals versus aurally presented numerals. If so, then greater math ability may be required to overcome the unfamiliar format of the APASAT. Results from the current study revealed that there was a higher correlation between math ability and APASAT performance than math and APVSAT performance. While the evidence presented above may explain, at least in part, the differential APASAT and APVSAT performance, it is unlikely that it can be used to explain the large discrepancy in modality performance.

The interference effect

The fact that the APASAT is more difficult than the APVSAT suggests that some aspect of aural presentation induces extra cognitive effort over visual presentation. The extra cognitive effort may be due to conflict between the input and response modes on the APASAT resulting in an 'interference effect'. That is, aural digit presentation may be masked by response articulation. As a result, more cognitive effort is required to attempt to overcome the interference.

As Bateman (1997) explained, the APASAT or PASAT has access to only one information processing channel, that which processes the spoken word. If there is only one channel, then conflict between articulating a response and listening to the next digit

could occur, particularly when ISI length becomes shorter. In fact, subjects from the APASAT group of the current study often commented that they had a hard time 'listening to the voice' while saying their answers aloud.

There is a general consensus in the literature that lower performance on the PASAT is due to an interference effect (Bateman, 1997; Fos et al., 2000; Hiscock et al., 1998; Madigan et al., 2000). Thus, interference would likely be reduced by changing either the input or output modality (Fos et al., 2000). The APVSAT accomplishes this since the input mode is visual while the output mode remains aural. While it may not be as easy to articulate a response and watch for the next digit, it is much easier than attempting to articulate and *listen* for the next digit at the same time (Bateman, 2000). In this sense, there is less interference between the articulated response and incoming aural stimulus on the APVSAT because they are processed along separate pathways. Lower thresholds or more correct responses on the APVSAT from the current study and other studies suggest that interference is indeed reduced on the APVSAT. As a result, less cognitive effort may be required on this measure.

Interference and head injury

If neurologically healthy individuals are susceptible to interference on the APASAT, then head injured patients may be even more susceptible. In a study comparing moderate-to-severe head injured patients to controls, one group of researchers found this to be true (Madigan et al., 2000). These researchers found that thresholds on a modified PASAT were higher than those on a modified PVSAT for both normals and head injured patients. In addition, the head injured group had proportionately higher

thresholds on the auditory task than the non-head injured group in comparison to the visual task.

One suggestion for this finding was that the auditory system is more susceptible to damage than the visual system (Madigan et al., 2000). However, since non-head injured controls also had worse performance on the auditory task this hypothesis did not seem likely. The more likely explanation for Madigan et al.'s results is that in addition to reduced speed of information processing, head injured patients were also more susceptible to auditory-verbal interference (Madigan et al., 2000).

Further support for head injured patients' susceptibility to interference comes from Kewman, Yanus, and Kirsch (1988). These researchers compared head injured to non-head injured information processing of auditory information with distracting vocal stimuli. The auditory information consisted of a passage being read by a male voice while the distractor was a second simultaneous passage read by a female voice. Results from Kewman et al.'s study indicated that the head injured group made more comprehension errors on the interference condition than the non-head injured group.

In another study, Van Zomeran and Brouwer (1987) also investigated interference effects in moderate-to-severe head injured patients. When a distractor target was introduced to a four-choice visual reaction time condition, the head injured group had significantly slower RTs than the non-head injured group. To provide an explanation as to why head injured patients were affected by interference, Van Zomeran and Brouwer (1994) suggested that as with other mental processes, these individuals needed more time than controls to deal with response interference. Thus, Van Zomeran and Brouwer (1994) concluded that head-injured patients show slowed controlled processing, or have a

decreased ability to guide attentional resources to deal with the interference (Weber, 1990).

To relate these findings to the previous section on interference in non-head injured individuals, the increased cognitive effort or working memory required for the APASAT seems to be proportionately increased in head injured cases. Thus, in addition to indexing reduced speed of information processing, the APSAT tasks may also provide an index of impaired working memory.

Working memory

A model of working memory will be provided to support the interference effect and further explain how extra cognitive effort is needed for the APASAT.

As previously mentioned, several researchers believe that the traditional PSAT is a measure of working memory *and* speed of information processing (Fos et al., 2000; Dieher et al., 1998; Diamond et al. 1997; Madigan et al., 2000; Ward, 1997). If this is true, then the APSAT may also tap into working memory as well as information processing. Also, in comparison to the APVSAT, the APASAT may involve more cognitive effort from working memory for reasons described in this section.

Working memory is a theoretical system that temporarily stores and manipulates information needed for essential cognitive processes such as learning and reasoning (Baddley, 1990). Baddley (1990) suggested that working memory consists of several components. The phonological loop is responsible for the manipulation of speech based information and the visuo-spatial sketch pad is responsible for visual information. The central executive is the 'attentional-controller' that oversees these subsidiary systems.

At first it may appear that the APASAT and APVSAT are accessing separate systems (Madigan et al., 2000). However, Baddley (1992) suggested that the phonological loop serves two functions, both of which are required for success on both versions of the APSAT. First, this system can maintain auditory information in a phonological store through subvocal repetition. Second, it can take visual information and register it in the phonological store by subvocalization (Baddley, 1992). Either of these functions can be disrupted by articulation, such as articulating a sum for the APSAT. Baddley (1992) suggested that articulation can disrupt the temporary storage of both auditory and visual information because the subvocal rehearsal process is disturbed.

If articulation *equally* disrupts the storage of auditory and visual information, then performance should be equal on the APASAT and APVSAT. However, as all results indicate, this is not the case. If the assumption of equal disruption of auditory and visual processing is changed to suggest that disruption is greater for auditory information than for visual information, then APASAT performance should be lower than APVSAT performance. The results from the current study and from past studies show this to be true.

The critical disruptive factor is that due to the paced nature of the PSAT, the stimulus and response inevitably overlap. With the APASAT, this overlap results in the response masking or partially masking the stimulus. As a result, the stimulus may not reach the phonological store and thus would not be rehearsed, or the stimulus may reach the phonological store, but then sub-vocal rehearsal may be substantially interrupted by articulation. On the other hand, the stimulus could still reach the store with the APVSAT since it would be possible to 'see' the digit and 'say' the response simultaneously. In

addition, sub-vocal rehearsal may not be as substantially interrupted as with sub-vocal rehearsal of the auditory stimulus.

The interference effect and the role of working memory on APSAT performance has two important implications. First, this theory suggests that the APSAT is not solely a measure of speed of information processing. Since several tasks such as storage of the digits, sub-vocal rehearsal, and mental computation must be simultaneously managed, a working memory aspect seems to be involved. Thus, success on the APSAT requires *both* rapid processing of information and management of sub-tasks within the hypothesized phonological loop. Second, head injured patients may be less equipped to handle the interference effect on the APASAT. This in turn may be clinically significant in terms of diagnostic and rehabilitative procedures.

Profile analysis

The previous section demonstrated that the modality results from the current study, as measured by number of correct responses and threshold, are consistent with results from other studies on the traditional PSAT procedure. Another result that is consistent with the literature is the finding that there were proportionately more missed responses than incorrect responses. For example, Wingenfeld et al. (1999) were investigating a new computerized PASAT in non-head injured individuals and discovered that as ISI length decreased participants tended to make fewer errors and to miss more items. These researchers suggested that this pattern of responding may or may not be similar with neurologically impaired groups and that it might assist with diagnostic procedures.

To expand on Wingenfeld et al.'s (1999) theory, it is possible that head injured populations may in fact miss more items than normals as a result of reduced speed of information processing. That is, with less resources available to make responses on time, it seems likely that responses would be missed more often since articulating a response, be it correct or incorrect, would take longer than simply missing it.

Another possibility is that speed is sacrificed for accuracy. That is, head injured individuals may purposely slow their rate of responding in order to achieve more correct responses. For example, if a patients heard the numbers "4...5...3", they may not say "9" in response to the first two digits in order to be able to correctly respond with the next sum which would be "8". Research comparing the patterns of missed and incorrect responses between head injured individuals and those without head injury may shed more light on this issue.

Problem complexity

Unlike the results found for modality, those found for complexity were not as obvious. The original hypothesis was that the inclusion of complex sums on the unrestricted APSAT would make this task more difficult and would thus have higher thresholds than the restricted APSAT which only had simple sums. However, thresholds on the unrestricted-APSAT were not significantly lower than those on the restricted-APSAT. This lack of complexity effect may have been due to the unrestricted APSAT consisting of both simple and complex sums. That is, the simple sums within the unrestricted APSAT may have been easier than the complex sums but the combination of the two may have averaged or counteracted the effects of the complex sums. To test this hypothesis, the performance in unrestricted-simple and unrestricted-complex sums were

analyzed separately . As predicted, performance was better for unrestricted-simple than for unrestricted-complex sums. Performance was measured in terms of number of correct responses and correct latencies. There were significantly more correct responses and shorter latencies for unrestricted-simple than for unrestricted-complex.

Complexity effects in the literature

While no one has directly compared a restricted version of the APSAT or PSAT to the original unrestricted PSAT, there is some evidence in the literature to suggest that a complexity effect does exist. For example, Bateman (1997) gave non-head injured subjects a restricted traditional PASAT that only had sums between 2 and 10 as well as the unrestricted traditional PASAT with sums between 2 and 18. While a direct comparison could not be made between these two measures due to differences in trial number and ISI length, a comparison of the proportion of correct responses could be made at the 2.0s ISI which was used in both measures.

At the 2.0s ISI, 66% of the responses were correct on the unrestricted PASAT while 77% were correct on the restricted PASAT, a significant difference. While not directly comparable, there were significantly more correct responses on the 2.5s ISI and 1.5s ISI of the restricted PASAT versus the 2.4s and 1.6s ISI on the unrestricted PASAT. Bateman (1997) developed the restricted PASAT as he felt the arithmetic computations on the unrestricted traditional PASAT were too difficult. His suspicions were confirmed by the greater proportion of correct responses on the restricted PASAT than on the unrestricted traditional PASAT.

Complexity effect in the current study

While Bateman (1997) tentatively found a difference, in terms of correct responses, between the traditional unrestricted PASAT and his modified restricted PASAT up until the faster ISIs (i.e., 1.2s and 1.0s respectively), the current study did not yield this type of result. Bateman suggested that he did not find significant differences at the faster ISIs because the two measures were equivalent in difficulty at a fast pace.

Thus the assumption seems to be that performance on restricted and unrestricted PSAT or APSAT versions should differ at all but the fastest ISIs. Since the APSAT represents performance for all ISIs, including the slower ones at which complexity would have an effect, then it should follow that restricted and unrestricted performance should differ. However, there was no significant difference between any of the measures on the unrestricted and restricted APSAT. Thus, Bateman's theory that complexity has an effect at all but the fastest ISIs does not explain the current findings. A more likely explanation for the lack of difference in thresholds, number correct, and correct response latencies between unrestricted and restricted APSAT versions is the inclusion of both simple and complex sums on the unrestricted APSAT. That is, there may have been a significant difference between performance on simple and complex sums within the unrestricted version that 'averaged out' to resemble performance on the restricted version.

Simple and complex sums within the unrestricted APSAT were analyzed and compared to test the above hypothesis. While a threshold measure could not be analyzed, the results did reveal that significantly more correct unrestricted-simple responses were given than correct unrestricted-complex responses. In addition, response times were faster for the unrestricted-simple than for the unrestricted-complex responses.

The most likely reason for this finding was that the simple sums were solved using time efficient retrieval strategies while complex sums involved less efficient strategies such as transformation (e.g., through 10: “ $7 + 5$ is really $7 + 3 + 2$ ”) (LeFevre et al., 1996). This ‘problem size effect’ has been studied in the literature and it appears that solution times to addition problems tend to increase with the sum of the problem due to the different strategies used for simpler and more complex problem types (LeFevre et al., 1996). This carries over to the APSAT procedure such that the use of non-retrieval strategies for complex sums may affect unrestricted APSAT performance in comparison to restricted APSAT performance.

Unrestricted-simple vs restricted-simple performance

To further investigate the effects of the inclusion of complex sums in the unrestricted APSAT, the performance on unrestricted-simple sums was compared to that on restricted-simple sums. It was expected that the contrast between the simple and complex sums would make the simple sums relatively easier within the unrestricted APSAT. As a result, unrestricted-simple performance would be better than restricted-simple performance. This hypothesis was supported by the results that revealed a greater proportion of correct unrestricted-simple responses over correct restricted-simple responses. However, the latency for correct responses was not faster for unrestricted-simple sums as would be expected.

While performance on the unrestricted APSAT was not significantly different from that on the restricted PSAT, the inclusion of complex sums within the unrestricted version does seem to have an effect on performance. That is, there are more errors made for complex sums and relatively less made for simple sums within the unrestricted

APSAT. Thus, measures yielded by the unrestricted version may reflect these inconsistencies in addition to speed of information processing and working memory.

Moderator variables

Math ability

A correlation between math ability, as indexed by the total score on the French Kit addition test, and APSAT threshold was calculated to determine the degree to which math ability and APSAT performance were related. As expected, the results indicated that there was a high and significant negative correlation between math ability and threshold. The relationship between math ability and APSAT performance was also investigated by modality of presentation. The results revealed that math was highly and significantly correlated to both the APVSAT and the APASAT. In fact, the relationship with the APASAT was higher ($r = -.74$) than that with the APVSAT ($r = -.53$).

Since there was significant relationship between math ability and APSAT performance, the proportion of variance accounted for by math was calculated next. Math ability was entered after modality and complexity, since both these variables had an effect on APSAT performance, to determine what proportion of 'left over' APSAT variance could be accounted for. As expected, math accounted for a significant proportion of APSAT variance (26%).

Furthermore, since there was a significant modality effect, math was regressed on APSAT threshold after complexity for auditory and for visual APSAT performance. It was expected that math would account for more auditory than visual variance (for reasons to be discussed later). As expected, math ability accounted for more variance for the aural version (54%) than for the visual version (28%). The same procedure was used

for restricted and unrestricted APSAT versions. Although no significant complexity effect was found, results indicated that the inclusion of complex sums in the unrestricted-APSAT had some affect on performance. Since complex sums are mathematically more difficult than simple ones, it was assumed that after modality effects had been controlled for, math ability would account for more unrestricted-APSAT variance than restricted-APSAT variance. The results revealed that math accounted for 33% of unrestricted-APSAT variance and only 18% of restricted APSAT variance.

Math ability in the literature

The current debate regarding the effect of math ability on APSAT performance began when Gronwall and Sampson (1974) first claimed that the traditional PSAT was not significantly correlated with math ability. Thus, the traditional PSAT was presented as useful for the examination of a variety of groups with wide ranges of math ability (Gronwall & Wrightson, 1974). However, due to the arithmetic nature of the PSAT, researchers began to question if there perhaps was a significant relationship between level of math ability and traditional PSAT performance.

For example, Ward (1997) proposed that a younger generation was less familiar with numeric bonds (i.e. simple addition) than an older generation due to the widespread use of calculators and computers. As a result, he suggested that if the traditional PASAT measured numerical ability in addition to speed of information processing, then the younger group would perform worse on the traditional PASAT than the older group. Ward compared the two groups of subjects on the 2.0 s ISI only as he felt this was the rate which clinicians may prefer due to its sensitivity to mild head injury, as suggested by Gornwall (1977). Results from his study did demonstrate that older adults (45 to 65 years

old) had more correct responses on the 2.0 s presentation rate than the younger, university participants (18 to 35 years old).

Ward (1997) concluded that the traditional PASAT reflected mathematical ability in addition to speed of information processing. If the PASAT indexed speed of information processing independently of math ability, then the younger subjects should have performed better than older subjects. However, this was not the case. To further support his findings, Ward (1997) demonstrated that his participants were equivalent on working memory as measured by digit span backward.

Crawford et al. (1998) provided some evidence to corroborate Ward's (1997) findings. These researchers compared three age groups (16 to 29 years, 30 to 49 years, and 50 to 74 years) on the traditional PASAT on all ISIs (2.4 s, 2.0 s, 1.6 s, and 1.2 s). Unlike Ward (1997), Crawford et al. (1998) found that the younger groups had more correct responses than older groups. Their findings may have differed from Ward's since they used the faster ISIs (1.6s and 1.2s) in addition to the 2.0s ISI used by Ward. That is, the older adult's familiarity with number bonds may not have made much of a difference in relation to their reduced processing speed at the faster ISIs. On the other hand, while younger subjects may have had less number bond knowledge, they may have been able to process information faster and still maintain what knowledge they had. Despite their different findings from Ward, Crawford et al. proposed that the relative differences in knowledge of number bonds served to attenuate the relationship between age and PASAT performance. That is, the strength of the relationship between age and PASAT performance was modest when compared to that found for other measures of speed of

information processing which do not require number bond knowledge (Crawford et al., 1998).

To further support the hypothesis that math ability is related to APSAT or PSAT performance, Shermann et al. (1998) investigated the relationship between math ability and traditional PASAT performance. The Wide Range Achievement Test – Revised (WRAT-R) was used to index math ability and the 2.0s and 1.6s ISIs of the traditional PASAT were used to index speed of information processing. Shermann et al. (1998) found a moderate and significant correlation between math ability and traditional PASAT performance.

Bateman (1997) also found that the traditional PASAT was correlated with mathematical ability as measured by the WAIS-R arithmetic sub-test. This researcher also looked at the relationship between modified PASAT/PVSAT and math. These modified versions were similar to those used in the current study in that sums were between 2 and 10 only. Bateman (1997) did not find a significant relationship between math ability and either of the modified PSAT versions. This is somewhat different than the results found in the current study that revealed significant correlations between math ability and both APSAT versions. One reason for Bateman's results may be that the WAIS-R Arithmetic sub-test may not be as sensitive a test for math ability compared to some others. In fact, this sub-test makes up part of the Freedom From Distractibility factor, which reflects attention more so than math (Wechsler, 1981). On the other hand, the math test used in the current study may not load on attention as much as it does not require the same type of mental manipulations required for the WAIS-R Arithmetic test.

A study by Chronicle and MacGregor (1998) is the final line of evidence which will be presented in support of the current findings. These researchers examined the relation between RTs on a calculation verification task and traditional PASAT performance. They did find a significant correlation; however, this may be due to the nature of the calculation verification task. The verification task required subjects to rapidly decide whether a solution to a mathematical problem was correct or incorrect and their RT was recorded. As such, the verification task may share some of the PASAT's subtasks such as making rapid additions in order to process each trial. The authors suggested that calculation accuracy, which requires the subject to present a solution, may not have the same type of relationship. However, the current study included calculation accuracy rather than calculation verification RTs and results were similar to those reported by Chronicle and MacGregor. In addition, other studies that used calculation accuracy rather than verification procedures reported similar results (Bateman, 1997; Deary et al., 1991; Johnson et al., 1988; Sherman et al., 1997; Ward, 1997). Thus, the relationship between math ability and APSAT performance is similar regardless of the type of math test used.

Math ability and problem complexity in the current study

Bateman (1997) was the first to use a restricted traditional PSAT with an adult population under the assumption that the computations for the unrestricted PSAT were too difficult. This assumption suggested that the computations on the PSAT required some level of math ability in addition to speed of information processing. Following this assumption, problem complexity and math ability will be discussed in unison. Since there no difference was found between the restricted and unrestricted APSAT versions,

the following discussion applies to the difference found between unrestricted-simple and unrestricted-complex APSAT performance.

As previously mentioned, the most likely reason for the difference between unrestricted-simple and unrestricted-complex APSAT performance may be that different types of strategies are used for each version. That is, simple sums are most likely solved with retrieval strategies while complex sums often require more time consuming strategies such as transformation in addition to retrieval strategies (LeFevre et al., 1996). In addition, those with better math skills may use retrieval strategies more often than those with lower math ability. While it was originally intended to analyze this hypothesis, there were not a sufficient number of participants to do so.

However, the examiner did ask the participants about the strategies they used on the APSAT. In almost all cases, subjects used strictly retrieval strategies on the restricted APSAT. On the other hand, for the complex problems on the unrestricted APSAT, other strategies were used. In addition, subjects who found the APSAT frustrating or hard tended to use more non-retrieval strategies than those who had less difficulty with the measure. More research relating the types of strategies used on the APSAT to math ability needs to be conducted to resolve this issue.

An interesting finding from the current study was that math ability was most highly correlated to the auditory presentation of the APSAT and accounted for more auditory APSAT variance than visual. The reason for this may be that the APASAT, or the PASAT, places more demands on working memory and speed of information processing due to the more difficult nature of this task (Bateman, 1997). That is, the interference effect makes the APASAT relatively harder than the APVSAT. As a result,

a higher level of math ability may help compensate for the interference effect and those with higher math ability may do better on the APASAT than those with lower math abilities.

Attention

It is difficult to assess which components of attention the APSAT measures. So far the APSAT has mostly been referred to as a test of speed of information processing. However, it is hard to truly isolate and measure one single component of attention. Yet, a test of one or more aspects of attention, such as the APSAT, should be more highly related to other tests of attention than to tests measuring other abilities such as mathematical skills (Sherman et al., 1997). Keeping this in mind, a correlational analysis between APSAT threshold and several measures of attention was performed in order to determine which aspects of attention this measure was most related to and to compare these to the correlation with math ability.

Of all the tests of attention, TMT-B had the strongest relationship with APSAT threshold. In addition, TMT-A, digit span backward, and digit symbol had moderate correlations with APSAT threshold. Since TMT-B had the highest correlation with APSAT performance, this measure was chosen as the 'representative' measure of attention and regressed along with modality and complexity.

When TMT-B was regressed alone after modality and complexity, the analyses revealed that TMT-B accounted for a significant proportion (18%) of the APSAT variance. Since there was a significant modality effect, TMT-B was regressed on APASAT and APVSAT thresholds separately. The results indicated that there was not much difference in the proportions of APSAT variance accounted for by TMT-B:

auditory = 32%, visual = 28%. This is not surprising as the correlation between TMT-B and APASAT threshold ($r = .53$) was similar to that with APVSAT threshold ($r = .56$).

Finally, since math ability was regressed on APSAT threshold for restricted and unrestricted groups, the same was done with TMT-B. The results revealed that the TMT-B accounted for more unrestricted APSAT variance (32%) than restricted APSAT variance (2.5%)

Attention vs math

The following section compares the variance accounted for by math and attention as reported in the previous sections. Next, the variance accounted for by math and attention when regressed one after the other will be compared. The purpose of this is to investigate the relative relationships of math and attention with APAT threshold. This was done to compare the relationships of these variables with auditory and visual and with restricted and unrestricted performance.

In order to determine if TMT-B or math ability accounted for more unique APSAT variance, these two variables were regressed after modality and complexity on APSAT threshold. As shown above, when TMT-B was regressed alone after modality and complexity, the analyses revealed that TMT-B accounted for a significant proportion (18%) of the APSAT variance across APSAT versions. In comparison to math (26%), this measure of attention accounted for less variance after modality and complexity regardless of APSAT version. Similarly, TMT-B only accounted for an insignificant 2.5% of restricted-APSAT variance while math accounted for a significant 18%. On the other hand, both measures account for similar proportions of unrestricted APSAT variance: TMT-B = 32% and math = 33%.

When TMT-B was regressed after modality/complexity and math, it accounted for less APSAT variance than when math was entered last: TMT-B = 6.2%, math = 15%. Similarly, when regressed after modality, TMT-B accounted less restricted and unrestricted-APSAT variance than when math was entered last: TMT-B = .8% restricted variance and 11% unrestricted variance; math = 16% restricted variance and 13% unrestricted variance.

In summary, when the relationship between TMT-B and APSAT threshold was compared by modality, there was a strong and significant relationship between TMT-B and both the APASAT and the APVSAT. Both relationships were significant and of similar magnitudes, this suggests that both the APASAT and APVSAT may assess a similar component of attention as measured by the TMT-B. On the other hand, there was a higher correlation between math ability and the APASAT than between math ability and the APVSAT. These findings suggest that while the APSAT has a similar relationship with attention regardless of modality as measured by the TMT-B, the APASAT has a stronger relationship with math ability than the APVSAT.

Evidence in the literature on the APSAT and attention

The correlations between the APSAT and the classic neuropsychological tests of attention in the present study suggest that the APSAT is indeed a test of attention. The following section describes evidence to support the same theory and to demonstrate that the TMT-B is highly related to APSAT performance in comparison to other tests of attention. The first line of evidence for a correlation between the APSAT and the TMT-B comes from O'Donnell et al. (1994). This group found that the number of correct responses summed over all four ISIs of the PASAT was most correlated with the TMT-B

($r=.58$) compared to other tests of attention (Visual Search and Attention Test-VSAT) and conceptual ability (Category Test, Wisconsin Card Sorting Test). In addition, both the PASAT and TMT-B were highly correlated with a psychomotor speed/focused attention factor (r 's = .83 and .76 respectively). They also found that the TMT-B was moderately correlated with the Category Test ($r = .43$), which suggested that it was also related to a conceptual factor. Furthermore, the TMT-B was moderately correlated with a conceptual processing factor ($r = .33$).

O'Donnel et al.'s evidence suggests that the TMT-B taps into some cognitive processes other than focused attention. Similarly, Shermann et al. (1995) found that both the PASAT and the TMT forms A and B were moderately correlated with a freedom from distractibility factor (FFD), the attention factor for the WAIS-R (r 's = .46, -.31, and -.35 respectively). However, TMT A and B were more highly correlated with perceptual organization (r 's = -.50 and -.38) than the PASAT was ($r = .23$) and they were also more highly correlated with this variable than with FFD.

In another study, Larabee and Curtis (1995) describe the type of conceptual processing measured by the TMT-B as visuospatial intelligence. This is based on their results that the TMT-B was highly and significantly correlated with a visuo-spatial intelligence factor ($r = -.62$). In fact, this correlation was almost as high as that between the Object Assembly sub-test of the WAIS-R and this factor ($r = .67$).

The current study revealed modest correlations between the APSAT and Digit Span subtests of the LAMB. Similarly, Larabee and Curtiss (1995) found that the PASAT and the WAIS-R Digit Span sub-test, which is similar to the LAMB's sub-test,

were most correlated with an attention/immediate memory and information processing factor (r 's = .53 and .66 respectively).

The present study also revealed a modest correlation between the SDMT and the APSAT. In another study, Deary et al. (1991) found that both the 2.0 s ISI of the PASAT and Digit Symbol sub-test of the WAIS-R, which is similar to the SDMT, were significantly correlated ($r = .39$). In addition, they found that the PASAT was highly related and Digit Symbol was moderately related to a freedom from distraction factor (r 's = .79 and .44 respectively). Based on their results, Deary et al. (1991) suggested that the PASAT was indeed a test of attention and concentration since it was correlated with an attention factor and not with verbal and performance factors from the WAIS-R.

Analysis of models of attention and their relation to the APSAT

The results from the present study and those in the literature all lead to the conclusion that the APSAT measures some aspect/s of attention. However, the claim that the APSAT measures one discreet aspect of attention, information processing, is becoming increasingly harder to support. This comes with the general acknowledgement that attention is no longer considered a unitary process (Mateer & Mapou, 1996; Mirsky et al., 1991; vanZomeran & Brouwer, 1994; Weber, 1990). There are several models of attention in the literature that judiciously describe the various components of attention; however, these models propose conflicting views on which tests measure which components of attention.

Before presenting these views, the major components of attention will be described according to Weber's (1990) two dimensional model of attention. Divided attention refers to an individual's ability to attend to two or more sources of information

simultaneously. Focused or selective attention is when one source of information is ignored while another source of information is attended to. Sustained attention or vigilance is a person's ability to maintain attentional control over an extended period of time.

These aspects of attention can be measured with a variety of neuropsychological tests. However, which aspect is measured by which test is a source of debate. For example, Table 7 illustrates that divided attention can be measured by the Digit Span Backward sub-test of the WAIS-R or the SDMT. Focused attention is reportedly measured by both TMT-A and B, Digit Span Forward (WAIS-R), or Digit Symbol Substitution (WAIS-R). Finally, sustained attention is reportedly measured by both the TMT-A and Digit Span Forward sub-test of the WAIS-R.

Insert Table 7 about here

The conflict amongst the classifications in Table 7 and the evidence that the APSAT is correlated with several different measures of attention suggests that there may be some process common to the different types of attention making it hard to differentiate among them. Weber (1990) calls this common process *control*, defined as the ability to direct and organize attentional resources. Control is synonymous with working memory in that working memory also involves organization as well as mental manipulation of information. Weber (1990) also defines a second dimension of attention, *capacity*, defined as the amount of information that a person can attend to within a given time. The

Table 7. Measures of attention

Test	Attention component	Author
TMT-A	Sustained attention	Mateer and Mapou (1996)
TMT-A and B	Focused attention	Mapou (1995) and Mirsky (1991)
Digit Span Forward *	Sustained	Mateer and Mapou (1996)
	Capacity/encoding	Mapou (1995)
Digit Span Backward*	Divided	Mateer and Mapou (1996)
	Mental manipulation	Mapou (1995)
Digit Span Forward and Backward*	Focused	Mirsky (1991)
Digit Symbol Substitution Test*	Focused	Mirsky (1991)
SDMT	Divided	Matter and Mapou (1996)
	Focused	Mapou (1995)

*** sub-tests from the WAIS-R**

other side to capacity is speed of information processing. These two terms are synonymous in that slower processing means less information can be attended to in a given amount of time or faster processing means more information is attended to.

The terms described above interact with control as well as the other previously defined components of attention (Weber, 1990). For example, divided attention requires that capacity be divided amongst several sources of information through control. Control is also needed for focused attention in order to direct attention away from one stimulus to another. Finally, sustained attention requires control in the sense that the goal of a task must be kept in mind and distractions must be avoided (Weber, 1990). If control is needed for all these processes, including speed of information processing, then it makes sense that many measures of attention will be inter-correlated. Thus it follows that the APSAT should be correlated with other measures of attention, which the results from this study demonstrate.

Head injury and attention

The above descriptions of capacity and control were developed by Weber (1990) to expand the two-part model developed by Schneider and Schiffrrin (1977). Within Schneider and Schiffrrin's model there are two types of attention: automatic and controlled. Automatic attention is a type of effortless process that occurs without conscious control and that is not limited by capacity. On the other hand, controlled processing is conscious and has a limited capacity or speed of processing. For head injured patients, it is usually this controlled type of processing, or concentration, that has been reduced (Weber, 1990).

Control, or concentration, can be reduced in one of or a combination of two ways. First, if capacity or speed of processing is reduced, then the individual will need more time to process a certain amount of information (Weber, 1990). As Weber explains, while the individual can still do the same things they did before, but these tasks now require more effort and can be tiring. On the other hand, if there is a control deficit, the individual may be able to process information as they once did. However, in this case they tend to lose track of what they are doing and are easily distracted due to the reduced ability to divide their attention amongst competing stimuli (Weber, 1990). Concentration is often reduced by a combination of capacity and control deficits. In addition, reduced capacity can somewhat affect control and vice-versa (Weber, 1990). The task for clinician is to determine whether primarily capacity or control, or both, have been affected by a head injury. As a result a rehabilitation program could be developed to address the specific type of deficit experienced by a head injured patient.

Clinical implications

The findings from the current study have several clinical implications for head injured patients. These implications are related to the modality of APSAT presentation, the use of complex sums within the APSAT, and the relation of math ability to APSAT performance. These implications are discussed under the assumption that the APSAT is, in fact, a measure of attention as demonstrated by the correlations with other measures of attention

Visual vs. auditory APSAT presentation

The most important finding from the present study was the effect of modality of presentation on APSAT performance. One reason for investigating this effect was to

determine whether one modality is preferable in a clinical situation or if both should be used. The findings suggest that both versions are useful either alone or in combination. The reasons for this suggestion will be described in the following paragraphs.

The relatively higher thresholds of the APASAT over the APVSAT in normals is proportionately worse in moderate-to-severe head injured patients (Madigan et al., 2000). As previously discussed, the most likely cause for this discrepant performance is reduced speed of information processing and/or greater susceptibility to auditory-verbal interference due to reduced control or working memory in head injured patients. One way to assess if a head injury has resulted in either reduced speed of information processing and/or control is to compare a head injured patient's own performance in both modalities on the APSAT .

One of the most common results of a closed head injury (CHI) is diffuse axonal injury (DAI) (Alexander, 1995; Binder & Rattok, 1989; King, 1997; Weber, 1990). This injury results in reduced speed of information processing due to the reduced transmission of information within the nervous system (Whyte, 1992). Another common result of CHI is damage to the frontal lobes (King, 1997; Ponsford & Kinsella, 1992) which affects the ability to control the allocation of attentional resources (Whyte, 1992). Assessment of the effects of one or both of these types of injuries may be accomplished through the comparison of a head injured patient's APASAT and APVSAT threshold.

With either types of damage, a head injured patient's APASAT threshold may be higher than their APVSAT threshold as demonstrated by Madigan et al. (2000). However, the degree of difference between the APASAT and APVSAT may indicate whether the damage has been predominantly diffuse or frontal. If damage is

predominantly diffuse, then the result should be primarily reduced speed of information processing on both visual and auditory modes. Thus, the difference between a head injured person's APASAT and APVSAT threshold would be qualitatively similar to a non-head injured person's performance except that both of the head injured person's thresholds would be equivalently higher. Figure 12. illustrates this hypothetical situation in an exaggerated manner for the purpose of clarity. In this case, the head injured patient's threshold on both the APASAT and APVSAT is higher than the non-head injured individual's as a result of reduced speed of information processing. However, since the head-injured individual still has a relatively intact working memory system, the threshold is not proportionately higher than that on the APVSAT in comparison to the non-head injured person. Again, this example is exaggerated as the effects of DAI would most likely have some effect on working memory.

Insert Figure 12 about here

However, damage to the frontal lobes would have a more drastic effect on working memory. Figure 13 demonstrates that if damage was sustained primarily to the frontal lobes, there would be a greater degree of difference between a head injured patient's APASAT and APVSAT threshold relative to the difference for a non-head injured individual. This would most likely be due to the head injured patient's reduced ability to allocate resources to the interference condition on the APASAT. Therefore the injury would have more of an effect on auditory than visual threshold due to the increased susceptibility to interference.

Figure 12. Hypothetical APSAT thresholds for head injured (primarily diffuse damage) and non-head injured groups

Insert Figure 13 about here

As a final example, if damage were sustained both diffusely and locally to the frontal lobes then there would be an even greater discrepancy between a head injured person's APASAT and APVSAT threshold in comparison to a non-head injured individual. As Figure 14 illustrates, the APVSAT threshold would be higher in this case than with DAI or frontal damage alone and the APASAT threshold would be proportionately worse. In this case, visual threshold is still primarily affected by reduced speed of processing/DAI and auditory threshold is affected by an additive effect of reduced speed/DAI and reduced working memory/frontal lobe damage.

Insert Figure 14 about here

The benefit of comparing head injured patients' APASAT and APVSAT scores is that it may reduce the chance of misidentification. For example, if patients sustain primarily frontal lobe damage and are only given the APASAT, they may appear to be slow due to reduced speed of information processing. In reality, the reason for their slowed performance was likely due to the reduced ability to organize resources through working memory. As a result of this misidentification, a rehabilitation program might be developed to compensate reduced *speed* of processing rather than the reduced ability to *plan and allocate* resources.

Figure 13. Hypothetical APSAT thresholds for head injured (primarily frontal lobe damage) and non-head injured groups

Figure 14. Hypothetical APSAT thresholds for head injured (diffuse and frontal lobe damage) and non-head injured groups

While it may be beneficial to compare a head injured patient's APASAT threshold to their APVSAT threshold, this may not be the ideal clinical procedure. Chances are that only a single speed of information processing measure would be used for a neuropsychological evaluation since other measures for working memory and frontal processes would be administered. Also, administering the APSAT twice presents other problems such as practice effects which have yet to be resolved.

Having the choice of two versions of the APSAT may be beneficial in the assessment of different severities of head injury. That is, the auditory version may be the ideal choice for mild-head injured patients since the visual version may not be sensitive enough to detect their deficits. On the other hand, the APVSAT may be sensitive enough to assess moderate to severe deficits and may be less frustrating than the APASAT for these patients. In a related situation, the APSAT may reveal misdiagnosis of head injury severity. For example, a patient may have an unexpectedly high threshold on the APASAT when they were classified as mildly impaired according to standard measures such as the Glasgow Coma Scale, length of post-traumatic amnesia, or length of loss of consciousness. In this case, the poor performance on the APASAT may indicate a more serious injury than originally diagnosed and the APVSAT would be a more appropriate measure.

Elimination of complex problems from the APSAT

The previous section indicated that both the auditory and visual versions may be useful in clinical situations. The following section further suggests that the unrestricted version should not be used. That is, the restricted-visual and restricted-auditory versions may be the best choices for clinical assessments. The results from the current study

revealed that the inclusion of complex sums within the unrestricted APSAT affected performance in two ways. First, there were more correct simple sums than complex sums within the unrestricted APSAT. Second, the contrast of simple and complex sums seemed to skew simple sum performance. That is, the complex sums made simple sums seem relatively easier resulting in better performance than when simple sums were given alone as in the restricted APSAT.

These results indicate that complex sums are harder than simple sums. This, in turn, may make the APSAT a more frustrating test. Thus it appears that the restricted APSAT may be the better choice than the unrestricted APSAT, especially for head injured individuals who may already find this task rather frustrating. Further support for the use of the restricted APSAT over the unrestricted APSAT is that math ability accounts for more unrestricted variance than restricted variance.

Clinically, this would mean that use of the unrestricted APSAT would be more appropriate for those with higher levels of math ability. While math ability is somewhat related to the restricted-APSAT, this measure would be more applicable to individuals with a variety of levels of mathematical abilities. Thus, it is suggested that the unrestricted-APSAT not be used for clinical assessment.

Suggestions for future research

Based on the results from the current study and from those presented from the literature, three areas for future research are suggested. First, while the evidence indicates that both head injured and non-head injured individuals are susceptible to auditory-verbal interference, although to different degrees, there is no evidence to suggest that the same is not true for visual interference. Madigan (2000) suggested that one way

to test this is with a serial addition procedure that requires both visual input and visual output. He suggested a modification whereby participants must decide whether a visually presented number is the correct sum of two visually presented numbers. However, Madigan suggests that this modification may alter the nature of the original task. Another possibility is to determine whether the auditory-verbal interference could be reduced. For instance, using the opposite gender voice may prove to be less interfering with the participant's own voice.

A second problem that needs to be addressed is the susceptibility of mild-head injured individual's to auditory-verbal interference. So far, the studies on interference have been with moderate-to-severe head injured individual's. Since non-head injured individual's are susceptible to this interference, it is probable that mild-head injured patient's susceptibility to interference will fall somewhere between that for non-head injured and moderate-to-severe head injured susceptibility.

A final suggestion for future research is related to the lack of complexity effect in the current study. While no difference in complexity was found between the restricted and unrestricted APSAT, further analysis indicated that simple sum performance was higher than that for complex sums. Thus, an investigation comparing a 'purely' unrestricted-APSAT (i.e. simple sums only) to a restricted-PSAT should reveal a complexity effect.

Conclusions

The original purpose of the present study was to investigate the effect of several variables on a new adjusting version of the traditional PSAT. Through this investigation, the usefulness of the APSAT as a measure of speed of information processing could be

assessed. As previously suggested, one of the advantages of the APSAT is that it yields a threshold as a primary measure. This measure may be a more accurate reflection of *speed* of processing than measures such as number of correct responses or average speed per correct response which are typically yielded by the traditional PSAT. Using this new threshold, the relationships between modality, problem complexity, math ability, attention, and APSAT performance were examined. The findings were then related to the assessment of the cognitive effects of head injury.

Early evidence suggested that a head injury resulted primarily in reduced speed of information processing (Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974). As a result, a tool was needed to isolate and measure speed of information processing. The original PSAT was developed and used specifically for this type of measurement. Those who used this measure generally concluded that a reduced number of correct responses on the PSAT implied reduced speed of information processing. If processing speed was the only cognitive process affected by head injury and measured by the PSAT, then the assumption could be made that head injured patients' performance on a visually presented PSAT would be the same for that on one that was presented aurally. Similarly, if processing speed was the only process measured by the PSAT, then non-head injured performance should be similar regardless of modality of presentation.

However, the effects of modality found in the literature demonstrated that people obtained more correct responses when the PSAT was presented visually than when it was presented aurally (Bateman, 1997; Fos et al., 2000; Hiscock et al., 1998). Similarly, the results from the current study and from Madigan et al. (2000) suggest that thresholds are higher on the APASAT than on the APVSAT. Past and current findings suggest that the

interpretation of PSAT or APSAT performance needs to be altered. Thus the major conclusion of the present study is that reduced performance or higher thresholds on the APSAT may reflect reduced processing speed *in addition to* increased susceptibility to interference. This interpretation led to the suggestion that both the auditory and visual versions of the APSAT could be used for clinical assessments in different ways. This new interpretation of APSAT/PSAT performance does not reduce the clinical value of this tool; however, it does increase the breadth of knowledge as to what the results mean.

APSAT performance was also interpreted relative to problem complexity. The effects of problem complexity on APSAT threshold were not as obvious as the effects for modality. However, the results suggested that the inclusion of complex problems in the unrestricted APSAT could have affected performance on the simple sums. Additional evidence revealed that the unrestricted-APSAT had a stronger relationship with math ability. Thus, the restricted-APSAT may be the more clinically useful tool. As a result of this finding, the second conclusion from the present study is that the unrestricted versions of the APSAT should not be used in a clinical setting. That is, of the four original measures, the restricted APASAT and the restricted APVSAT may be the most beneficial for head injury assessment.

In addition to finding and explaining the effects of modality, problem complexity, and math ability on APSAT performance, the present study also demonstrated that the APSAT is related to other measures of attention. The APSAT may not be a measure of speed of information processing alone as originally suggested by Gronwall and Sampson (1974). However, the evidence in the literature and from the present study indicate that this tool is indeed a measure of attention, and it reflects *both* speed of information

processing and working memory. Thus, the third conclusion from the present results is that APSAT threshold may provide a more accurate reflection of *speed* of information processing and working memory rather than speed of information processing alone.

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Appendix A**Interview**

Date Administered: _____

Subject Number: _____

Name: _____

Gender: _____

Phone #: _____

Age: _____

Address: _____

DOB: _____

Date of Injury or 1st Diagnosis: _____

Occupation: _____

Handedness: _____

Education in Years: grade school

0 1 2 3 4 5 6 7 8

High school

9 10 11 12

Trade/College

13 14

University

13 14 15 16

Master's level

17 18

Ph.D. level

19 20 21

Medications: _____

Medical History (get details from all that are checked):

seizures/epilepsy

Motor Vehicle Accident

diabetes

Falls leading to Unconsciousness

depression

Head Injury

learning disability

Hand/Arm injury

previous seen Psychiatrist, Psychologist, Counselor

 Briefly describe index injury (what they remember, length of unconsciousness, first memory following impact, etc) & current subjective symptoms of cognitive difficulties
Persistent Symptoms

Subject's Description: _____

Appendix B**ADDITION TEST — N-1**

This is a test to see how quickly and accurately you can add. It is not expected that you will finish all the problems in the time allowed.

You are to write your answers in the boxes below the problems. Several practice problems are given below with the first one correctly worked. Practice for speed on the others. This practice may help your score.

Practice Problems:

4	7	12	84	7	34	17	45	31	80
9	6	5	54	38	81	50	41	32	78
1	15	67	72	80	21	74	89	19	15
<input type="text" value="/4"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Your score on this test will be the number of problems that are added correctly. Work as rapidly as you can without sacrificing accuracy.

You will have 2 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Page 2

Part 1 (2 minutes)

8 3 7	2 31 8	12 42 33	43 71 11	67 93 32	23 74 8	83 14 19	63 99 3	19 37 83	48 17 39
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

19 8 27	69 40 44	6 67 38	30 98 39	30 42 13	73 17 19	39 90 82	32 43 91	17 33 38	81 83 42
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

4 98 31	73 34 22	36 20 34	18 63 92	40 3 39	3 26 89	16 18 39	49 27 36	44 7 80	99 88 77
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

23 47 17	11 23 48	76 41 33	83 47 83	33 39 16	42 23 18	13 87 38	31 8 33	62 38 49	34 34 78
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

14 41 38	74 86 93	63 38 34	38 23 77	38 86 33	63 29 22	47 74 31	84 34 19	62 13 26	22 83 19
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

6 37 98	91 13 87	17 38 67	33 31 63	73 78 43	66 89 32	78 34 63	19 36 43	63 23 43	47 2 39
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

DO NOT TURN THE PAGE UNTIL ASKED TO DO SO.

STOP

Page 3

Part 2 (2 minutes)

76 38 71	69 93 85	34 33 21	48 45 99	77 24 44	53 49 77	18 61 22	94 5 37	38 38 88	42 34 76
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

6 23 44	46 53 37	57 53 35	55 31 13	46 37 99	85 34 8	28 73 44	92 34 65	14 65 85	48 29 77
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

85 9 13	30 34 42	67 78 45	72 98 62	48 1 98	62 81 23	31 36 48	11 74 66	98 87 39	37 32 62
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

73 32 61	9 27 83	49 61 14	23 7 69	36 32 88	36 60 17	17 49 31	43 15 38	17 97 82	41 57 78
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

13 26 58	88 45 9	67 47 62	96 78 14	90 30 26	77 34 61	62 73 23	39 19 26	97 37 31	84 79 8
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

82 12 65	80 39 4	55 10 41	96 68 29	6 85 37	91 21 49	9 82 43	77 24 38	86 11 48	77 84 39
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

DO NOT GO BACK TO PART 1 AND
DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO.

STOP.

Appendix C

INFORMED CONSENT

The purpose of an informed consent is to ensure that you understand the purpose of the study and the nature of your involvement. The informed consent must provide sufficient information such that you have the opportunity to determine whether you wish to participate in the study.

Present Study: “How fast can you react?”

Research Personnel:

If you have any questions, please contact Dr. Tom Tombaugh (Principal Investigator 520-2659) or Dr. Laura Rees (Secondary Investigator 730-4297). Should you have any ethical concerns about this study, please contact Dr. Monique Sénéchal (Chair, Department of Psychology Ethics Committee, 520-2600 x 1155) or the Departmental Chair Person (Dr. K. Matheson, 520-2648).

Purpose:

The purpose of this study is to examine how people perform on a series of newly developed measures of reaction time.

Task Requirements:

This study requires that you perform to the best of your ability on the reaction time measures. We will be measuring how fast you can respond to various stimuli presented on a computer screen. The stimuli may be auditory or visual letters, numbers, or words. Prior to beginning the reaction time tests, an interview will be conducted concerning your medical history. A brief test of your ability to perform basic arithmetic (e.g. adding and subtraction) may be given.

Duration:

The study will last approximately 60-90 minutes.

Potential Risk/Discomfort:

There are no potential physical or psychological risks in this experiment.

Anonymity/Confidentiality:

The data collected in this experiment is confidential. The coded data are made available only to the researchers associated with this project.

Right to Withdraw:

You have the right to refuse to answer any specific questions or participate in any specific task. You also have the right to withdraw your consent and terminate your participation at any time.

I have read the above description of “How Fast Can You React?” and understand the conditions of my participation. My signature indicates that I agree to participate in this experiment.

(Name)

(Signature)

(Date)

(Researcher)

(Signature)

(Date)

Appendix D

DEBRIEFING

Thank you for participating in our study. Reaction time measures are thought to reflect speed of information processing (i.e., speed of thinking), and your participation in the study will help us standardized these new measures of reaction time.

As you are aware, speed of information processing can be reduced in those individuals who have sustained any compromise to central nervous system functioning (e.g., disease, trauma, fatigue, stress, intoxication, etc). When information processing speed is reduced, individuals have a more difficult time attending to stimuli in their environment - it can make completing relatively automatic tasks like listening to the radio and cooking dinner at the same time, impossible for some people. Our main goal for this study is to examine how those individuals who have sustained a traumatic brain injury perform on these tests, that clinicians will be able to chart recovery over time and that the information will be useful when you are making decisions (e.g., about when to return to work, etc.).

Once again, thank you for participating in our study.

If you have any questions, please contact Dr. Tom Tombaugh (Principal Investigator, 520-2659) or Dr. Laura Rees (Secondary Investigator, 730-4297). Should you have any ethical concerns about this study, please contact Dr. Monique Sénéchal (Chair, Department of Psychology Ethics Committee, 520-2600 x 1155) or the Departmental Chair Person (Dr. K. Matheson, 520-2648).