Assessment of Attention Deficits in Traumatically Brain-Injured Patients: Limitations of a Computerized Continuous Attention Test

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James Matthew Sawchyn
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We accept this thesis as conforming to the required standard

[redacted]

R.W. Skelton, Ph.D., Supervisor (Department of Psychology)

[redacted]

F.J. Spellacy, Ph.D., Departmental Member (Department of Psychology)

[redacted]

P. Fisher, Ph.D., Outside Member (Department of Health Information Sciences)

[redacted]

M.R. Uhlemann, Ph.D., External Examiner (Psychological Foundations in Education)

Supervisor: Ronald W. Skelton, Ph.D.

Abstract

The primary aim of this study was to examine the clinical diagnostic utility of the Seidel Continuous Attention Test (SCAT) in adults following mild to moderate brain injury. A secondary aim was to determine whether differential performance within conditions of the SCAT related to characteristics of attention such as impulsivity, inattention, or ability to sustain performance. Additionally, an auditory distraction component was incorporated into the original version of the SCAT to determine if simple distraction would influence performance in the brain-injured group. Eleven brain-injured patients were compared to age- and education-matched controls on SCAT performance. Measures of response time and response time variability reflected performance differences between the clinical and control groups, and also identified differences between mildly and moderately neuropsychologically impaired clinical subjects. Response omissions and commissions were generally not useful in distinguishing between clinical and control subjects, with the exception of 3 clinical subjects. There was little difference in responding to a simple target ("X") compared to responding to a more complex target ("X" preceded by an "A") and no effect of simple auditory distraction. Several clinical subjects appeared to demonstrate a deterioration of performance over time. It was concluded that, while attention tasks such as the SCAT may be useful in detecting deficits in prolonged attentional performance in more seriously impaired adult patients, that the relative insensitivity,

and the length of the task makes it unsuitable for general clinical use. The relationship to current theories of attention is also discussed.

Examiners:

[redacted]

R.W. Skelton, Ph.D., Supervisor (Department of Psychology)

[redacted]

F.J. Spellacy, Ph.D., Departmental Member (Department of Psychology)

[redacted]

P. Fisher, Ph.D., Outside Member (Department of Health Information Sciences)

[redacted]

M.R. Uhlemann, Ph.D., External Examiner (Psychological Foundations in Education)

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Introduction

Closed head injury is a wide spread and serious problem, with an estimated incidence between 200 and 1,000 per 100,000 citizens (Bigler, 1988; Rosenthal, et al., 1990). In British Columbia approximately 50 to 60% of these injuries result from motor vehicle accidents, with the largest portion of victims between the age of 15 and 30 years old (Recovery, 1990). Extended hospitalization and prolonged disability are present in 10 to 40% of victims (Recovery, 1990), resulting in staggering social and economic costs for the care of these individuals. Given the long survival time of this relatively young population, the number of chronically disabled individuals is continually growing.

Although advances in acute treatment of head trauma have added favourably to prognosis, survivors of closed head injuries are invariably faced with a broad range of difficulties which can include physical, cognitive, social, emotional and personality problems (Lezak, 1983; Ponsford & Kinsella, 1992; Sohlberg & Mateer, 1989). Cognitive or social difficulties are often as serious, or more disruptive than physical (visible) handicaps, and present unique challenges to rehabilitation efforts. Typical cognitive problems experienced by survivors of traumatic brain injury are difficulties with attention, changes in learning and memory abilities, perceptual disturbances, rapid fatigue, and a general slowing of information processing (Prigatano, et al., 1987). Cognitive and behavioural deficits can be devastating in and of themselves and may also contribute to deficiencies in social and familial relationships and decreased employability. It has been estimated that only 20 - 35% of brain-injured patients are employed at 2 years post-injury (Imes, 1983; Moore & Bartlow, 1989).

Attention deficits have been identified as a common and fundamental problem following brain injury, representing a crucial component in recovery and rehabilitation (Kay & Silver, 1989; Van Zomeran, Brouwer, & Deelman, 1984; Lezak, 1978). Attention deficits are reported across a wide range of injury severity, including minor injuries, or patients with good recovery, who are apparently symptom-free years after their initial "minor injury" (Rimel, Giordani, Barth & Jane, 1982 (cited in Binder, 1988); Stuss, 1985). Deficits in attention are significant because they may underlie other cognitive and associated difficulties following brain injury (Ben-Yishay, et al., 1985; Prigatano, 1987). These can include problems in perception, learning and memory, and communication, which are also important for successful rehabilitation (Wood, 1986; Sohlberg & Mateer, 1989). Finally, deficits in attention can influence the validity and interpretation of psychological tests, making accurate assessment and patient-monitoring difficult.

Despite agreement that attention plays a critical role following brain injury, diagnosis of deficits can be complicated, often derived through a combination of patient reports, clinical judgement and neuropsychological investigation. In fact, debate continues in the literature as to the exact nature of attention deficits following brain injury and there does not appear to be a universally accepted definition of attention (Posner & Rafal, 1987; Sohlberg & Mateer, 1987). One aim of the present paper will be to briefly review current models of attention which may be appropriate and useful within the clinical rehabilitation setting.

A second obstacle to a more thorough understanding of attention deficits is the lack of neuropsychological tests available specifically for the assessment of such deficits (Lezak, 1983; Stuss & Benson, 1986). Generally speaking, there are tests available that rely heavily on attention processes and therefore are used to assess attentional functioning. As will be discussed, these measures can be complicated and performance may be impaired for a number of reasons. Thus, a second aim of this paper will be to evaluate the diagnostic utility of a computerized test of attention that has not been extensively utilized with brain-injured populations, but may be of clinical and experimental value. These two aims are interdependent because in order to gain a cohesive understanding of attention deficit following brain injury, it will be important to have objective measures to correspond with scientifically and clinically appropriate theoretical models.

Defining Attention

Current theoretical models of attention tend to be complex and ambiguous. The ambiguity results, in part, from the fact that theoretical applications of the term "attention" are often inconsistent with clinical uses of the term, which require greater specificity to be useful in a rehabilitation setting. There has also been a move toward operational definitions of attention, partly due to the practical demands of clinical rehabilitation, which are less tolerant of ambiguity. Unfortunately, rather than a unified concept of attention, the pursuit of objective clinical measurement has lead to a componential understanding of attentional functioning. Emphasized components in attentional models are typically reflective of the method of measurement, and the theoretical orientation of the researcher or clinician. For example, researchers studying cognitive-information processing (e.g., Eysenck, 1982), deficits from brain injuries (Kay & Silver, 1989; Van Zomeran, et al., 1984), or childhood disorders (Keogh & Margolis, 1976; Douglas & Peters, 1979) all have their own specific biases in defining and measuring attention. In fact, attention can be described as a multifaceted concept with many valid theories attempting to explain it (Eysenck, 1982). The following paragraphs will briefly review predominant understandings of attention that have been proposed in theoretical and clinical contexts. This will be followed by a brief review of current neuropsychological techniques used in the assessment of attention.

The notion of attention is often equated with, or at least related to, information-processing capacity. Since humans can only attend to a limited amount of information in a finite period of time, they must have a means of coping with the vast amount of information that is potentially available for processing. Broadbent (1958) introduced the concept of selectivity, which views attention in terms of stimuli in the environment receiving priority over other stimuli (i.e., target information versus non-target information). Targets, the stimuli to be fully processed, are selectively attended to, and non-targets are ignored or inhibited from processing. The so-called "selectivity models" are further divided and classified by the stage at which stimulus selection is thought to occur. Early selection theories maintain that processing of targets and non-targets occurs at a perceptual level. In these theories, perceptual processes actively limit the amount of sensory information available for further processing (Broadbent, 1958; Treisman, 1969). The late selection theories (e.g., Schiffrin & Schneider, 1977) suggest that preferential processing of target stimuli over non-target stimuli occurs after the information has been processed at the perceptual level. In other words, the "attentional filter" is further along in the system. The late selection theories presume that all information is available for processing, but attentional mechanisms "choose" the material to be processed.

To consider attention beyond the level of perceptual processing, Baddeley and Hitch (1974) introduced the theoretical constructs of working memory and the central executive. Baddeley and Hitch hypothesized that the central executive acts as a controller of attention with the capacity for short-term storage of information. The notion of short-term or working memory provides a theoretical construct to explain how the focus of processing can be briefly shifted from target to target, or "divided" (presumably very rapid shifting) between targets. Inclusion of a short-term memory component in the attentional system also allows consideration of higher-order information processing. However, since the capacity of working memory is directly related to the processing resources that can be devoted to different tasks (occurring independently or simultaneously), subsequent debates have centred on the capacity of this theoretical structure.

Another theoretical framework of attention distinguishes between conscious-controlled processing and unconscious, or automatic processing (Posner, 1980; Schiffrin & Schneider, 1977). Such distinctions relate to the degree of effort or awareness that is required to perform a task. To illustrate the difference between conscious-controlled versus unconscious-automatic processing, consider the example of a beginning driver. Presented with the task of driving a car, an individual must commit considerable "mental resources" to the simultaneous tasks of watching the road, acceleration, shifting, braking, and perhaps maintaining a conversation with a passenger. The inexperienced driver may perform these tasks in a step-wise, controlled manner and with a high degree of conscious effort. The experienced driver requires very little conscious effort to perform the same tasks. A related distinction has been made between Focused Attention Deficits (FADs) and Divided Attention Deficits (DADs) (Van Zomeran, 1981). FADs result when an unconscious or automatic process conflicts with a consciously demanding task requirement, whereas DADs result from limitations in the speed of unconscious or automatic processing. What is important to note about conscious versus unconscious and controlled versus automatic processing is that conscious-controlled can evolve into unconscious-automatic through practice. Presumably this shift in the nature of processing is bidirectional, as occurs in a person who has not driven a standard transmission for many years, or following injury to the brain.

Current conceptualizations of attention have retained and incorporated important considerations from earlier theoretical work. Some research in the area has attempted to examine simple perceptual processes to gain insight into the construct of attention. Another approach has been to study the interaction between basic perceptual processes and higher levels of information processing such as rapid decision-making or problem solving. In considering the diversity of approaches to attention theory and research, Posner and Rafal (1987) identified what they thought to be three predominant "senses" of the term attention. The first of these, alertness, refers to a generalized physical and mental state of arousal, or readiness to respond (see also Posner, 1975). Alertness includes normal variations in the sleep-wake state (tonic arousal) and alterations that result from the sudden presentation of external stimuli (phasic arousal). The second sense of attention, selective attention, designates specific information for processing, while at the same time excludes other available information. Unlike phasic arousal, which prepares an organism for responding to any and all stimuli, selective attention "improves responsiveness to selected information" (Posner & Rafal, 1987, p.184). The third sense in which the term attention has been applied refers to the role of vigilance. According to Posner, vigilance refers to the amount of conscious mental effort that can be committed to a given act and the ability to sustain this mental effort over long periods of time. While alertness and selectivity are presumed to be primarily automatic processes, vigilance, although strongly influenced by the other two components, is part of the "conscious attention system."

The work of Sohlberg and Mateer (1987; 1989) follows the thinking of Posner and colleagues, but was also compelled by the need for "a traceable model of attention" that could be applied to normal behaviour, as well as brain injury behaviour and functional outcome. Their model of attention was derived as a "multidimensional cognitive capacity critical to memory, new learning, and all other aspects of cognition" (Sohlberg & Mateer, 1989, p 112). In essence, Sohlberg and Mateer sought a conceptualization of attention that could be operationalized and that would correspond to clinical observations in a rehabilitation setting. Their model considers five components:

focused, sustained, selective, alternating and divided attention. Three of these components relate to, and in some sense, overlap with Posner and Rafal's alertness, selectivity, and vigilance.

In the Sohlberg and Mateer scheme, focused attention reflects the ability to discretely respond to specific stimuli in various sensory modalities. For example, a patient with a deficit in focused attention may have difficulty responding to simple auditory, visual, or tactile stimuli. Individuals with deficits of this kind would likely have severe cognitive impairments including difficulty attending to, learning and retaining information. Deficits in focused attention might also be reflected as inconsistent responding, even on simple tasks (e.g., poor orientation to cognitive tasks). Focused attention can be thought to relate to Posner's description of alertness. Individuals with low levels of alertness, will have deficits consistent with focused attention deficits, as described by Sohlberg and Mateer.

The second level in the attention hierarchy, sustained attention, refers to aspects of performance relating to time. Sohlberg and Mateer consider sustained attention in two contexts. The first reflects "the duration of time over which a given level of performance can be maintained" (Sohlberg, & Mateer, 1989, p.115). Clinically, such a deficit would be identified in individuals failing to focus on a task and maintain responding for more than a brief period (e.g., good performance for a period, followed by a decline). The second consideration of sustained attention reflects the consistency of performance over a duration of time. Examples include variable responding, "lapses" in ability to focus, as well as difficulty on tasks that require mental manipulation or storage of information in short-term working memory.

The terms sustained attention and vigilance are often used interchangeably, but may also refer to subtly different processes. For example, sustained attention can be thought to involve the capacity to focus on a selected stimulus or multiple stimuli for a given period of time, and may be likened to concentration. Vigilance involves an ability to respond to infrequent and unpredictable stimuli that appear over a longer period of time (i.e., sustaining attention on the possibility of a target stimulus). "Concentration," might also be thought of in terms of sustained attention on tasks that require considerable "mental effort" such as solving a multi-step arithmetic problem.

Sohlberg and Mateer suggest that brain-injured patients do not appear to be particularly impaired in their ability to sustain attention over time. Patients are usually able to maintain performance comparable to control samples with no disproportionate slowing in response times or accuracy. However, more seriously injured persons have been frequently reported to have difficulties with sustained attention (Jennett & Bond, 1975). During the Second World War there were practical reasons for studying the deterioration of vigilance performance in radar operators (Davies & Parasuraman, 1982). Since that time the clinical importance of sustained attention has been recognized as crucial for performance on any task requiring attention, concentration, or prolonged cognitive processing (Lezak, 1983).

Although there appear to be few studies of "attention lapses," the concept is often used incidentally to describe poor performance on cognitive tests. Lapses in attention may be operationalized as response omissions or extremely long response times on continuous performance tests (Van Zomeran & Brouwer, 1987). Attentional lapses provide an intriguing explanation for deficiencies in attentional performance, however, indirect evidence suggests that such lapses are not the rule following mild head injury (Newcombe, 1982). This issue warrants further investigation.

The third level of Sohlberg and Mateer's attention hierarchy, selective attention, can also be described by the phrase "freedom from distractibility." Selective attention involves the ability to maintain a behavioural or cognitive set while ignoring distracting or competing stimuli. The source of competing stimuli could be internal (e.g., distraction due to excessive worrying, or other distracting thoughts), or external stimuli (e.g., extraneous conversations in a crowded room). Deficits in selective attention can present a serious obstacle to rehabilitation. For example, an individual with this kind of deficit would not be able to function in an environment with any more than a few competing stimuli. Reading with the radio on or working in a room with others might become extremely frustrating.

The next level, alternating attention, involves the capacity for mental control, allowing an individual to move between tasks having different requirements. In a sense, alternating attention reflects the ability to control selective attention or to momentarily "turn off" a mental set, attend to another, then successfully return to the initial set. A deficit of alternating attention might be indicated by confusion or response interference when required to rapidly shift the focus of attention between mental sets or between actual tasks. Consider the example of a receptionist who is required to alternate between typing letters, answering the phone and dealing with clients. In order to successfully perform each task, the receptionist must be able to shift between tasks, yet maintain the on-going status of each so that the attentional focus may be alternated with minimal disruption.

The fifth level in the Sohlberg and Mateer hierarchy, divided attention, refers to the ability to perform multiple tasks simultaneously. This can occur when two or more responses are necessary, or where a single response must be offered but requires processing of several stimulus elements. The implications for everyday functioning are illustrated in examples such as driving a car, carrying on a conversation in a busy place, cooking, or grocery shopping. Each of these tasks would be difficult for a person with a divided attention deficit. Sohlberg and Mateer suggest that divided attention may actually represent a case of "rapid and continuous alternating attention or unconscious automatic processing for at least one of the [on-going] tasks." However, these authors and others have indicated that deficits of this nature are important and frequent enough in the rehabilitation setting to warrant a specific descriptive attentional category. The presence of divided attention deficits following brain injury is well established and is among the most researched areas in attention (Gronwall, 1987; Stuss, et al., 1989).

Although the preceding representation of attention is limited, and admittedly simplified, at least by non-clinical experimental standards, it provides an indication of the variety of senses that the term attention has been used. Furthermore, one can see that the five "levels" of Sohlberg and Mateer's model of attention are not mutually exclusive components, but are more accurately described as an interactive hierarchy. Each successive level requires intact, or near-intact functioning of the previous level. In order to have sustained or selective attention, an individual must have an intact ability to focus attention. Likewise, some instances of divided attention may be more accurately described as very rapid alternating attention.

The five-level conceptualization implicitly suggests a crude scale to grade severity of an attentional deficit. Severity, in this case would refer to the ability to perform tasks reflective of a given level of the hierarchy but not tasks of a higher level. Individuals with focused attention deficits represent the most seriously impaired while those having divided attention problems are able to function, but only in organized and regimented environments that are relatively free from distraction.

Another appealing feature of Sohlberg and Mateer's conceptualization of attention is that each level is not defined by performance on a specific task. Rather, levels of the hierarchy reflect performance characteristics that can be delineated by a range of tasks.

This feature has both advantages and drawbacks. On one hand it permits a broad-based approach to assessment and rehabilitation training. Multiple tasks can be used to assess and retrain relatively discrete areas of attentional functioning (i.e., at one level of the hierarchy). On the other hand, while using a wide variety of tasks for rehabilitation purposes is desirable, one runs the risk of introducing various superficial or secondary task characteristics into assessment procedures. For example, many rehabilitation tasks incorporate counting and manipulating letters or numbers, rely on rapid perceptual processing, or involve complicated verbal or manual response demands. Such task components are not directly related to attention per se, but are introduced to objectify the process being retrained or assessed. A second drawback of the five level scheme is that it has not been demonstrated that the five levels of attention have any existence of their own, other than as heuristic constructs. For example, no evidence exists to show that scores on tasks within a level of the hierarchy are highly correlated, while correlations on tasks measuring across levels are low (Van Doren, 1991).

Despite these problems, the Sohlberg and Mateer scheme represents a coherent model of attention designed specifically for clinical application. The five-level conceptualization was developed in concert with the Attention Processes Training program (APT; Sohlberg & Mateer, 1986) and has yielded encouraging outcome results in a rehabilitation setting (Sohlberg & Mateer, 1987). This scheme provides a context for further reference to attention issues in this paper.

Attention and Brain-Injury

Significance of attention problems following head injury. As previously indicated, problems with attention, concentration, and fatigue result from a range of injury severity. Attention and memory problems usually resolve over time, though may persist for a period of months to years (Jennet & Bond, 1975; Moore & Bartlow, 1989;

Sohlberg & Mateer, 1987; 1989). Importantly, attention and memory deficits are among the first symptoms present following brain injury, and in many cases are among the last symptoms to resolve. Such deficits are also important in that they have the potential to influence other cognitive and social characteristics of a patient. For example, what may initially appear to be a memory or learning deficit, can be based in a more fundamental problem with attention. The inability to fully attend to information, can impede the comprehension, storage and appropriate retrieval of that information. Attention deficits may require a person to devote excessive amounts of mental energy to information processing, leading to rapid fatigue and frustration, in addition to an inability to shift between cognitive tasks. Some authors have suggested that in traumatic brain-injured patients, cognitive improvement is attributable mainly to a generalized improvement in the ability to maintain both focused and selective attention and to an enhanced ability in efficient information processing (Ben-Yishay, et al., 1985; Prigatano, 1987). Thus, the fundamental nature of attention, makes it a central factor in attempting to understand cognitive deficits and their recovery following brain-injury.

Reports of attention problems. The most frequent complaints by brain-injured patients, or reports by their relatives, are of poor concentration, poor memory, and easy fatiguability (Binder, 1986; Goethe, & Levin, 1984; Posner & Rafal, 1987; Rutherford, 1989). Caveness (1969) found that in a sample of Korean War veterans having sustained a brain injury, 41% complained of concentration problems up to five years post-injury, compared with 14% of non-injured veterans. Subsequent research has confirmed an increased incidence in attention and concentration complaints following brain injury (McKinlay, et al., 1981; Van Zomeran & Van den Burg, 1985; see Gronwall, 1987 for a comprehensive review). One must not discount the finding that self-report rates of concentration problems in the general population have been estimated between 4-8%

(Gronwall, 1987) and may be higher (Gouvier, Uddo-Crane, & Brown, 1988), suggesting that a portion of attention problems may not be related to brain injury. In particular, interpretation of self-report problems may be difficult in cases of mild injury, with complaints often being vague (Lees-Haley & Brown, 1993). Still, self-report studies have shown that the incidence of attention problems generally decreases within 3 months of the injury, with a significant proportion of patients reporting difficulties up to and beyond 2 years (Rutherford, Merrett & McDonald, 1977; 1979; Wrightson & Gronwall, 1981; Van Zomeran & Van den Burg, 1985; Moore & Bartlow, 1989).

Objective Assessment of Attention Deficit

Although the value of self-report should not be underestimated, there is undoubtedly a difference between the complaint rate of attention problems and the actual number of brain-injury patients suffering measurable deficits. Numerous studies have utilized neuropsychological testing to study attention deficits in brain-injured populations. While the results of these efforts have not been entirely consistent, (e.g., use of differing subject populations, theoretical orientations and objective measures of attention), the general consensus has been that brain-injury patients usually show deficits on neuropsychological measures thought to involve attention, concentration, and memory (e.g., Ponsford & Kinsella, 1992; Shum, McFarland, & Bain, 1990).

Assessment of attention deficits can be accomplished both informally and formally. Informal assessment includes observation of a patient's behaviour as they attempt to attend to a task or in various situations. Of particular clinical interest is how the patient can attend in the presence of distraction, or when required to shift rapidly from one topic or target to another. Anecdotal reports of relatives or hospital staff can also be included as part of the informal assessment of a patient's ability to sustain attention during complex functional behaviours (Kay & Silver, 1989). Formal assessment usually consists of neuropsychological measures such as response time, continuous or vigilance performance tasks, visual and auditory tracking and discrimination, and tests of mental flexibility with varying cognitive demands (Brooks, 1989; Kay & Silver, 1989; Lezak, 1983). Despite the lack of a unified theory of attention, there remains a practical need to establish which formal objective measures are sensitive to attentional deficits in the brain-injured (Stuss & Benson, 1986; Ponsford & Kinsella, 1992). The following paragraphs will briefly review some of these measures.

Paced Auditory Serial Addition Task (PASAT). The PASAT (Gronwall, 1977) is among the most widely used measures of cognitive impairment following brain-injury. This task involves auditory presentation of a standardized, random series of spoken digits. Subjects are required to add pairs of numbers, such that each number is added to the one immediately preceding it. For example, if the presented numbers were "2-8-6-1. . ." the subject's correct responses, beginning upon presentation of the number 8, would be "10-14-5. . . ". The number series is presented at four different pacings with interstimulus intervals of 2.4s., 2.0s., 1.6s., and 1.2s.. Typical measures from this task include percentage of correct responses, mean time per correct response, and the error rate.

The PASAT is usually thought of as a measure of information processing. It provides an estimate of a patient's ability to register sensory input, rapidly process information, verbally respond, inhibit encoding of his/her own response, while attending to a subsequent stimulus. Though it was originally developed in the 1950s, during the past 15 years of clinical use the PASAT has acquired a strong normative base, providing reproducible and stable recovery curves. In a survey by Brittain, et al. (1991), the PASAT was the only one of several neuropsychological measures significantly correlated with perception of behaviour change as judged by the patients and close associates.

Administered as a repeated measure, the PASAT has been used as a guide in determining ability to return to work (Gronwall, 1977; 1989) and as an indicator of cognitive retraining efficacy (e.g., Sohlberg & Mateer, 1987; 1989).

The PASAT is not without interpretive complications. First, it employs at least one skill (mental arithmetic) not normally considered to be a component of attention. Since arithmetic is a central feature of this task, this skill must be intact (both pre- and post-injury) for the patient to perform adequately. The PASAT also relies heavily on short-term memory processes, requiring storage and retrieval of numerical information. Furthermore, both age and IQ scores are related to scores on the PASAT (Brittain, et al., 1991), as are family expectations and patients' motivation for recovery (Gronwall, 1989). Finally, as Van Zomeran and Brouwer (1987) indicate, subjects are required to divide their attention between listening, calculating and responding, making the PASAT a very taxing and frustrating experience which many brain-injured patients cannot manage (floor effect). In fairness, many of these complications have been acknowledged by Gronwall and her colleagues (1977; 1989).

Other conventional neuropsychological measures. Clinicians and researchers have utilized other neuropsychological measures that are thought to examine attentional processes. For example, factor analyses conducted on the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) and the Wechsler Memory Scales (WMS; Wechsler, 1945; WMS-R;Wechsler, 1987) have indicated that attention is a relevant factor in the performance of brain-injured persons (Clark, et al., 1983; Larrabee, Kane, & Schuck, 1983). These studies suggest that the attention factor is related to performance on tasks such as short-term memory span for numbers (Digit Span Tests), ability to count backwards and recite the alphabet (Mental Control Tests), and ability to rapidly code numbers and symbols (Digit Symbol Coding Test) (Barth et al., 1989).

The Digit Span subtest of the WAIS-R involves auditory presentation of a sequence of numbers with subjects required to immediately repeat the sequence. As the test proceeds, the length of the number series is gradually increased. In the Digits Forward condition, subjects repeat the number sequence as presented, while in the Digits Backwards condition subjects repeat the number strings in reverse order. Barth, et al. (1989) report that although Digit Span - Forward was rarely found to be impaired, Digit Span - Backward was an effective indicator early after brain injury. These claims are not without contention (e.g., Levin, Benton, & Grosman, 1982) and there is some controversy about exactly what the Digit Span tests are measuring. It has been argued that both of these tasks rely more on working memory capacity than "attention." However, much of the relevant literature centres around the issue of whether the Digit Span tasks are differentially associated with language and visuospatial skills or with general cognitive deficit (e.g., Banken, 1985; Black & Strub, 1978). There has also been debate regarding the relationship of each task to left- versus right-hemispheric functioning, and the area of the hemisphere crucial to successful performance. The issue of which of these tasks is more sensitive to brain dysfunction does not appear to have been resolved (Weber, 1988).

The Digit Symbol subtest of the WAIS-R requires subjects to rapidly translate a series of letters and symbols on a printed page. This task is considered a classic measure of attention and is sensitive to the effects of brain injury (Lezak, 1983; Prigatano, et al., 1987). In a review of attention and speed of information processing measures, Ponsford & Kinsella (1992) suggest that the Symbol Digit Modalities Test (Smith, 1973) was the best discriminator of deficits in these abilities (Symbol Digit Modalities is very similar to the Digit Symbol subtest of the Wechsler scales, differing primarily in the direction of the required translation: digit to symbol versus symbol to digit). These visual search tasks involve focused and sustained attention and directed visual shifting. However, performance can also be influenced by impairments in motor speed, mental disorders, visual scanning defects, and defects in associative learning (Kaufman, 1968).

Other common indices of attention deficits include the WAIS-R Arithmetic subtest (requiring subjects to solve verbally presented math problems), cancellation tasks (e.g., Test D2, Brickenkamp, 1981; a paper and pencil test requiring subjects to identify randomly interspersed targets from rows of distracter stimuli), and the Trail Making tests (Reitan, 1971; 1985; similar to a connect-the-dot puzzle, requiring the subject to connect sequential points on a sheet of paper which may or may not have distracter items). These tasks of mental arithmetic performance and rapid, repetitive visuo-motor integration are believed to examine sub-components of attentional capacity (Lezak, 1983; Sohlberg & Mateer, 1989). Furthermore, the Arithmetic, Digit Span, and Digit Symbol subtests have been shown to have high loadings on a factor termed "freedom from distractibility (FD)," while other WAIS-R subtests, such as the Similarities subtest, do not load on this factor (e.g., Sattler, 1988). This finding suggests that the FD-tasks may be assessing common cognitive components, likely to be related to attention mechanisms. Trail Making and Test D2 cancellation tasks have the advantage of large bodies of normative data, but they do not always discriminate between brain-injured and control samples (Stuss, et al., 1989).

The Stroop colour-word task (Regard, 1981; Stroop, 1935) has been evaluated as a measure of divided attention deficits. Typically this task employs three subtests, the first requiring rapid reading of colour names, the second requiring rapid identification of coloured ink, and the third requiring the identification of the ink colour of printed colour names (e.g., say "red" for the word "BLUE" printed in red ink). Thus, the third condition of the Stroop Task requires the suppression of habitual or automatic tendencies to read the word rather than name the colour. The expected result is an increased response time, caused by colour-word interference, especially in cases of incongruent colour-word stimuli (i.e., the Stroop effect). Ponsford and Kinsella (1992) found that although brain-injured subjects were slower on each of the subtests (reading words; naming colours; naming non-colour words written in coloured ink), they did not show a disproportionate slowing in the colour-word task (colour words, written in colour ink). In fact, in their study, brain-injured subjects tended to be less susceptible to the Stroop interference effects than control subjects.

As previously alluded to, many of the measures discussed above can be "contaminated" by requirements which are secondary to attention. These might include verbal, mathematical, sensory (intact visual scanning), motoric (rapid, controlled fine motor movements), or memory requirements (short term memory in the PASAT, or associative memory as required by Symbol Digit Modalities). Such task-bound confounds make it difficult to distinguish between attention deficits and associated problems in other areas.

Response time measures. Tests of response time (RT) have been found to distinguish brain-injured patients from non-injured controls, as well as differentiate patients with varying degrees of injury severity. Among the common features of brain-injured patients, even of mild severity, is mental slowness reflected by increased time to respond or by a deterioration in accuracy on time-limited tasks (e.g., Gronwall, 1977; Brooks, 1984; Tromp & Mulder, 1991). The slowness has been linked to components of attention, however, it is unclear whether slowness is primarily an attention problem, a deficit in some other central cognitive component (such as a limitation in "working memory"), or a general slowing of the entire "information processing system." Although several arguments have been forwarded regarding this issue, Tromp & Mulder (1991) have found support for the notion that novelty has a crucial influence on speed of performance. From this perspective, slowed RT in brain-injured patients could be explained as a failure to focus on or be aroused by novel stimuli (i.e., an inability to selectively attend to or alternate to a particular stimulus).

Using a RT paradigm, Van Zomeran (1981) studied attention problems and their recovery following brain-injury. Simple RT (responding to one discrete stimulus) was found to be equally prolonged after injuries of varying degrees of severity and performance on such tasks tended to recover within one year of the injury. In contrast, choice RT (tasks having two or more competing stimuli, with subjects required to quickly respond to one of those stimuli) was found to be particularly sensitive to the effects of brain-injury. Van Zomeran and his colleagues demonstrated that performance on choice RT tasks was impaired to a greater degree in patients with injuries of increased severity (as defined by coma duration) and that performance continued to improve up to and beyond two years. It has also been shown that choice RT performance is related to scores on the Glasgow Outcome Scale (a general measure of outcome following head trauma; Jennet, et al., 1975). In particular, choice RT was predictive of eventual neurologic and social outcome including work status, satisfaction with family life, and leisure activity (Van Zomeran, 1981).

Clearly, RT measures are sensitive to deficits associated with brain injury. However, the number of stimulus alternatives and stimulus-response compatibility appear to be key factors. Van Zomeran explained the differences between simple and choice RT performance as deficits in divided attention as opposed to deficits in selective attention. This might suggest that an impairment in unconscious-automatic processing (i.e., slowness in attending to and processing alternative, competing stimuli) may be responsible for the observed deficits in choice RT. When such a break down in rapid, automatic processing occurs, divided attention is no longer possible because the patient must resort to a conscious-controlled approach to attend to available stimuli. The slowness of conscious-controlled processing leads to decreased ability to adequately utilize the information required for the divided attention task.

Stuss, et al. (1989) used both simple and choice RT tasks to evaluate RT variability as a measure of attention. RT variability was described in two contexts: First, Stuss and colleagues found that the standard deviation of response times was higher for brain-injured patients when compared to matched controls. Second, the brain-injured subjects showed greater variability when performance was considered across repeated assessments over periods of days to weeks. Disturbance in the consistency of performance is often overlooked in the assessment of brain-injured patients because they are usually seen once and tasks are usually brief. Although such patients may be able to perform at an acceptable level, their ability to maintain stable performance over time may be compromised at more subtle levels, such as measured by RT variability.

A final comment should be made regarding the relationship between selective attention and information processing speed. Van Zomeran (1981) has shown that choice RT can be used as a simple method of determining speed of information processing. Given that humans have a limited capacity to process stimuli from their environment (Broadbent, 1958), it follows that the speed at which a person is capable of attending to, encoding, and storing or responding to a stimulus will partially determine what that person will notice and how much will go unnoticed. For example, if one is slow to process a single stimulus in an environment, the increased time required to attend to that stimulus reduces the time available to attend to other concurrent stimuli. The result appears as an "attention deficit," either in selectivity, alternating attention, or divided attention.

Continuous performance tasks. The Continuous Performance Task (CPT) was originally developed to detect and study brain damage in children and adults (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). Early findings suggested that CPT performance was consistently worse in brain-damaged individuals than in non-injured controls. These differences were thought to be associated with decreased alertness and inability to sustain attention. Since the early work of Rosvold and colleagues, CPTs have been widely used to assess attention deficits in children suffering from disturbances in attention (e.g., Conners, 1985; 1992; Seidel & Joschko, 1991; Halperin, Sharma, Greenblatt & Schwartz, 1991). While CPTs have received some consideration in the experimental literature, they have not been extensively examined in adult populations, and until recently have not been routinely used in clinical settings.

CPTs typically involve presentation of a series of auditory or visual stimuli over a period of time (usually 20 minutes or longer), with subjects required to respond to target stimuli while ignoring distracters. Such tasks involve alertness (focused attention), sustained attention, selectivity (resistance to distracters), as well as scanning or listening ability, and motivational influences (Wood, 1988). Performance on CPTs is usually considered in terms of speed and accuracy (Davies & Parasuraman, 1982; Brouwer & van Wolffelaar, 1985; Buchtel, 1987). For example, Brouwer and van Wolffelaar assessed the ability to sustain attention over a 40-minute period with subjects required to press a switch in response to an auditory click. In this case, a target click was weaker in intensity than other clicks, presented against a background of white noise. It was found that brain-injured patients were able to maintain performance accuracy but had slower response times than normal controls. Response accuracy also provides useful information about attention deficits. For example, omission errors or misses (failure to respond to a designated target) can reflect deficits in focused attention, selectivity, or sustained attention. Errors of commission or false alarms (responses to non-targets) are thought to relate to response characteristics such selective attention, response inhibition or impulsivity (Halperin, Wolf, Greenblatt, & Young, 1991; O'Dougherty, et al., 1984).

In the past 2 decades, computerized CPTs have begun to replace the complicated and cumbersome devises previously used to assess sustained attention. While computerized administration systems are desirable for their ease of stimulus manipulation, accuracy, and consistent measurement capabilities, unfortunately there are few standardized versions of this type of task (Conners, 1985; 1992; Gordon & Mettelman, 1987; Seidel & Joschko, 1991). CPTs may vary on important features such as *total number of stimuli, total test duration, interstimulus interval, probability of target* occurrence, stimulus duration, complexity of targets, and methods of calculating scores. This lack of consistency has made evaluation of CPTs difficult (Parasuraman, 1984).

Although data on CPT performance following brain-injury is limited, it appears that higher error rates and longer response times can be expected, relative to control groups. No between-group differences (i.e., brain-injured versus normal controls) have been consistently shown when CPT performance is evaluated in terms of time-on-task (Van Zomeran, Brouwer, & Deelman, 1984; Buchtel, 1987; Parasuraman, Mutter, & Molloy, 1991; Ponsford & Kinsella, 1992). While brain-injured patients may show reasonably accurate performance, response times tend to be longer and variability of performance increases as the task progresses (Seidel, Van Doren, & Joschko, unpublished data; cited in Van Doren, 1991).

CPTs have high face validity for the study of attention following brain injury. Individual patients can often rise to meet the demands of attention tasks that only require a few moments of "mental exertion," but performance may deteriorate or become inconsistent when optimum concentration is required for longer periods. Indeed, many brain-injured patients complain of an inability to concentrate for extended periods of time. Stuss, et al. (1989) raised an additional consideration, suggesting that attention deficits seldom occur as a single entity (i.e., as only focused or only selective attention deficits). Rather, there may be an interaction of focused and selective attention problems superimposed on or coinciding with deficits in the ability to sustain performance. The interactive nature of these deficits can make them elusive, and repeated or prolonged evaluations may be necessary to elicit them. Buchtel (1987) summarized the potential of the CPT as follows:

> "The multifaceted nature of a vigilance task would seem to make it ideal for determining the degree of attentional deficit in patients after head trauma, even with minor damage. Because of the graded, objective nature of the data, the vigilance task should also serve to chart improvements and declines in attentional capacities over time" (p.373).

In addition to the appealing face validity, performance on CPTs has been shown to correlate with other neuropsychological measures thought to be related to attention. For example, CPT scores correlate with the WAIS Arithmetic and Digit Span subtests, both of which load high on the "freedom from distractibility factor". Some CPTs have been shown to be sensitive to the effects of pharmacological manipulations (Seidel, 1988; Tiplady, 1988). Stimulus characteristics (i.e., brightness, colour) do not appear to be a critical feature, nor is modality (auditory versus visual stimuli; Davies & Parasuraman, 1982). CPTs generally have simple task demands, and do not rely on complicated sensory-motor skill, cognitive processing or verbal responding. These features make CPTs appropriate for use with populations who may have limitations other than attention deficits or with those who are easily frustrated.

<u>The Seidel Continuous Attention Task (SCAT)</u>

The Seidel Continuous Attention Task (SCAT; Seidel, 1988; Seidel & Joschko, 1991; 1992) is a computerized CPT originally developed to study sustained attention in school aged children suspected of having Attention Deficit Hyperactivity Disorder (ADHD). Detailed administration procedures and task characteristics are described in the methods section of this thesis and in Appendix A. Briefly, subjects are presented with a sequence of letters, of which the letter "X" is a target, the X-task. Subjects are required to respond to the target by quickly pressing the space bar on a computer keyboard and ignore all non-target letters. In a second task, subjects are required to respond to the letter "X" if, and only if, it was preceded by the letter "A," the AX-task. Seidel and Joschko found that the SCAT could distinguish between clinical (ADHD) and normative groups of children between the ages of 6 and 11 years. A variety of performance indices derived from the SCAT were found to be significantly different between the two groups, with the clinical group performing slower, more variably, and less accurately. The SCAT could also differentiate between children on and off methylphenidate medication, replicating a finding by Conners, Eisenberg, & Barcal, 1967 (cited in Conners, 1992). Two of three children showed better performance on than off medication, while the third child failed to show any changes (Seidel, 1988). In all cases, SCAT measures were shown to correlate significantly with attentional, but not with non-attentional dimensions of the Revised Connors questionnaires (Goyette, Conners, & Ulrich, 1978).

Although the SCAT has only been validated with children demonstrating attention deficits, preliminary work with normal and brain-injured adults has yielded promising results. Using the SCAT, Van Doren (1991), found that a sample of 9 normal female adults had an average RT of 567 ms. and an average variability of 63 ms.. 9 brain-injured males had an average RT of 667 ms. and an average variability of 95 ms., which is comparable to the performance of normal, 9 year old boys. Van Doren also collected pilot data studying the sensitivity of the SCAT to attention training and found positive results. However, in a larger patient sample, the SCAT (and other indices of attention) failed to identify significant treatment effects related to attention training. These results were attributed to the specificity of the training tasks rather than a failure of the SCAT to discriminate between groups. Van Doren's work suggests that the SCAT may be a useful tool in differentiating brain-injured from normal adults and possibly for monitoring the progress of brain-injured patients. In 8 out of 9 patients (initial Glasgow Coma Scale rating between 3 and 14; time since injury ranging from 40 - 224 days) the mean RT (collapsed across X- and AX-tasks of the SCAT) was at least one standard deviation slower than the mean of the control group. 6 out of 9 patients had RT variability scores at that were least one standard deviation above the control group's mean variability. It should be noted that hit rates and false alarms did not clearly differentiate between the brain-injured patients and the control subjects, possibly due to a ceiling effect (i.e., too few misses and false alarms). Nevertheless, Van Doren's results are promising.

There are several important issues that remain to be addressed regarding use of the SCAT with an adult brain-injured population. First, it is important to note that Seidel and Joschko have shown that SCAT performance improves with age and appears to level off with near-perfect performance by approximately age 12. Given the potential for a ceiling effect in an older, normal population it is not clear whether the SCAT could be useful in distinguishing between intact and brain-injured adults. Additionally, Van Doren's research failed to indicate if control subjects were matched with brain-injured subjects on factors such as age and intelligence. At least one of these factors (age) has been demonstrated to influence SCAT performance, and intelligence is also likely to be related. Furthermore, there was no indication that the AX-target condition of the SCAT was studied independently of the X-target condition. Differential performance could yield potential valuable information, given that the AX-condition is thought to relate to characteristics such as impulsivity. A further consideration regarding the AX-condition is that provision of the "A" stimulus prior to the "X" may serve as a warning cue. It has been suggested that brain-injured subjects do not benefit from visual warning cues as do normal subjects (Costa, 1962; Ponsford & Kinsella, 1992; Arguin, Cavanagh, & Joanette, 1993). Additional consideration of performance on the AX-condition (compared to the X-condition) may be useful in clarifying these issues. Finally, the SCAT may have potential for identifying subtle attention deficits in brain-injured patients and could be of use in tracking recovery and evaluating the efficacy of various rehabilitation interventions.

Objectives and Rationale

The central aim of the present research was to evaluate the diagnostic utility of the Seidel Continuous Attention Task on an adult population brain-injured individuals, of mild to moderate severity, who were involved in a typical rehabilitation program. A number of specific questions were of interest regarding performance on SCAT. First, could the SCAT distinguish between brain-injured and normal subjects? Second, could the SCAT identify specific attention deficits such as inattention and impulsivity? Third, could a simple modification in the SCAT permit the assessment of distractibility?

Several features of the SCAT commended it for use with an adult brain-injured population: 1) The SCAT is a relatively pure measure (i.e., there are no complicated cognitive, perceptual and response demands associated with the task); 2) The SCAT can be used or modified to study several components or levels of attention, including focused, sustained, and selective attention, and simple task modifications could allow for the assessment of alternating and divided attention; 3) The SCAT is computerized, allowing for accurate measurement of response time, and making its administration and modification relatively simple. This third feature would be important if this task were to see broader use in the future.

After reviewing the attention literature, a number of specific questions were of interest regarding performance characteristics within conditions of the SCAT. As indicated, no previous attempt has been made to distinguish between performance on the X- and AX-tasks. It was predicted that differences in response time, as well response accuracy should exist between the X- and the AX-tasks, especially for brain-injured individuals. Such performance differences within subject and between tasks could allow for comment on qualitative aspects of attention in brain-damaged persons such as impulsivity or inattention.

An additional goal of the present study was to examine the performance characteristics of subjects while responding under conditions of auditory distraction. The subjective reports of brain-injured patients and the impressions of clinicians suggest that distractibility by task-irrelevant information is a major problem for these individuals. Van Zomeran and Van den Berg (1985) reported that two years after severe head injury, 33% of patients reported having difficulties with concentration, and 21% reported difficulty doing two things simultaneously. Lezak (1978) also found that in a sample of 38 head-injured patients, 87% showed distractibility. Deficits in selectivity would be particularly apparent under conditions of prolonged performance with auditory distraction. Although subjects in the present study were not provided any particular instructions regarding the auditory stimuli (i.e., the distraction was not intended as a divided attention task), it was predicted that deficits in selectivity would be particularly apparent through performance declines on the response time and response accuracy measures.

A second reason for the addition of the auditory distraction related to the problem of task difficulty. As previously indicated, performance on the SCAT has been shown to improve with increasing age, until approximately 12 years. Given this performance curve, it is possible that adult performance on the SCAT would be at or near-perfect. In fact, this situation occurred in pilot work utilizing the SCAT on a group of university undergraduate students. The potential for a ceiling effect would complicate interpretation of performance differences between brain-injured individuals and normal controls. This complication arises because of the uncertainty in determining the severity of deficit required before deficient SCAT performance occurs. With the addition of the distraction condition, the task load was increased without alteration to the original task requirements, or adding specific processing requirements. Thus, it was hoped that both clinical and control subjects would demonstrate poorer performance under conditions of distraction.

Methods

Subjects

Clinical subjects. Clinical (brain-injured) subjects were solicited from the head injury rehabilitation program at Gorge Road Hospital (GRH) in Victoria, British Columbia. Subjects ranged in age from 23 to 45 years (n=11; mean = 33 years) and all had suffered mild to moderate closed head trauma. The GRH program represents a typical, comprehensive rehabilitation program, offering neuropsychological assessment, group and individual treatment in both cognitive skills retraining and compensation strategies, as well as occupational and living skills therapy. Among the rehabilitation services offered at GRH is Attention Process Training (APT; Sohlberg & Mateer, 1986). Briefly, APT is a multi-step program of cognitive tasks designed to retrain attention skills. The program is arranged hierarchically to conform to Sohlberg and Mateer's (1987) theoretical model of attention. As patients master skills at a simple level they progress to more challenging tasks, at higher levels in the attention hierarchy (see Sohlberg & Mateer, 1986; 1987 for a complete description of APT). Patients involved in APT were invited to participate in the present attention research. The rationale for this inclusion criterion was that individuals with deficits significant enough to warrant involvement in APT were likely to have attentional problems identifiable by the SCAT. These subjects were also considered by the clinicians to be typical of the individuals participating in rehabilitation programs.

Functional deficit was confirmed by review of neuropsychological assessment data obtained at patient intake. Files were reviewed for indications of previous head injuries, neurologic disorders or psychiatric illness. In addition, files were reviewed for indication of significant sensory or motor limitations that might have influenced performance on the SCAT. The basic sensory and motor requirements for the SCAT are outlined in the test instructions and are based on the subjects' ability to successfully complete the practice component of the task. No brain-injured subject was unable to complete the practice trials. Thus, all were included in the complete SCAT testing.

Demographic information was obtained from each patient and confirmed through review of the clinical neuropsychology records. This information included age, sex, handedness and education. Additional patient information was obtained from case files, including time since injury, injury severity (Glasgow Coma Scale when available), injury type (location, where available), and time since initial assessment.

Limitations in sample size. A number of factors limited the number of brain-injured patients involved in the study (N=11). First, the number of patients in an APT group at a given time was limited to 5 to 10 participants. Of the groups solicited, the majority of the patients involved were interested and willing to participate, although scheduling conflicts made participation impossible for some. Second, a number of patients indicated that they would be unable to find an appropriate friend or relative to meet the requirements of the control subjects. As indicated, 3 clinical subjects who initially indicated that they could arrange for a matched control subject, were unable to follow through on those arrangements. Third, once the study began, it became apparent that control subjects were performing at or near-perfect levels (based on error rates). This was the case even under conditions of auditory distraction, making it difficult to contrast performance differences between the groups. In fact, the number of errors committed by the clinical subjects, as a group, was also noted to be relatively small. Thus it was decided to terminate the collection phase prematurely and explore the data for performance patterns in a smaller set than was initially planned.

Control subjects. Brain-injured subjects were asked to invite a similar-aged, same-sex friend to serve as a matched control. Although control subjects could not be identically matched for age or education, this method represented a practical means of comparing persons with similar backgrounds and interests. Control subjects were screened to preclude previous psychiatric or neurologic disturbances or head injuries. Informed consent was procured from all participants.

Apparatus and Conditions

Software. The current version of the SCAT was written and compiled using C++ for the IBM-PC. All stimulus, timing, and response handling capacities were controlled using the SCAT software. Visual stimuli consisted of 12 capital letters (A,C,E,H,K,N,P,Q,S,U,X,Z) approximately 10 millimetres in height, displayed in green at a central location on the monitor. These stimuli were originally selected based on previous vigilance task data and display characteristics of the computer hardware (e.g., length of time to display specific letters; Seidel and Joschko, 1991). For the sake of consistency and to allow for the use of previously collected norms, these same stimuli were retained. Stimuli were presented once every 1.5 seconds for a duration of 0.2 seconds.

The original version of the SCAT (Seidel and Joschko, 1991) was composed of two subtests, each consisting of 600 individual letters presented in a standardized order. Of these 600 randomized stimuli, 90 (15%) were target letters, with the restriction that 30 targets appear within each block of 200 stimuli. This restriction allowed comparison of performance between blocks. Total time per subtest was 15 minutes.

In the present experiment, an additional component was added to assess SCAT performance under conditions of auditory distraction. Thus, the modified version had four conditions, each of which presented, in a standardized, random order, 400 individual letters of which 60 (15%) were targets. In the first condition subjects were instructed to respond by quickly pressing the space bar on the computer keyboard whenever an "X" appeared in the letter sequence (X-task). The second condition was identical to the first, with the exception that subjects were also required to listen to a random sequence of letters presented via audio head phones (X-distracter task or XD-task). The auditory distracter consisted of the same stimuli as in the visual mode, presented in a different standardized, random order, but with the same X / non-X ratio per block of 200 stimuli. The third and fourth conditions were similar to the first two conditions with the exception that subjects were required to respond to an "X" if, and only if, it was preceded by an "A" (AX-task and AXD-task respectively). Again, for both visual and auditory presentations, the target / distracter ratio was held at 15%.

The administration sequence of the four conditions was partially counterbalanced, with the distraction / no distraction conditions blocked. This was intended to control for possible effects of presentation order (e.g., fatigue, motivation level, etc.). Presentation order for the "X"-target versus the "AX"-target was not counterbalanced as previous research has failed to show an order effect for target type (Van Doren, 1989). Thus, for half of the subjects, the presentation order was X, AX, XD, and AXD, while the remaining subjects received the XD-, and AXD-tasks followed by the X-, and AX-tasks. Control subjects received the same administration order as their matched counterparts. Total administration time for the four conditions was 40-minutes, with a brief pause between conditions to allow a short break, and for preparation of the next condition. For a description of the SCAT instructions see appendix A.

Hardware. The SCAT has been adapted for administration using IBM-PC-compatible hardware, making it highly portable and compatible with microcomputers in wide circulation. For the present study an IBM-PC-compatible 386SX laptop computer was used for test administration. An external 9" x 11" colour video graphics adaptor (VGA) monitor and an external standard IBM-compatible keyboard were used. Display brightness and contrast were adjusted to provide a comfortable level of text illumination. A cover consisting of plasticized cardboard was placed on the keyboard such that only the space bar was exposed during test administration. A green rectangular sticker was adhered to the top of the space bar and a red sticker, of the same size adhered to the ledge of the keyboard directly in front of the space bar. Response times using this hardware / software configuration were accurate to within 15 ms..

For the auditory distraction conditions a standardized tape was produced. Auditory stimuli were presented in a male voice, at a rate of 1.5 seconds per letter. The tape was played back on a Sanyo C32 portable cassette tape player over AIWA HP-M11 headphones. Volume was set at a level such that stimuli could be clearly heard and which was comfortable for the subject.

Procedure

Subjects were individually tested by a trained examiner in a quiet testing room at Gorge Road Hospital. Clinical subjects were previously administered the Digit Span, Arithmetic, and Digit Symbol subtests of the WAIS-R, the Stroop task, the Test D2 Cancellation task, the Wechsler Memory Scale-Revised, the PASAT and the Trails A and B tests (see Introduction and Appendix B for descriptions). These tests were administered by either a trained psychometrist or one of two neuropsychologists as part of the intake procedure for the GRH rehabilitation program. Demographic information was also available from intake testing, and was confirmed during the SCAT session.

Subjects were provided a brief description of the task followed by standardized task instructions (see Appendix A). Subjects were instructed to place the index finger of their dominant hand lightly on the green sticker on the keyboard and were encouraged to respond as quickly and accurately as possible. During administration the examiner sat quietly out of view, but remained in the room to correct any technical problems or answer questions that arose (generally deferred to the end of the test to preclude unnecessary distraction).

Upon conclusion of the SCAT, data was recorded to diskette using a 3 digit code to identify the subject's file. Subjects were provided a general debriefing. See Appendices B and C for examples of written consent and debriefing forms.

Measures. Reaction time (for correct responses), reaction time variability (standard deviation of RT), misses (failure to respond to target), and false alarms (responses to non-targets) were recorded and totalled for each 400 trial condition. A response time greater than 1500 ms was recorded as a miss in the event of an excessively delayed response. Following presentation of each stimulus on the video monitor, the SCAT software disregarded subject input for a period of approximately 100 ms. This "response buffer" was intended to protect against delayed responses (from the preceding trial) being counted false alarms for the subsequent trial.

Results

Tables 1 and 2 present a summary of demographic characteristics for each of the clinical subjects as well as 8 matched controls. 3 clinical subjects were unable to provide a matched control, however, given the exploratory nature of the study, it was decided to include data for these unmatched cases.

Table 1. Demographic Characteristics of the Clinical Sample.

I.D.	Age	Ed	Sex	TSO
1	29	10	M	46
2	37	14	M	48
3	23	13	M	19
4	31	17	M	22
5	45	12	F	95
6	32	12	F	89
7	44	13	F	—
8	33	17	M	46
9	23	14	M	46
10	31	12	F	47
11	38	14	M	67
Mean (S.D.)	33.3 (7.21)	13.5 (2.11)	7:4 (♂:♀)	54.8 (31.29)

Note. I.D.: Subject identification; Ed.: Years of education; S.D.: standard deviation; TSO: Time since injury onset (weeks).

The number of subjects examined was quite small and as such statistical analyses should be considered with caution. A single factor Analysis of Variance (ANOVA) confirmed that the clinical and control groups were statistically matched in terms of age ($F(1, 16) = .95$), $p = .34$) and number of years of education ($F(1, 16) = 2.60$, $p = .13$).

The original hypotheses did not specifically focus on relationships between the four dependent variables (i.e., RT, RT variability, number of misses, number of false

Table 2. Demographic Characteristics of the Control Sample.

I.D.	Age	Ed	Sex
1c	29	16	M
2c	34	14	M
3c	24	12	M
4c	27	16	M
6c	31	17	F
7c	37	14	F
8c	30	16	M
Mean (S.D.)	30.2 (4.31)	14.9 (1.98)	5:2 (♂:♀)

Note. I.D.: Subject identification (matched with corresponding clinical subject); Ed.: Years of education; S.D.: standard deviation.

alarms), thus it was decided to complete four separate univariate analyses. In each of these analyses 2 between-subjects factors (group, order of task presentation) and 2 within-subjects factors (distraction (no-distracter versus auditory distracter), target type ("X" versus "AX")) were considered (i.e., 2 X 2 MANOVAs with repeated measures across each of the 4 within-subjects conditions). Since 4 separate analyses were completed, a p value of less than .025 was considered statistically acceptable.

In no case was order of presentation found to be a statistically meaningful variable (RT: $F(1,14) = 0.156$, $p = 0.70$); RT variability: $F(1,14) = .56$, $p = .47$; misses: $F(1,14) = .021$, $p = .89$, false alarms: $F(1,14) = .18$, $p = .67$). As such, the four analyses were repeated with group as the single between-subjects factor and with distraction and target type as the within-subjects factors.

Response Time

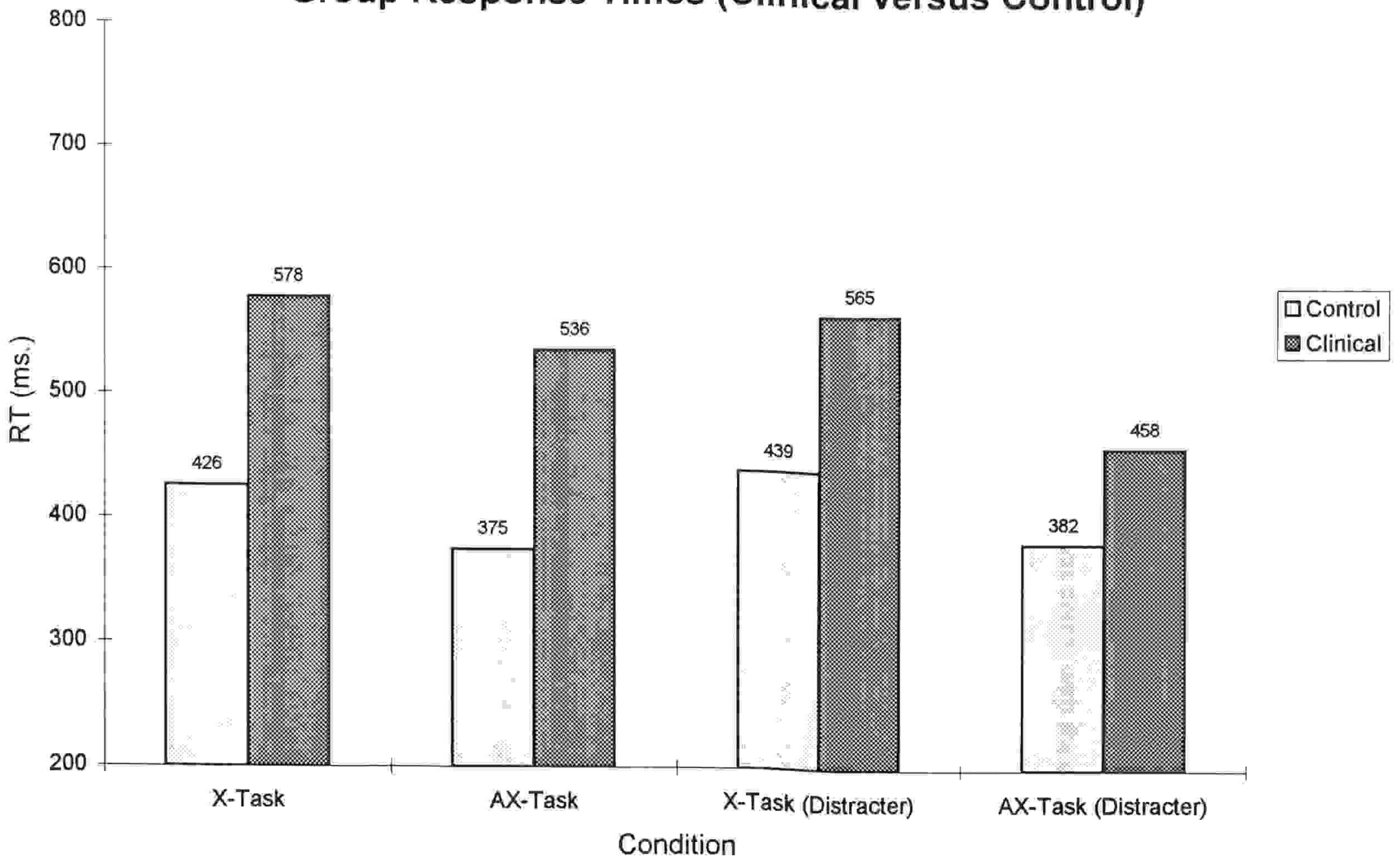
Response times were recorded for responses that were hits, with a maximum of 60 RT observations possible in each of the four within-subjects conditions. Thus, a greater number of misses resulted in fewer numbers of response time observations. Since the clinical group had a tendency to make more errors, these subjects had a fewer number of RT observations from which individual means were derived. Nonetheless, the clinical group displayed a tendency to respond more slowly overall ($F(1,16) = 4.60$, $p = .046$). A main effect of target type was also indicated, with all subjects responding more quickly to the AX-target ($F(1,16) = 8.32$, $p < .01$). RT was not sensitive to the effects of auditory distraction, nor was there an interaction between group and distraction condition or group and target type.

Under the parameters of the SCAT software, the maximum RT recorded was 1500 ms. Thus, it was possible that in some instances an extremely slow response could have been recorded as a miss, with the subject failing to respond within the allotted time. To account for this possibility and in order to obtain an equal number of RT observations for each subject, a second analysis included misses as response times equal to 1500 ms.. The inclusion of missed targets as 1500 ms. response times increased the mean RT for each group in each of the four within-subjects conditions (X-task, AX-task, XD-task, and AXD-task). However, the differences between the brain-injured group and the control group were not enough to reflect in the statistical analysis, likely because of the added variability. Figure 1 displays response times across the four conditions for both clinical and control subjects. Figure 1 and all subsequent analyses do not incorporate misses as response times of 1500 ms..

Visual inspection of the individual RT data suggested a possible anomaly with one of the brain-injured subjects. As mentioned, the 4 within-subjects conditions were counterbalanced across distracter type to limit the influence of fatigue or practice across distraction conditions. Although no statistically significant order effect was identified, it is possible that the low number of subjects limited the interpretability of this analysis. In particular, the pattern of response times displayed by one subject (subject 8) showed that

Figure 1

Group Response Times (Clinical versus Control)



his performance declined considerably in the AX-task, which happened to be the last of the four conditions administered. No other clinical subject demonstrated such a pattern.

For exploratory purposes, it was decided to repeat the RT analysis, excluding the unusual RT data. As previously, there was a tendency for the clinical group to respond more slowly than the control subjects ($F(1,15) = 3.69$, $p = .074$) and there was no effect of distraction. However, all subjects responded more quickly to the AX- target ($F(1,15)=56.79$, $p < .01$) and a group by target interaction was noted, with the clinical group being faster on the AX-target ($F(1,15) = 5.81$, $p = .029$). It appeared that the pattern of responding demonstrated by the one unusual subject was opposite to that of the rest of the clinical subjects, at least with respect to RT and type of target. The most likely explanation for the pattern displayed for this subject is the influence of fatigue across the four conditions. The performance of this individual will be considered more closely below.

Response Time Variability

The second planned MANOVA examined RT variability. The standard deviation of each individual's response times was combined to yield a mean standard deviation for each group, in each of the 4 conditions. Analysis of this index of variability suggested that the clinical group was more variable in their response times ($F(1,14) = 6.38$, $p < .025$). No effect of distracter or target type was noted in this analysis, nor was there any interaction between these factors and group. For consistency, the same analysis was completed without the anomalous RT data for subject 8, but this did not drastically change the pattern of RT variability.

Misses

Overall, the number of misses observed was relatively small in all conditions of the SCAT. For the control group, misses were virtually absent, while the clinical group missed approximately 3.8% of the possible targets across all conditions. Not surprisingly, MANOVA using the number of response omissions as the dependent variable suggested that there were no between-groups differences. No effect of auditory distracter was found, nor did target type appear to play a role. Figure 2 displays the number of misses made by each of the clinical subjects.

When scores for the anomalous clinical subject were removed and the analysis of misses repeated, there was still no notable differences between the 2 groups. However, a main effect of target was noted ($F(1,15) = 9.07$), $p = .009$). Given that most of the misses were made by the clinical group, it was surprising that the interaction term (Group x Target) was not also statistically significant ($F(1,15) = 3.43$, $p = .084$).

False Alarms

The pattern of false alarms was similar to the number of misses except that both the control and the clinical groups made false alarms. The control subjects made between 0 and 3 false alarms per condition, with a group mean of only 0.61 across all conditions. The clinical group had approximately the same range of false alarms (mean of 1.70 across all conditions), with the exception of 2 subjects, one of whom made 13 and 14 errors in three of the four conditions. Given the large degree of intersubject variability, MANOVA failed to show a group difference with respect to the number of false alarms ($F(1,16) = .93$, $p = .35$), and there was no effect of the auditory distracter ($F(1,16) = .003$, $p = .96$). There was a trend towards an effect of target type, with all subjects more likely to commit a false alarm in the AX-conditions ($F(1,15) = 3.91$, $p = .065$). No other statistically significant findings were noted with respect to false alarms. Exclusion of subject number 8 did not alter the pattern of the analysis for false alarms. Figures 3 and 4 display the number of false alarms committed by the clinical and control subjects.

Figure 2
Misses (Clinical Subjects)

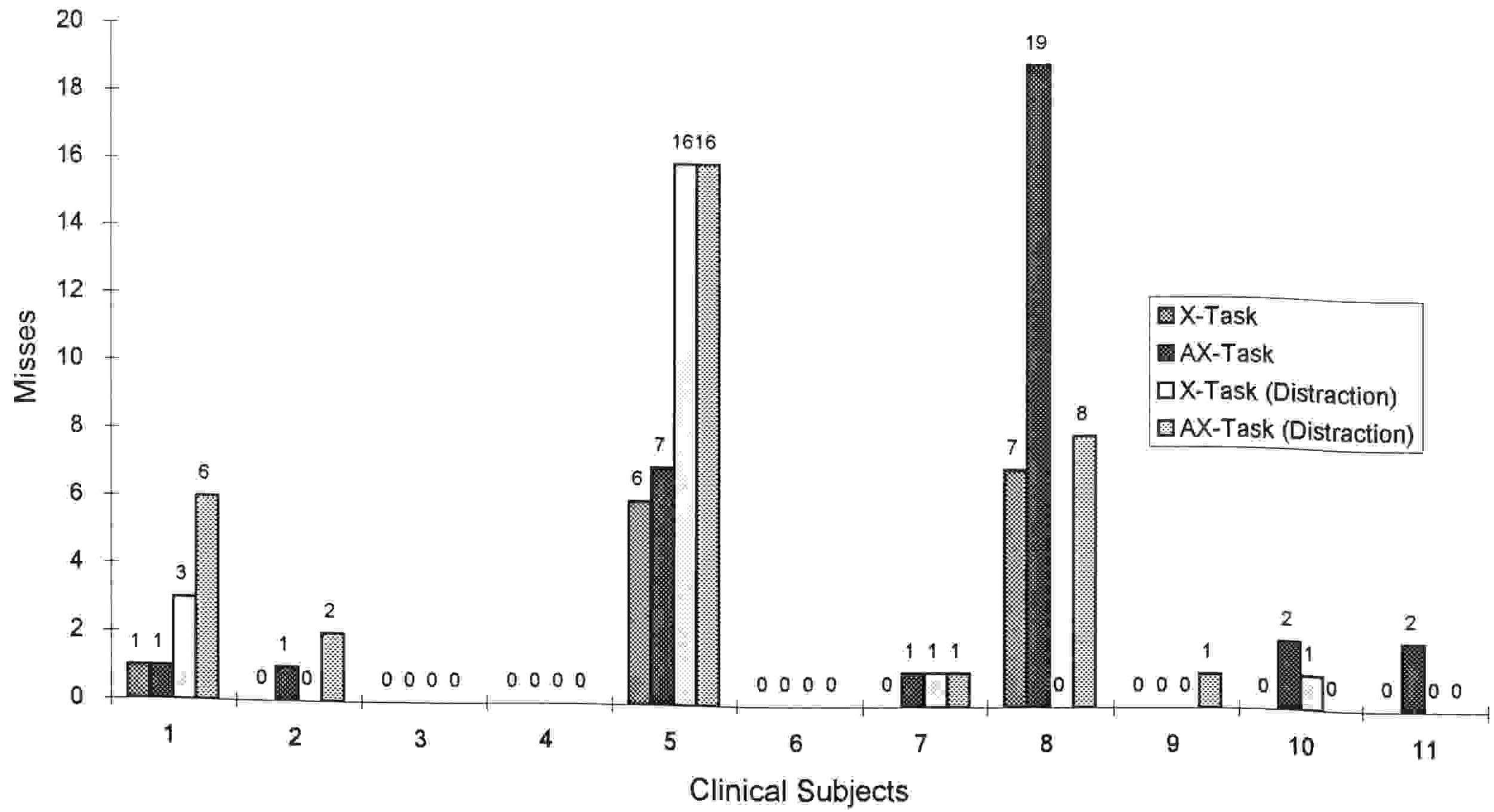


Figure 3
False Alarms (Clinical Subjects)

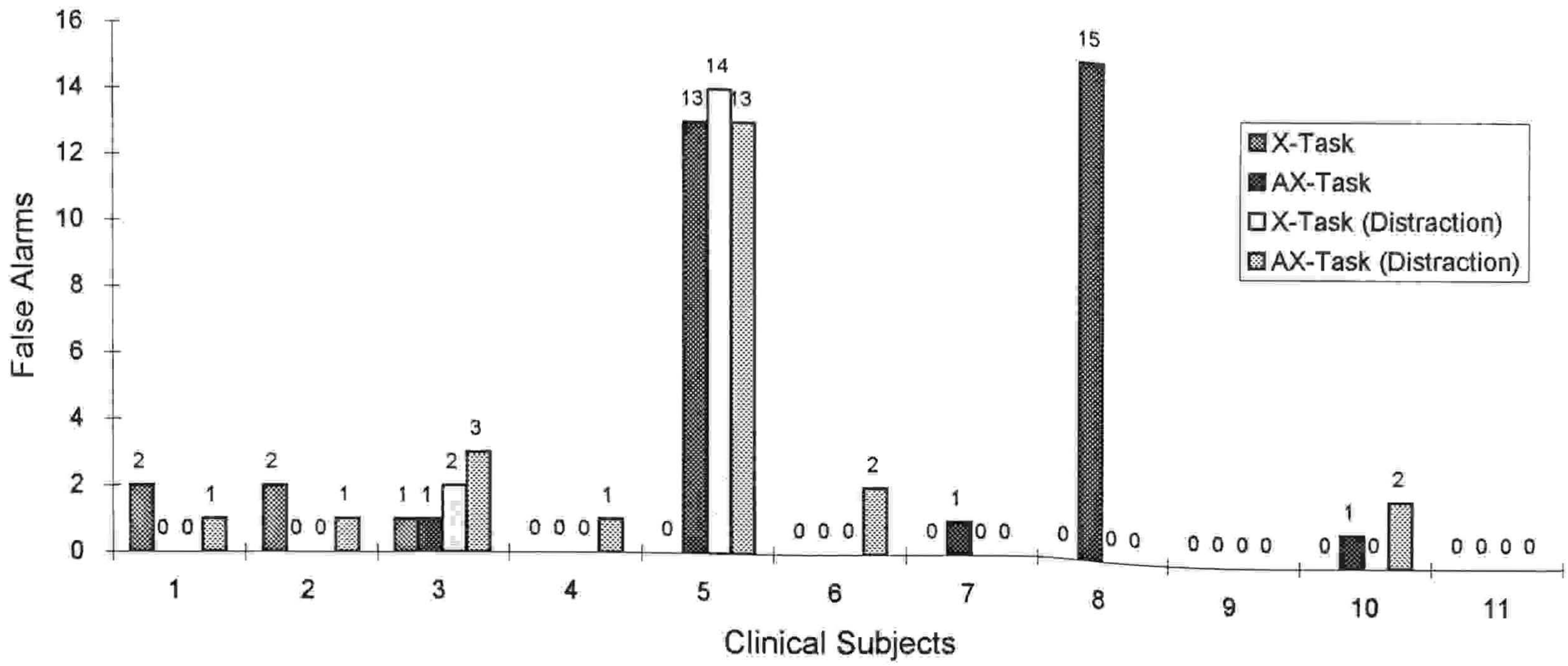
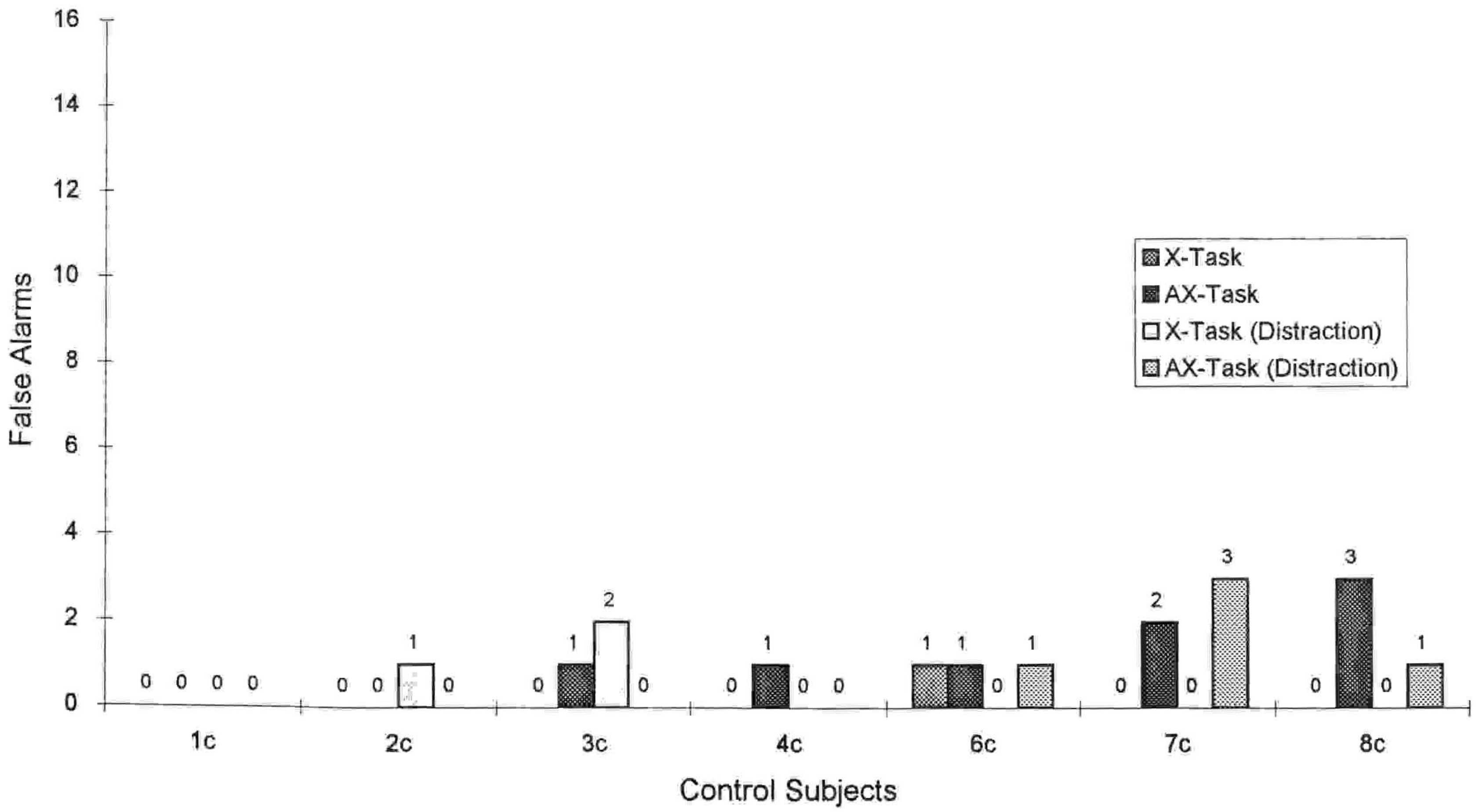


Figure 4
False Alarms (Control Subjects)



Severity of Deficit and Neuropsychological Testing

Examination of the profile of neuropsychological test results suggested the possibility of two subgroups within the clinical sample. An arbitrary, although clinically justifiable, criterion was selected such that clinical subjects performing below the 20th percentile on 2 or more of the selected neuropsychological tests were classified as "moderately neuropsychologically impaired." The remaining clinical subjects performed within the average range on all of the neuropsychological tests. These subjects had a wide range of scores and may have performed within the lower-average range on some tests. While technically still within the average range, "lower-average" performance may represent an impairment for a particular individual as compared with their pre-injury ability. Alternatively, some of the brain-injured subjects performed in the high-average range on certain measures. Thus, the classification as "mildly neuropsychologically impaired," may not have accurately labelled all of the remaining brain-injured subjects, but best describes them as a group.

The mildly- and moderately- impaired clinical groups were compared on a number of demographic variables. There were no meaningful differences in the mean time since onset (TSO) between the two subgroups ($F(1,8) = .001$, $p = .97$). There was also no difference in education levels ($F(1,8) = .018$, $p = .897$), although the moderately-impaired subjects tended to be slightly older than the mildly-impaired group (mean of 6 years difference, $F(1,8) = 6.2$, $p < .05$). Table 3 displays the neuropsychological test characteristics of the entire clinical sample, with test performance below the 20th percentile indicated with a star (★).

To compare the performance differences between the two subgroups of the clinical sample, four additional MANOVAs were conducted. As with the first set of presentation was not statistically meaningful in any of these analyses. Thus, the

Table 3. Neuropsychological Performance of the Clinical Sample.

I.D.	WAIS-R Digit Span	WAIS-R Arithmetic	WAIS-R Digit Symbol	Stroop Test	Test D2 Total	PASAT	Trails A & B	Classification
1			★	★		★		Moderate
2	★					★	★	Moderate
3				—		—		Mild
4								Mild
5	★			★				Moderate
6					★		—	Moderate
7	★			—		—	—	Mild
8			★	★	★	★	★	Moderate
9			★				—	Mild
10						★		Mild
11			★	★	★		★	Moderate

Note. ★: indicates neuropsychological test scores less than the 20th percentile; —: indicates missing neuropsychological test data (see text); Mild = less than 2 neuropsychological test scores below the 20th percentile; moderate: 2 or more neuropsychological test scores above the 20th percentile.

following analyses include group (i.e., mildly-impaired clinical versus moderately-impaired clinical subjects) as the between-subjects factor and distraction and target type as the 2 within-subjects factors.

When the two clinical subgroups were compared, the mildly-impaired group had response times that were virtually identical to the controls, whereas the moderately-impaired subjects had substantially longer response times (see Figure 5). MANOVA verified that the moderately-impaired group was significantly slower to respond to targets under all conditions ($F(1,9) = 10.47$, $p < .01$). A trend towards an effect of target type was also identified, with responses to the AX-target tending to be faster for all of the clinical subjects ($F(1,9) = 4.63$, $p = .06$). When the same analysis was completed, excluding the data for subject 8, the effect of target type was even stronger ($F(1,8) = 58.71$, $p < .01$), however, the interaction between target type and group was not statistically meaningful, regardless of the inclusion the unusual data. Once again, the influence of the auditory distracter failed to reach statistical significance ($F(1,9) = 1.08$, $p = 0.22$).

Analysis of the RT variability between the two clinical subgroups revealed similar results as in the RT analysis. Figure 6 suggests that the moderately-impaired clinical group was more variable in their performance than the mildly-impaired group ($F(1,9) = 14.41$, $p < .01$). There was no disproportionate change in RT variability across target type or distraction. However, as expected, when the anomalous data for subject 8 was excluded from the analysis, the moderately-impaired clinical subjects had a non-significant tendency to make perform more variably in the AX-target conditions ($F(1,8) = 5.84$, $p = .04$).

Figure 5
Response Time Performance for 3 Subgroups

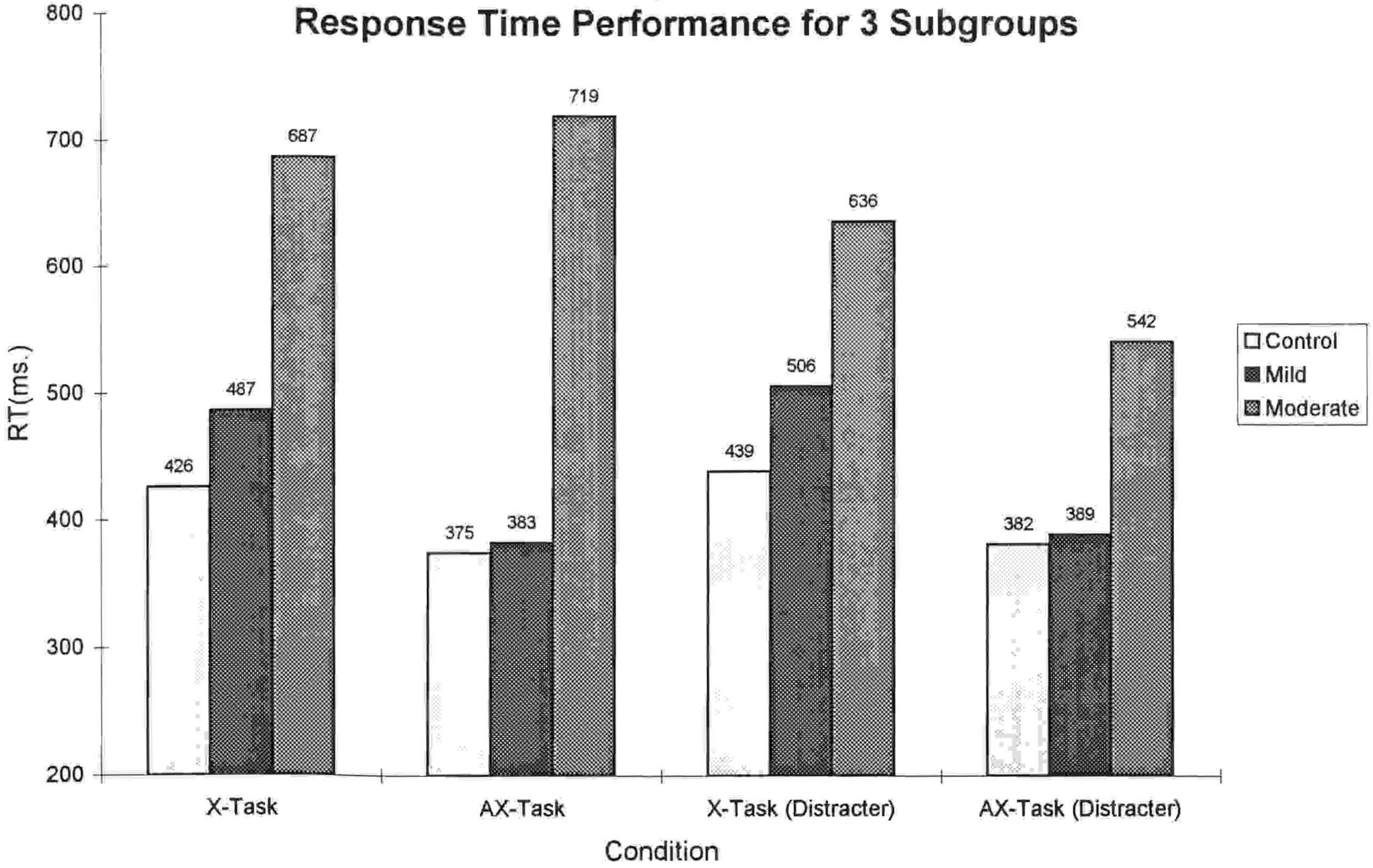
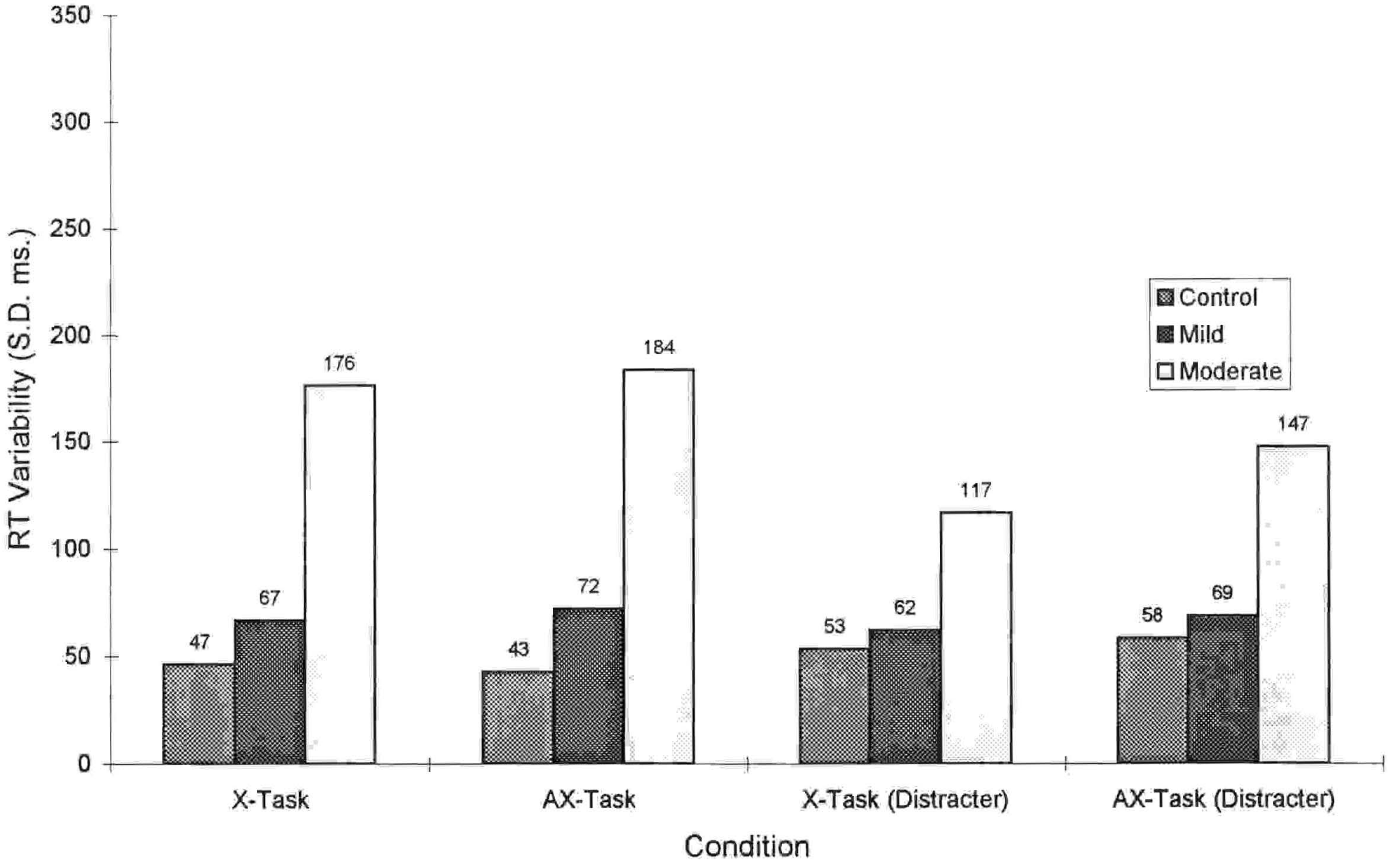


Figure 6
Response Time Variability for 3 Subgroups



The moderately-impaired clinical group displayed a tendency to commit a greater number of errors than the mildly-impaired group. Figure 7 displays the pattern of misses between the two clinical subgroups, with MANOVA identifying a trend for the moderately-impaired group to commit more misses ($F(1,9) = 5.13$, $p = .05$). No differences in the number of misses were noted with respect to target type or distraction. However, when subject 8 was excluded from the same analysis, a group by target condition interaction was shown, with the moderately-impaired subjects making more misses on the A-X target condition ($F(1,8) = 13.8$, $p < .01$). Once again, there was no identifiable effect of distraction.

Finally, with respect to false alarms, no statistical differences were noted between the moderately-impaired and the mildly-impaired subjects ($F(1,9) = 2.14$, $p = .18$). No differences between target type or distraction conditions were identified within the clinical subgroups, and exclusion of subject 8 from the subgroup analysis did not alter the overall pattern of false alarms. Figure 8 displays the false alarms for the two clinical subgroups with the control group included for purposes of comparison.

Individual subject performance

Given the variability of performance in the clinical group, which was not unexpected, it was decided to compare the individual scores of the brain-injured subjects to the mean of the control group, as would typically be done if the SCAT were used as an assessment instrument. For this comparison, the data was collapsed across all four conditions. Mean RT, mean RT variability, total number of misses, and total number of false alarms were compared to the corresponding data for the entire control group. Table 4 presents individual subject data, with bolded numbers representing scores that were above the critical cutoff in the t distribution ($t(7,0.025) = 2.365$).

Figure 7
Misses for 3 Subgroups

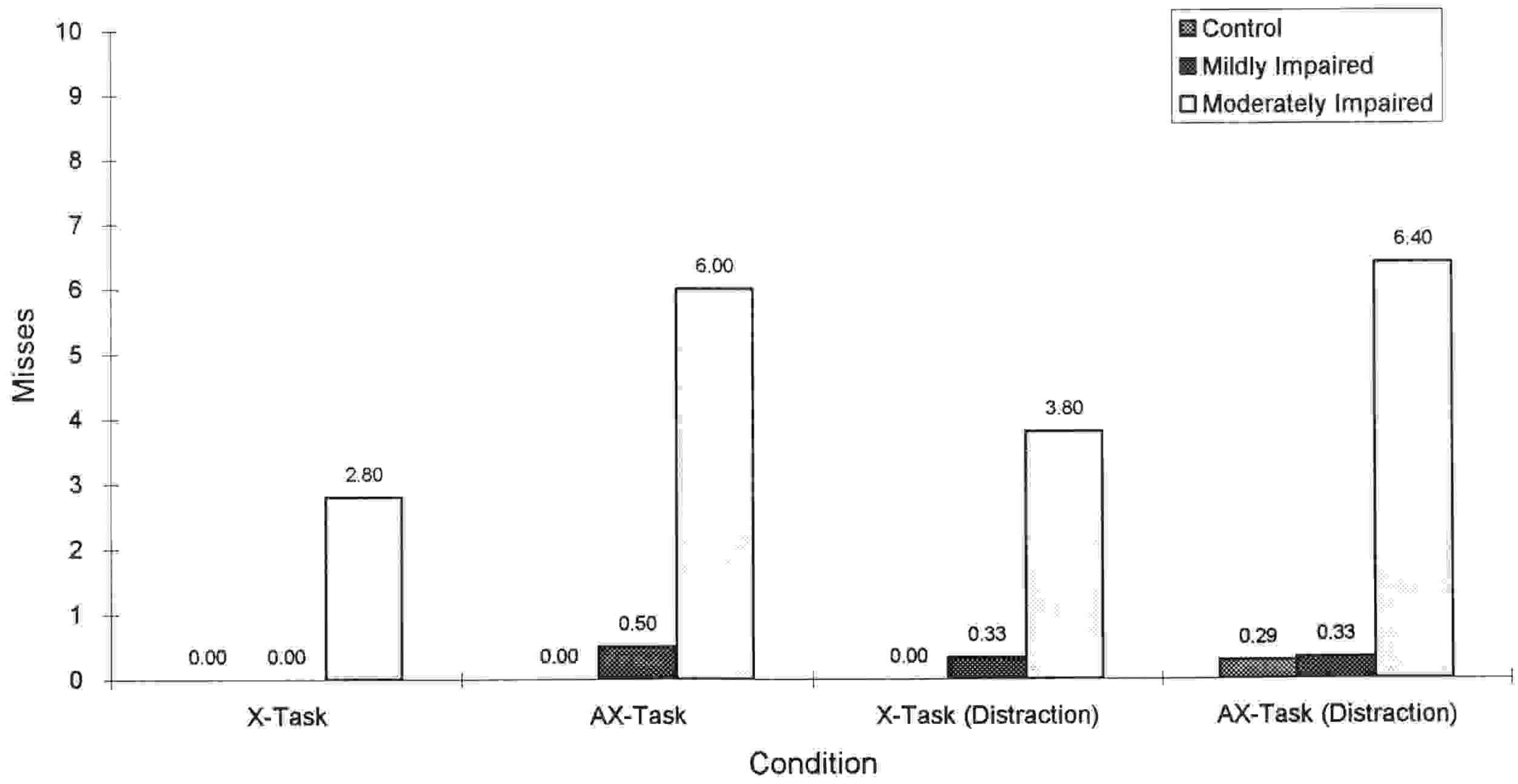
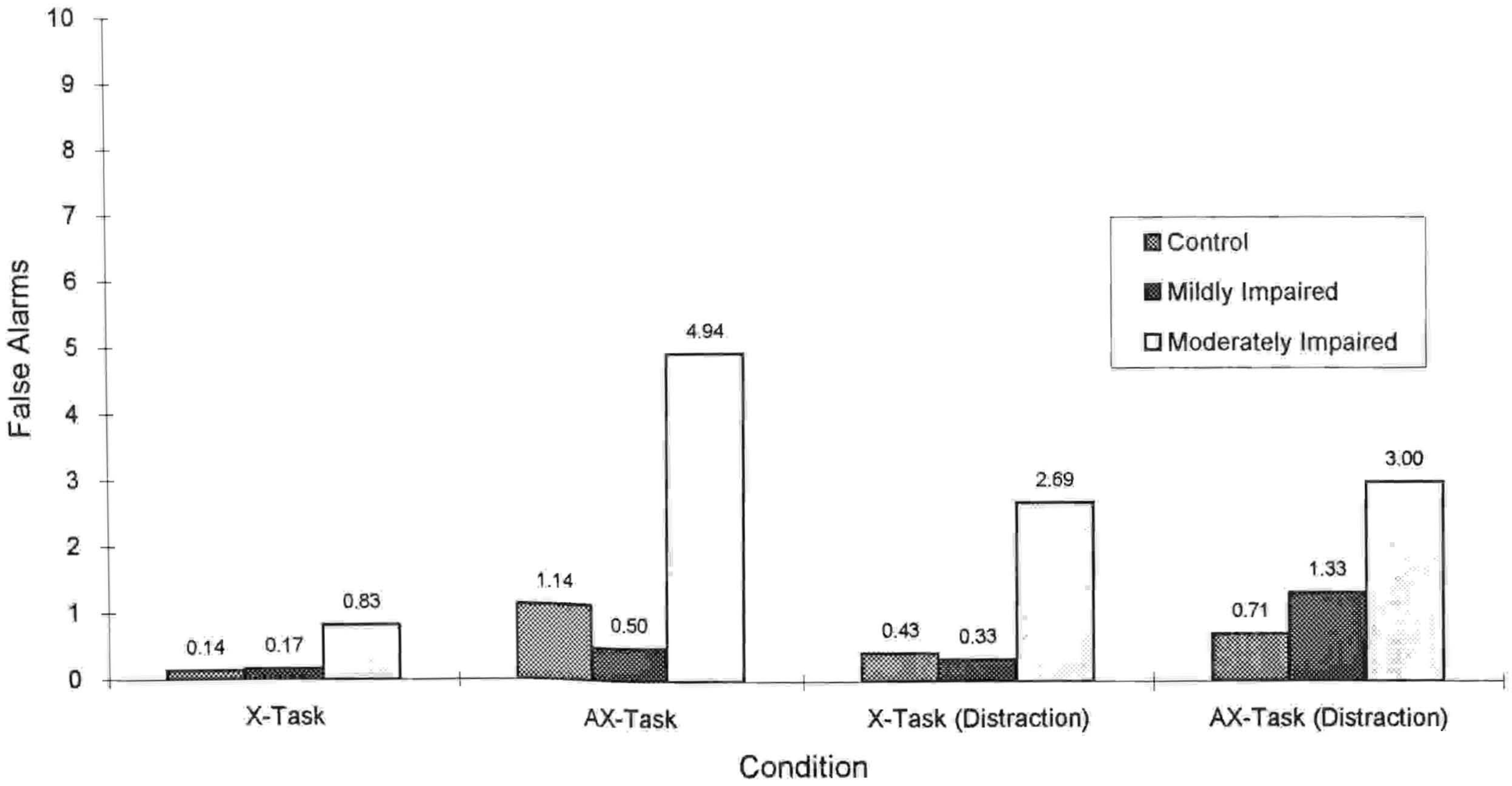


Figure 8
False Alarms for 3 Subgroups



Examination of Table 4 suggested unusual patterns of performance for several of the moderately-impaired subjects. As previously indicated, subject 8 was noted to display an atypical pattern of RT data across the 4 conditions of the SCAT. However, Table 4 shows that subjects 8, 5, and 1 all made unusually large numbers of errors. To further investigate, data for each individual subject was graphed for visual inspection. Each of the four SCAT conditions was subdivided into 2, 5-minute blocks, and the data was plotted in chronological sequence over the course of the 40 minute session. Only two of the clinical subjects (number 8 and number 5) displayed unusual patterns of performance when considered across the entire SCAT administration. Figure 9 displays the RT and accuracy of subject number 8, with errors collapsed to reflect both misses and false alarms. Figure 10 displays the pattern of RT and accuracy for subject 5 over the course of the SCAT administration. Possible implications of these individual performance patterns are considered in the discussion.

Table 4. Individual SCAT Performance.

Classification	Mean RT	SD of RT	Misses	False Alarms	ID
Controls	405.3(27.26)	50.24 (5.41)	0.07 (0.13)	0.60 (0.33)	—
Moderate	**740**	**177**	**34**	**15**	8
Moderate	**734**	**234**	**45**	**40**	5
Moderate	**708**	**161**	**2**	0	11
Moderate	**612**	**102**	**3**	**3**	2
Moderate	437	**106**	**11**	**3**	1
Mild	**592**	**99**	**3**	1	7
Mild	463	**67**	**3**	**3**	10
Mild	429	62	0	**2**	6
Mild	412	56	0	1	4
Mild	393	**67**	**1**	0	9
Mild	359	55	0	7	3

Note. Control group presented as means (S.E.M. in parentheses); I.D.: subject identification number; bolded numbers represent scores above critical t cutoff; Classification is based on neuropsychological data presented in Table 3.

Figure 9
Performance Over Time (Subject 8)

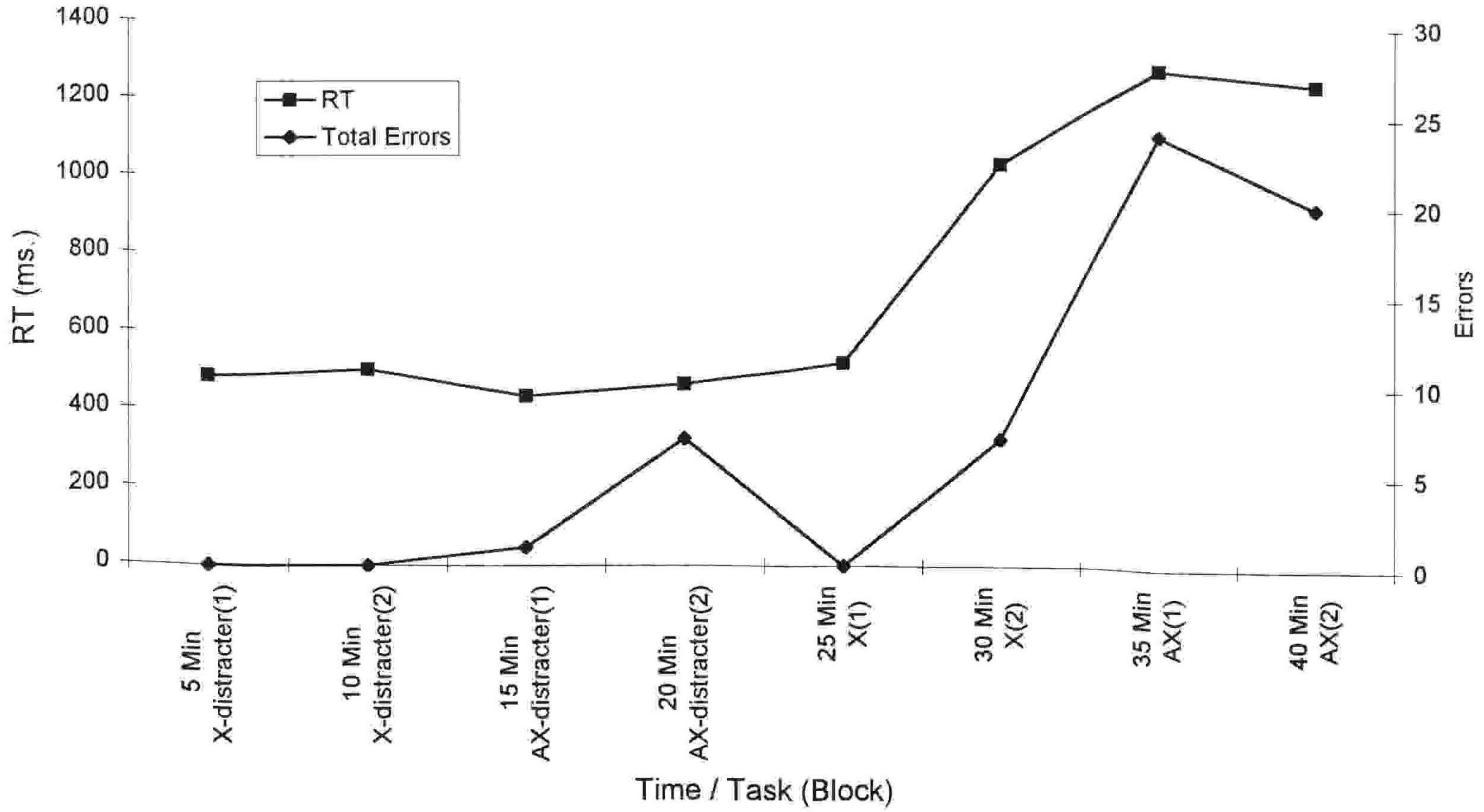
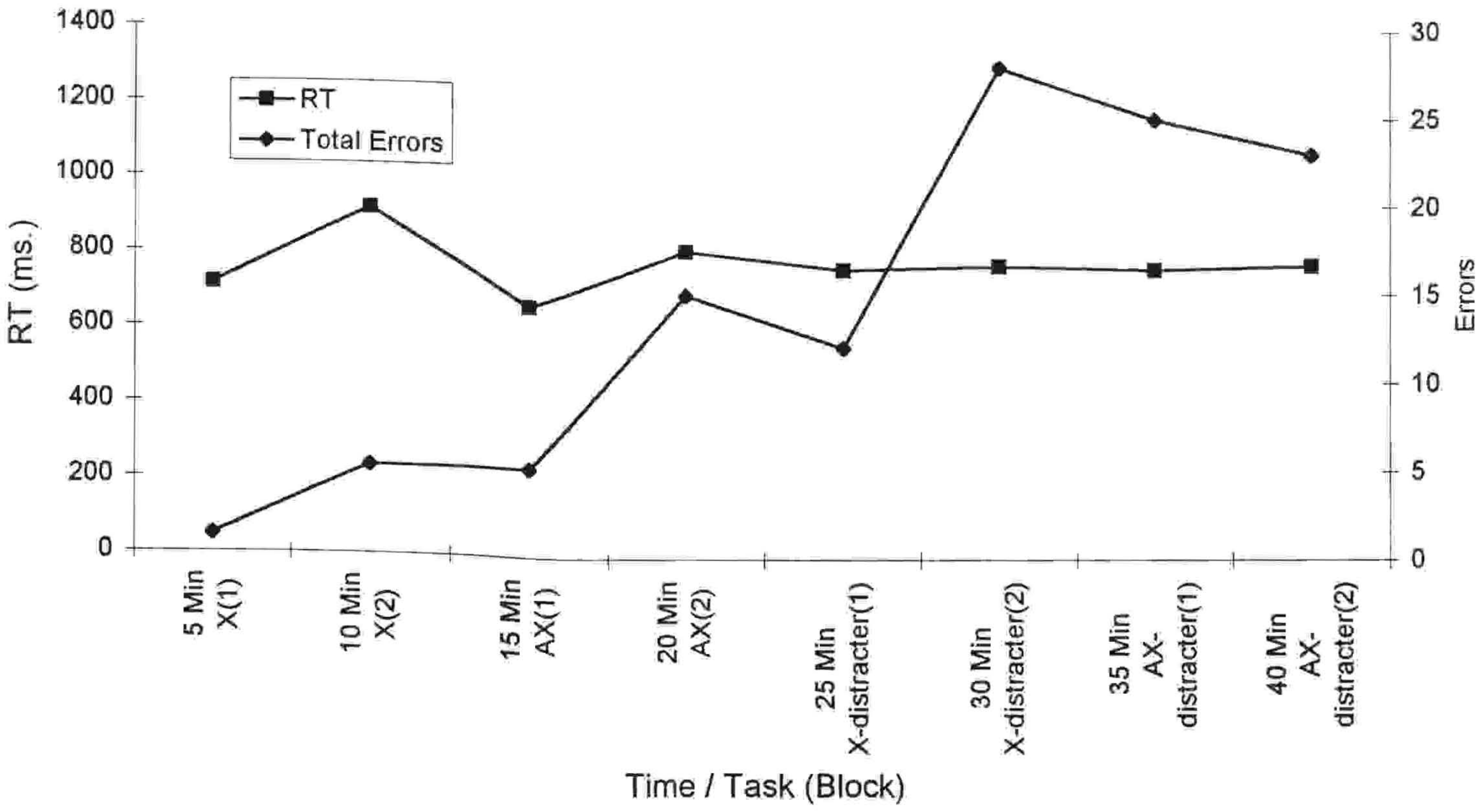


Figure 10
Performance Over Time (Subject 5)



Discussion

The primary goal of the present study was to evaluate the diagnostic utility of the Seidel Continuous Attention Test on a group of mildly to moderately brain-injured patients. The results revealed clear limitations in this utility. The response times of the clinical subjects tended to be slower, but error rates did not vary a great deal, except for two of the clinical subjects. Performance on the X- and AX-tasks also did not differ between the clinical and control subjects. Finally, performance under the distraction conditions added for this study did not differ from performance without the distraction. These findings are discussed with respect to the type of patients tested with consideration given to theoretical frameworks of attention described by Sohlberg and Mateer (1987) and others.

Description of the Subject Samples

Given the nature of closed head injury, a degree of subject variability is inherent in terms of injury characteristics, demographic characteristics, and level of functional deficit, all of which influence performance on many neuropsychological tests. In other words, a representative sample would also be expected to be a variable sample. In the present study, subjects were solicited from the Gorge Road Hospital Rehabilitation Program (Greater Victoria Hospital Society, Victoria, B.C.). These patients were either transferred from acute hospital care or referred from physicians from the Victoria community. Entrance into the program was conditional upon successful screening by an admissions panel consisting of a psychiatrist, a neuropsychologist and a social worker. Several factors were requisite for admission to the program, including presence of "functional impairment" caused by a brain injury, potential to improve in at least one of a variety of cognitive, behavioural, physical or emotional areas, and agreement by the patient to abstain from the use of alcohol or other intoxicants. Furthermore, only subjects participating in the Attention Process Training Program were involved in the SCAT research. Inclusion in this program was dependent upon a combination of subjective complaint of attention or concentration difficulties by the patient, results of neuropsychological test data, and the judgement of the clinical psychologists working with the patients. It could be argued that narrowing the sample to patients with specific, well-documented focal lesions would have increased the interpretability of the results, but this would have run counter to the intent of the study (i.e., evaluation of the clinical utility of the SCAT with brain-injured patients, in general). Thus, the subjects involved were felt to be appropriate for this goal, with certain patient features "pre-screened" by admittance to the Attention Process Training Program.

The selected patient group had a mean age of 33 years (range 23-45 years) and appeared to represent a demographically appropriate sample (Recovery, 1991). The clinical group included 7 males and 4 females with an overall level of education of 13.5 years (slightly higher than expected). Given that performance on many neuropsychological tests improves with increased levels of education (Lezak, 1983), this feature of the clinical sample could be thought to favour improved performance on the SCAT, if it had any influence at all.

The matched-friend method of obtaining control subjects was felt to be appropriate to the current study, because such individuals can be expected to be more similar to the clinical group in terms of demographic variables, such as education and socio-economic status, than would a group selected from the general population or from a more convenient group such as hospital employees or university students (Dikmen & Temkin, 1987). However, finding a reasonable control sample for the clinical group proved to be somewhat difficult, with 3 out of the 11 patients unable to invite a same-sex, age-matched (±5 years) friend to participate. This problem was also encountered by

Allison (1993), who used a similar technique to provide a comparison group. Allison suggested that this difficulty may be reflective of the social isolation that is frequently reported by patients after a brain injury. Since the three unmatched clinical subjects did not appear to have any obvious demographic anomalies and given the exploratory nature of the study, it was decided to include observations from these subjects. The control group had a mean age of 30.2 years and education of 14.9 years. Although not of primary importance, it is also likely that clinical and control subjects were matched on a variety of psychosocial variables, including lifestyle (hobbies, living situation), personality (likes, dislikes), among others.

As indicated, a small number of clinical subjects were involved in the study, limiting the interpretability of the statistical analyses. Thus the analyses were considered tentative and exploratory in nature. Once the data from the first 19 subjects had been collected, and it was clear that the difference between the clinical and control subjects was not dramatic, it was felt that further data collection would not have been useful toward addressing the general objectives of the study. However, in addition to the statistical analyses, individual and qualitative performance characteristics of the clinical subjects provided some insight into the clinical utility of the SCAT and the nature of the deficits demonstrated by the brain-injured individuals involved. These considerations will be discussed below.

Neuropsychological data. As part of the rehabilitation process, all clinical subjects had undergone a neuropsychological assessment. With the consent of the patients, these data were reviewed to gain a more objective indication of the nature and seriousness of their cognitive difficulties. Considering the purpose and context of the neuropsychological assessment (i.e., rehabilitation), combined with the fact that assessment data had been collected prior to involvement in the present study, it was not surprising that some subjects had missing data. In each case, consultation with the rehabilitation psychologists confirmed that the missing tests had not been administered because they were not considered essential to diagnosis or rehabilitation. For instance, if the PASAT was considered too difficult or frustrating to warrant administration it was omitted from the test battery of a given patient. Alternatively, a test such as Reitan's Trails A & B might not be considered sensitive enough in some cases. Such comments are interesting because they reflect the semi-empirical process by which psychometrists select measures which they feel to be appropriate for different individuals.

Review of the neuropsychological data for the APT patients involved in this study proved to be interesting. The sophistication or sensitivity of a particular neuropsychological test, the nature of the deficit being assessed, as well as the quality of the normative data, will determine the resolution of the particular scale (i.e., how impaired does the performance of an individual need to be to be classified as having a deficit). Individual scores falling below the 20th percentile are usually considered to represent performance in the low-average to impaired range of ability in the particular ability being assessed (Lezak, 1983). This means that 80% of the comparison population will be performing at or better than the measured individual (performance at the 16th percentile is approximately 1 standard deviation below the mean score of the normative sample). As Table 3 shows, using a criterion of performance below the 20th percentile on at least 2 out of 7 measures (selected for their sensitivity to attention deficits), 5 out of the 11 clinical subjects were not demonstrating measurable deficits in attention (i.e., performance above the 20th percentile). There may be several explanations for this observation, the most likely being the process by which patients arrived in the APT program. When considering placement in rehabilitation programs, emphasis may be placed on factors such as reports of the patient or relatives, functional impairment observed over a period of time, and clinical judgement, in addition to the results of neuropsychological testing (e.g., Gronwall, 1987). This apparent "split" in the clinical sample was considered to be a natural feature of the sample and was incorporated into *post hoc* analyses as will be discussed below.

Distractibility

The brain injury literature often refers to patient complaints of concentration and distractibility problems which appear immediately following the injury and can last up to and beyond a period of 2 years (e.g., Van Zomeran & Van den Burg, 1985; Lezak, 1978). This observation was noted in the present sample, with several patients informally commenting about experiences of concentration difficulties following their injuries. Common examples involved situations such as reading the newspaper while a television or radio was on within proximity. Some commented that they found such situations very taxing, while others felt that such a task would be impossible for them. The present study attempted to gain insight into the nature of these complaints by comparing performance on the SCAT with and without a simple auditory distraction.

Based on the theoretical hierarchy of attentional processing espoused by Sohlberg and Mateer (1987), the distraction phenomenon could be explained from several points of view, depending on the nature of the primary task and the type of distraction. In the present study, the primary task involved monitoring a paced presentation of letters for a specific target, while the distraction consisted of a paced presentation of auditory stimuli of the same type and content as presented in the primary task. The rationale for using this kind of "simple" distracter was that it introduced a component of extraneous stimuli, without requiring the subject to process or respond to it. The auditory stimuli also lacked specific informational content, but since it was similar to the stimuli used in the primary task, interference effects or distraction could be expected. Finally, since the subjects were not required to monitor or respond to the auditory distracter, the nature of the primary task remained the same (i.e., a simple "choice" response time task, versus a divided attention task with more than one processing or response requirement). Thus, from a theoretical standpoint, the distraction was intended to challenge the subject's ability to remain focused on the primary stimuli, and selectively ignore the irrelevant information.

Perhaps not surprisingly, the performance of the control subjects did not differ between the distraction and no-distraction conditions. Given the simple processing and response requirements required by the SCAT, control subjects were expected to have little difficulty with the addition of an auditory distraction. However, this was also found to be the case for the brain-injured subjects, in both the X- and the AX-target conditions. This null finding could not be attributed to practice effects or other order effects, since the order of presentation (i.e., distraction versus no distraction) was counterbalanced and found to be a non-significant variable.

Given the prevalence of concentration and distractibility complaints among brain-injured patients, the lack of a distracter effect was unexpected. Comments made by the clinical subjects helped shed some light on this issue. For instance, when providing test instructions, the initial reaction of some of the clinical subjects suggested that they felt the distraction condition would be difficult for them. Yet after completing those conditions the same subjects indicated that they found the auditory stimuli relatively easy to "tune out." In fact, in the absence of a true no-distraction condition (i.e., use of white noise or ear plugs to block out the background noise of the hospital test environment) at least one subject commented that she found the distraction condition easier because the stimuli were predictable and paced, "like a really bad Rap song." Apparently this subject had used the "distracting stimuli" to block out more random and subtle background noise and subjectively felt that her performance was better (inspection of the data revealed that her performance was slightly poorer on the distraction conditions, but not significantly so). It could be hypothesized that the lack of information content of the auditory distracter, along with the repetitive, paced nature, made it more amenable to habituation, to use the behavioural terminology. Clearly, the mildly- to moderately-impaired subjects were not susceptible to simple, cross-modal distraction, when the primary and distracting stimuli did not require demanding cognitive processing or response requirements.

The lack of a measurable distracter effect raises two important questions. First, what is the nature of distractibility among brain-injured patients, and second, what task dimensions are important in determining whether a brain-injured person will be able to attend or will become distracted? Studies of selective attention have tested a subject's ability to focus on a relatively weak source of information in the presence of strong distraction. As described by Van Zomeran and Brouwer (1987), the terms "weak" and "strong" refer not to the physical intensity of the stimuli, but to the association between the stimulus and a response. For example, in the classic Stroop paradigm, subjects are required to suppress an automatic process (e.g., reading the word "RED") in favour of identifying the colour of ink the word is written in. In the Stroop task, the strong association is between the stimulus word and the relatively automatic response to read. The weak association, the primary task, is to name the colour of the stimulus word. When used to identify residual deficits in adults after brain injury, researchers have found that patients performed more slowly than controls on the Stroop test. However, there was no significant difference in speed for the colour naming with interference task (i.e., colour-word condition; Stuss, et al., 1985; Van Zomeran et al., 1984). These results suggest that brain-injured subjects have no disproportionate difficulty selecting and remaining focused on the colour dimension, the weak association.

In another study, Gronwall and Sampson (1974; cited in Van Zomeran & Brouwer, 1987) tested selective attention by having brain-injured patients monitor and shadow (i.e., verbalize the auditory information as it is presented) one message presented to the left ear, while ignoring a different message presented to the right ear. There were no intrusions from the irrelevant message, and the authors concluded that their patients showed no deficits in selective attention, despite having sustained a head-injury the day before. However, when the messages were switched from one ear to the other half way through the test, the control group showed a sudden performance disruption and found it difficult to get back on task. The brain-injured patients went on shadowing the same ear, with no disruption in performance. This paradoxical effect was interpreted to suggest that the brain-injured subjects were better able to focus their attention and confine themselves to shadowing the appropriate ear. Van Zomeran and Brouwer (1987) suggest that the effect was noted because the control subjects retained the capacity to analyze for meaning, while the brain-injured subjects did not.

In the present study, the relationship between the primary and distracting stimuli was such that the brain-injured subjects were able to selectively attend to the SCAT task. Based on Van Zomeran and Brouwer's comments, and the findings of Gronwall and Sampson (1974), it is unlikely that increasing the stimulus intensity would have had a substantial influence on the overall performance. It is unclear what effect changing the content of the distracter would have had (i.e., increasing the informational content or "salience" of the distracter). However, it is likely that increasing the processing demands of the primary task, such that more attentional resources are required (e.g., a task such as the PASAT), would make the brain-injured subject more amenable to distraction or interference effects. Alternatively, one could change the "nature" of the task, such that alternating or divided attention are required (i.e., processing and responding to two simultaneous stimuli). Divided attention tasks are not generally considered to measure distraction, but assess the ability to allocate (divide) attentional resources efficiently. As indicated in the literature review, brain-injured subjects have been frequently found to demonstrate deficits on such tasks.

In summary, no evidence of deficits in distractibility (selective attention) was found using the SCAT task with an auditory distraction. Based on the literature review, one conclusion is that brain-injured patients are slower in dealing with irrelevant stimuli, and thus do not show interference effects unless they are actually required to process that information, as in a divided attention task. Increasing the information content (i.e., the salience) of the distraction, may have had an influence, but this remains to be determined.

Alertness, Inattention and Impulsivity

The use of a "simple target" (X) and a "complex target" (AX) is a traditional feature of continuous performance tests (e.g., Rosvold & Mirsky, 1956), allowing examination of subtle characteristics of attention. For example, performance on the AX-condition may relate to features such as alertness, since the "A" in the AX-target can be used as a warning to a potential target, the "X." Halperin and colleagues (1991) have also suggested that subtle performance differences between the X- and AX-conditions can be used to examine aspects of impulsivity and inattention. In addition, Van Zomeran (1981) used a single-target and multi-target task to examine the role of cognitive load and processing speed in tests of attention. In most studies, impulsivity, arousability, effects of cognitive load and processing speed are examined by considering RT characteristics as well as the number and types of errors observed under varying target conditions.

> "Schneider and Shiffrin (1977) used measures of speed of response and accuracy in their assessment of the efficiency of controlled information processing. They concluded that divided attention deficits result from limitations in the rate of controlled information processing. Divided attention deficits (in speed and/or accuracy) would become apparent with increasing load. Three central constructs in measuring the efficiency of divided attention are, therefore, speed of

performance, accuracy of performance, and increasing effects of load or complexity" (Ponsford & Kinsella, 1992).

In the present study, performance of the brain-injured and control groups was compared across X- and AX-conditions of the SCAT, with both groups found to have faster response times in the AX-condition. This finding supports the hypothesis that the occurrence of the "A" served to warn or cue the subject for the possibility of an impending target. Although the clinical subjects were slower overall (i.e., on both the X- and AX-tasks), their response times were not proportionately faster or slower than the control group in the AX-condition. To further support the "warning hypothesis," when the clinical group was divided into mildly- and moderately-impaired (based on their performance previous neuropsychological testing), there was still no notable slowing in the moderately-impaired group. This pattern of RT data is consistent with the findings of Ponsford and Kinsella (1992), who used an auditory tone to cue the potential occurrence of a target. Ponsford and Kinsella found no evidence to support the presence of abnormal alertness (i.e., impaired focused attention) in their sample of severe brain-injured patients, and the present data appears to suggest the same for mildly- and moderately-impaired patients.

Another approach to studying deficits in focused or selective attention has been to examine patterns of errors and their possible significance. Halperin and colleagues (Halperin, et al., 1988; Halperin, Wolf, Greenblat & Young, 1991) and others (e.g., Conners 1985; 1992) have found that accuracy on the AX-task may be a particularly sensitive index of inattention and impulsivity. For example, inattention on the AX-task could lead to both misses and false alarms. Misses could result from inattention to the "X" component of the target. False alarms might result from inattention to the "A" component of the target, causing a false response to a "not-A, X" sequence. However, false alarms are probably more closely related to impulsivity. For example, on the AX-task, impulsivity could result from a decreased ability to withhold a response to the warning stimulus (i.e., responding to the "A" before the occurrence of the "X"). Similarly, the impulsive subject would be more likely to respond to a non-target following a cue (A, not-X error) or to a target which was not preceded by a cue (not-A, X error). False alarms occurring on the X-task, or occurring after noncue-nontarget sequences on the AX-task, probably reflect behavioural dyscontrol rather than a pure focused attention deficit or impulsivity (Halperin et al., 1988). Miscellaneous error responses (e.g., responses to auditory and visual distracters) are reflective of problems in selectivity (Conners, 1992).

Although an analysis of specific types of errors could yield potentially interesting information, this was not possible with the SCAT for two reasons. Firstly, in Seidel's original development of the stimulus series, no consideration was given to analysis of specific errors, and thus there were unequal opportunities to commit each type of error. The stimulus sequence and target can be altered within the SCAT software, making this a potential area for future study. Secondly, the low numbers of errors (4 or less in 8 out of 11 clinical subjects and all control subjects) made analysis of types of errors meaningless.

Given the small number of subjects in each group, the type of analysis used and the small number of errors committed, consideration of group error rates was not particularly illustrative. When the clinical group was subdivided into mildly- and moderately neuropsychologically impaired, based on the prior neuropsychological testing, it was found that the moderately-impaired group made more errors overall. However, even this analysis was of questionable validity, given that 2 of the moderately-impaired subjects contributed most of the errors to this subgroup of 6 patients. The most revealing portrayal of the errors was achieved by comparing the numbers of misses and false alarms made by each individual clinical subject to the mean of the control group, as depicted in Table 4. This table shows that, when compared on an individual basis, each of the moderately-impaired clinical subjects committed significantly more errors than the control group. This could be offered as evidence that the moderately-impaired members of the clinical group had a deficit in their ability to detect targets. However, one must also consider that the control group made an average of .07 misses across the 4 conditions. This low base rate of misses, meant that as a few as 2 misses out of a possible 240 targets, over the course of 1600 stimulus presentations, would place an individual error score significantly above the mean of the control group.

The same problem arose for false alarms. Table 4 suggests that 7 of the clinical subjects committed significantly more false alarms than the control group. Four of these "false responders" had been classified as moderately-impaired, while the other 3 had been classified as mildly-impaired. Subjects need only have committed 2 false alarms over the course of the 1600 stimulus presentations to result in a score that was significantly above the mean number of false alarms in the control group.

A major problem with CPTs in their usual format is the "floor effect." That is, the number of targets is often so few and errors so infrequent that the test is relatively insensitive to lapses in attention, even with subjects known to be inattentive (Newcombe, Halperin, Healy, O'Brien, Pascualvaca, Wolf, Morganstein, Sharma & Young, 1989; cited in Conners, 1992). This limitation results from having subjects respond to rare target events in a task that is so easy that all but the most impaired subjects perform well. In the present study, the low numbers of errors committed by nearly all subjects made an individual's score a questionable diagnostic indicator of inattention or impulsivity since even 1 or 2 errors would lead to a diagnosis of inattention. Error rate, even if it could distinguish the two groups, did not seem capable of discriminating normal from impaired performance with sufficient reliability to be considered clinically useful.

Examination of Figures 2 and 3 shows that 7 of the clinical subjects made between 0 and 2 errors on any of the 4 conditions. Two subjects made between 3 and 6 errors, and 2 subjects made more than 6 errors on any one of the 4 conditions. This distribution of error frequency suggests that most of the clinical subjects made very few errors. In other words, their performance was not markedly different from that of the control subjects. Nevertheless, the performance of 2 subjects was substantially less accurate than the other clinical subjects. Subject 5 missed 45 of a possible 240 targets (18%), and made 40 false alarms. Subject 8 missed 34 (14%) of the targets, and committed 15 false alarms. The performance of these two subjects may have been qualitatively different from the rest of the clinical subjects and will be considered separately below.

In summary, all subjects showed proportionately faster response times on the AX-task compared to the X-task, and thus appeared able to use the "A" in the AX-condition as a cue or warning for a potential target. While this observation suggests that the X/AX performance differences were of little clinical utility, the finding does not necessarily contradict Van Zomeran, who suggested that increasing cognitive load slows response times in brain-injured individuals. The "complex" target in Van Zomeran's studies involved simultaneous presentation of target and distracters, while the SCAT requires attention to only one stimuli at a time, though 2 stimuli need to be processed in succession. This requirement did not differentially slow response times between the mildly- and moderately-impaired clinical groups. One possible explanation is that the cue effect of the AX-target was enough to compensate for any negative influence of having a more "complex" target.

Similarly, error rates and specific types of errors have, though useful in identifying specific attention deficits in children, these measures were not useful with most of the adult brain-injured subjects of this study. As anticipated, the control group made very few errors, rendering the SCAT very sensitive to occasional errors made by individual clinical subjects. In addition, the small number of errors committed prevented analysis of the types of errors made. These problems seriously limited the clinical utility of the error measures in understanding attention difficulties in a population with varying deficit severity.

Performance Over Time

Vigilance decrement. Considering the frequency of complaints of concentration and fatiguability following traumatic brain injury, one might expect to see a deterioration in performance within a test session (referred to as vigilance decrement, presumably reflecting deficits in sustained attention). This possibility was briefly examined.

Administration of the 4 SCAT conditions required a total of 40 minutes, which normally would allow for an assessment of vigilance decrement. However, there were subtle differences among the four SCAT conditions and a brief pause occurred between the conditions. In other words, the SCAT was not truly continuous over a 40 minute period, but only for 4, 10 minute conditions. Despite this feature, each of the 4 conditions was divided into 5 minute blocks and changes in RT, RT variability, and error rates over the course of the test session were sought. There were no dramatic performance changes for all but two of the clinical subjects, who will be discussed separately below. This lack of observable change over time is consistent with previous studies, suggesting that although the performance of brain-injured subjects can be expected to deteriorate over time, the deterioration does not appear to be disproportionate when compared to the performance of normal controls (Parasuraman, Mutter & Molloy, 1991). Parasuraman and colleagues found that during the first month after mild head injury, sustained attention (as measured by vigilance performance) was unimpaired under normal task conditions. Parasuraman suggested that performance decrements might be expected under task conditions that required sustained effortful processing. It is likely that given the simplicity of the SCAT, and the relatively short duration of each condition, that subtle changes in performance over time would not be detectable in the brain-injured group.

Performance deterioration in two exceptional subjects. Two clinical subjects made a large number of errors; in fact, 10 to 20 times the mean number made by the other clinical subjects. One of these subjects had an unusual pattern of RT data, such that response times became markedly longer over the last 15 minutes of the test session. The large number of errors committed by this subject also occurred predominantly in the last 15 minutes of the test session (see Figure 9). Since performance deteriorated over the last 5 minutes of the third condition and in each of the 2 blocks of the fourth condition, (i.e., both within and between conditions), it is unlikely that the change in performance was due to a particular target-type or distraction condition. One possible reason for the performance decrement would be fatigue during the last the last 15 minutes of the test. Sohlberg and Mateer's, theory would consider this to be a failure of "sustained attention deficit." Alternatively, Posner and Rafal (1987) might describe this pattern as a decreased level of overall alertness (tonic arousal), supported by the observation that this subject responded more slowly and less accurately, missing 50% of the targets and making almost as many false alarms as hits, though omissions on the AX-task could also be seen as a failure of phasic arousal.

The second subject identified as having an unusually large number of errors, presented a different pattern of performance over time (see Figure 10). Unlike the previous subject, there was no evidence of a substantial change in RT over time or conditions. Yet this person showed a dramatic increase in errors between 15 and 20 minutes into testing (i.e., the first and second half of the second condition; AX, no distraction). As the session progressed, the numbers of errors increased, and between 25 and 30 minutes (i.e., the second 5 minute block of the third condition), she missed more than 60% of the targets, and falsely responded to 14 non-targets. Given that the numbers of false alarms rose in this period, with no concomitant deterioration in RT, it could be argued that this subject was sacrificing accuracy for the sake of fast response times (e.g., Braun, Daigneault & Champagne, 1989). However, this "speed-accuracy trade off" hypothesis does not account for the increased number of misses made toward the end of the task, given that response times were only recorded for correctly identified targets. Perhaps all that can be said about these two unusual subjects is that one illustrates the interdependence of RT and error rate, while the other illustrates their independence.

Van Zomeran (1981) measured EEG activity during a vigilance task and found that brain-injured subjects showed fewer, rather than more, drowsy intervals than control subjects during the second half of a vigilance task. Van Zomeran argued that this result could be explained in terms of a "coping hypothesis." In other words, brain-injured patients may attempt to compensate for their deficits by expending more effort on the task. By changing this interpretation slightly, it could also be argued that attention deficits are problematic partly because the brain-injured patients do increase the amount of energy expended, leading to earlier fatigue, and sacrifice of response speed or accuracy. This theory might help to explain why brain-injured patients, who have successfully completed a particular task, feel disproportionately fatigued once they have finished. By chance, it was discovered that one subject reported feeling extremely tired and had a headache for the rest of the day following her SCAT session. Such "post-task fatigue" is an area which remains to be thoroughly explored.

Table 4 identified a third clinical subject as having made a larger number of errors than was expected, missing 11 targets and committing 3 false alarms over the course of the 4 conditions. The RT data for this subject did not show either a slowing trend, or a definite pattern of errors (though there were only 14 errors to examine). Although 6 of this subject's 11 errors were made in the last condition, only 1 error was made in the last 5 minute block of the task. Fatigue, leading to inattention, might be a possible explanation in this case, but was not as convincing with this subject.

In summary, although vigilance decrement is an attractive characteristic to examine in the brain-injured patient, neither the current results nor the literature consistently supports such a pattern of performance. Data for 2 of the clinical subjects suggested that the SCAT is capable of detecting decrements in performance, either in accuracy, response times, or both. Such decrements seemed to relate to fatigue that occurred over the course of testing and might be classified as a problem with sustained attention. Each of these subjects was included in the moderately neuropsychologically impaired group, one performing poorly on a variety of neuropsychological measures, and the other identified as impaired on only 2 of the neuropsychological indices. No other particular features, either demographic or injury related, seemed to relate to the tendency to fatigue.

Processing Speed and Attention

As previously discussed, there is overwhelming evidence that brain damage, in any location, tends to slow RT. In cases of diffuse brain-injury this slowing is often the most conspicuous problem and can be observed with a variety of objective tasks requiring speeded performance (e.g., Gronwall, 1977; Brooks, 1984; Tromp & Mulder, 1991; Van Zomeran, 1981). In the group of brain-injured patients involved in the present study, slowed response times were consistently noted across all target and distraction conditions. Response times on the SCAT were significantly greater in the clinical group than in the control group, but differences within the clinical group were even more striking. As expected, patients with moderate neuropsychological impairments performed slower than their lesser-impaired counterparts. Closer inspection of the mean response times for each individual suggested that 4 of the 5 moderately-impaired subjects had response times that were significantly higher than the control mean (see Table 4). Only 1 out of 6 mildly-impaired patients had a RT that was significantly longer than the control group. Thus, the RT index of the SCAT seemed to identify those brain-injured patients who had more serious attentional deficits, consistent with the previous neuropsychological testing.

While slowed RT appeared to be a reasonable marker of brain-injury, it was not sensitive to changes in target-type or distraction. Overall, the clinical group was slower on the X-conditions than the AX-conditions, but there was no evidence of disproportionate slowness on the X-task, compared to the control group. The insensitivity of RT to target-type interactions was evident for both the mildly- and the moderately-impaired clinical subgroups. RT was also insensitive to the presence of the auditory distraction, under all subject groupings.

The slowness in RT that occurs following brain injury cannot simply be explained as the result of sensory or motor impairments, for many studies have controlled for or ruled out this possibility (Van Zomeran & Brouwer, 1987). As the cognitive demands of a RT task are increased, either by using more complicated targets, increasing the amount of simultaneously presented information, or increasing the number of "mental steps" required for a response (e.g., rapid arithmetic manipulations), brain-injured patients demonstrate a disproportionate slowing compared to matched control subjects (Van Zomeran, 1981; Tromp & Mulder, 1991). Such experimental manipulations have been interpreted to suggest that slowed mental processing occurs particularly in the cognitive stages of stimulus encoding and response selection. The more information that is presented, either simultaneously, as in divided attention tasks, or sequentially, as in the SCAT, the more overwhelmed the encoding system becomes. This is reflected as a slowing of RT or, if the system fails to cope with the information quickly enough, a decrease in response accuracy.

The literature also suggests that slowed information processing is particularly evident under conditions where divided attention is required, or where rapid "controlled processing" is required (Van Zomeran & Brouwer, 1987). From the Mateer and Sohlberg (1987) perspective, slowed responding to a simple stimulus (i.e., response to the presence of a stimulus) could be described as a focused attention deficit. Similarly, slowed response to a target appearing within a sequence of non-targets (e.g., the X-task), might be indicative of a selective attention deficit. While the terms "focused-" and "selective-attention deficit" describe some of the brain-injured patients in the present study, it is the slowness that seems to underlie the performance of these individuals. Even under instructions to respond as quickly as possible, most of the clinical subjects could perform reasonably accurately, and if given enough time, they probably would have correctly identify all of the targets. Thus, while the terms selective attention deficit and divided attention deficit may describe the clinical features of the patient, a strong case has been made for slowness being implicated as an underlying feature of attention deficits. The nature of this slowness remains unclear. Whether it reflects a reduction in the physical capacity of the attentional system (i.e., a reduction in the number of input or processing circuits), or the speed with which information can travel through these circuits, remains open to debate.

A physiological explanation for slowness following brain injury has not been widely agreed upon. A general consequence of mild or moderate closed head-injury appears to be the shearing of long fibres (white matter) as the parts of the brain move relative to one another at the moment of impact (Adams, et al, 1982). In more serious cases there may also be axonal damage in the brain stem and contusions of the cortical grey matter. Contusions frequently occur at the poles of the frontal and temporal lobes as these areas compress against the rigid surfaces of the inner skull, leading to neuronal loss in relatively localized areas. However, in reality, contusions rarely happen in isolation of diffuse axonal damage caused by rapid rotation of the head. The nonspecific slowing observed after mild and moderate brain-injury may be related to diffuse lesions of white matter tracts. Van Zomeran and Brouwer (1987) liken this to a decreased signal-to-noise ratio in the central nervous system. They suggest that impairments in cognitive control required in divided attention tasks, or impaired ability to focus (or sustain attention) are probably more typical of patients with local cortical contusions (especially in the frontal cortex) and axonal damage in the brain stem.

In summary, the response times of brain-injured individuals was shown to be a useful index of general impairment. Response times on the SCAT appeared to distinguish between subgroups of clinical subjects and between the moderately-impaired and control subjects, but were not useful in distinguishing the performance of the mildly-impaired subjects to that of the control group. The RT measure was also largely insensitive to the effects of interactions of target type or distraction, on either clinical or control subjects. In other words, RT does not appear to be sensitive to subtle performance deviations that occur with minimally impaired brain-injured patients. RT was also insensitive to performance differences that occur between slight variations on attention tests, even with more seriously impaired individuals.

Response time variability. Although no specific predictions were derived concerning RT variability, certain attentional characteristics are thought to be related to this index. For example, RT variability may be related to the notion of "lapses" in focused or selective attention. It could be hypothesized that attentional lapses are a consequence of the high level of effort made by clinical subjects as they attempt to compensate for deficits; an effort level that cannot be continuously sustained. Momentary declines in attentional performance would not necessarily be identified by decreased mean response times, but may be reflected in RT variability.

In the present study, the variability of RT was found to be significantly greater in the clinical group across all SCAT conditions. However, there was no indication of an interaction between group and auditory distraction condition, or group and target condition. Most of the variability of the clinical group could be attributed to the moderately-impaired clinical subjects (see Figure 6), and a significant difference was shown between the mildly- and moderately-impaired groups. Ironically, the pattern of RT variability was not consistent across the clinical subjects. Some showed a consistent degree of variability across the 4 SCAT conditions, some showed greater variability on the AX-conditions (a main effect suggested that both clinical and control subjects were more variable on the AX-conditions), and subject 8 showed increasing variability of RT over the course of the test session (consistent with the effect of fatigue thought to have influenced the performance of this individual). Table 4 suggests that each individual in the moderately-impaired group was significantly more variable in RT than the control group. However, 3 of the 6 mildly-impaired subjects also demonstrated significant variability. Thus the interpretability of RT variability is somewhat obscure when considered on a group basis, and individual analysis should be undertaken in conjunction with the other SCAT indices.

A final comment regarding RT variability is warranted. Stuss, et al., (1989) have argued that most subjects make some compromise between speed and accuracy, and that this compromise will be influenced by such factors as the individual's response style as well as the particular instructions that they receive or infer from the examiner. Stuss suggested that variability is much less likely than speed to be affected by response sets or expectations. By examining plots of means and standard errors of RT over the course of testing, one may see that brain-injured subjects get systematically slower as time progresses, as subject 8 did in the current sample. If the standard errors are also small, this can indicate that the subject is in fact adjusting his or her pace (speed / accuracy criterion) to the task. With truly inattentive individuals, slower response times and larger variability at the end of the task, rather than the beginning, indicates a loss of vigilance over time. Subject 8 demonstrated an increase in RT variability that was consistent with the increase in RT and the increase in errors. Subject 5, on the other hand, demonstrated relatively constant mean response times throughout the test session, but the variability RT individual's response times became greater toward the end of the session. When considered together for these subjects, RT, RT variability and accuracy seem to implicate a decrement in vigilance, which was likely caused by general fatigue. The point to be taken is that to derive a complete picture of an individual's performance, it is useful to simultaneously consider RT, variability and error indices on a task such as the SCAT.

Concluding Remarks

The primary question of interest in this study was whether the SCAT could identify attention deficits in traumatically brain-injured adults. Certain indices of the SCAT, particularly RT, seemed to distinguish between brain-injured patients and control subjects, and between mildly and moderately neuropsychologically impaired brain-injured patients on a group by group, but not a case by case basis. Futhermore, the SCAT did not distinguish the mildly-impaired patients from control subjects. However, this group of mildy-impaired patients is particularly problematic when it comes to neuropsychological assessment because most neuropsychological measures do not identify them as having attention difficulties, even though they report experiencing difficulties with concentration and attention, and have been selected to participate in the Attention Process Training Program. It is possible that such patients experience very subtle deficits ("minimal brain dysfunction"), to which the SCAT and other measures are insensitive. Alternatively they may experience cognitive difficulties of a different nature than has been traditionally examined by neuropsychologists. It is also possible that they suffer no more from attentional difficulties than the rest of the normal population. Perhaps in future studies it would be useful to examine the relationship between subjective complaint of attentional deficit and the actual performance on neuropsychological measures.

While the RT measures of the SCAT were sensitive to differences between the moderately-impaired brain-injured patients and normal control subjects, measures of performance accuracy were not particularly discriminating, making it difficult to comment on specific deficits in selectivity such as inattention or impulsivity. Occurrence of 2 or 3 errors over the course of the 40 minute test administration could be considered sufficiently outside the distribution of normal responding, but based on the narrow margin for random responses, the potential for false identification of an attention disturbance could be problematic. While certain brain-injured subjects with more serious neuropsychological deficits performed less accurately on the SCAT, it was not entirely clear that the primary concern was one of impaired selectivity, as opposed to a general decline in performance over time, perhaps due to impaired arousal. Thus, as a group, the clinical subjects did not appear to be more impulsive, or inattentive, at least as described by response accuracy measures.

While the problem of low error rates was anticipated, the addition of a simple (information-free) auditory distraction to the task did little to increase the number of errors and thereby provided no new information about the distractibility (or lack thereof) in the clinical subjects studied. Although there are undoubtedly better ways of assessing distractibility, it appears that deficits in selectivity, especially cross-modal selectivity, are not of primary importance in brain-injured individuals. Manipulation of the processing demands of the SCAT, by changing the nature of the target, modifying the distraction (e.g., more intrusive auditory or visual distractions), or changing the task requirements (e.g., presentation of simultaneous stimuli requiring selective or divided attention), could potentially increase the numbers of errors demonstrated by clinical and normal subjects, making more meaningful analysis possible. However, given the problems with ceiling effects, the clinical and experimental value of such an endeavour utilizing the SCAT is questionable.

RT and RT variability on the SCAT were noted to be sensitive to the effects of brain-injury, and RT is frequently used to identify deficits in attention. However, as a clinical tool, one must question the value of administering a prolonged task such as the SCAT when the same data could be collected in a much shorter period of time. In certain cases, it may be of clinical interest to determine the ability of a patient to sustain their performance over time, and a tool such as the SCAT may be useful to this end. From the data collected, patients must be experiencing more "significant" cognitive difficulties before deficits in the ability to sustain performance begin to appear. Even in the group of moderately-impaired subjects, difficulties with sustained attention did not seem to be the norm. Thus, a shorter task, capable of accurately measuring RT, would be of equal or greater value as an assessment technique for the majority of injuries of mild to moderate severity.

From a theoretical standpoint, emphasis has been placed on the role that processing speed and cognitive load play in the performance of brain-injured persons (Van Zomeran, 1981). The fact that cognitive load and speed of processing are intimately connected is crucial. Theoretical explanations and neuropsychological measures of attention should be considered in terms of what the subject is required to process, and the effect of slowed processing speed on performance. For example, from the Sohlberg and Mateer perspective, focused attention deficits could derive from a very serious decrement in processing speed, particularly with short duration stimuli. Selective attention deficits might occur if the subject is unable to quickly make decisions about target-distracter distinctions or from the ability to process the target only enough to ignore it, then return to the task at hand. Alternating attention deficits could result from an inability to quickly encode, process and store information, switch to a secondary task, quickly encode, processes and store, then return to the original task. Finally, divided attention deficits could be considered as a reduction in the rate that each of the two tasks can be simultaneously managed. When slowness becomes an issue, subjects must devote more conscious and controlled processing to each task they are attending to (versus automatic and quick processing), which leads to an overall deterioration in performance. On the SCAT, processing requirements were not excessive and most of the brain-injured subjects were able to cope with the task requirements (with some slowing and decreased accuracy). In essence, the association of the SCAT indices to the theoretical descriptions of attention problems was unsubstantiated due to the relative poor resolution of response accuracy, and the failure of the mildly impaired subjects to perform differently from controls in terms of response time. Thus, while the SCAT has been demonstrated to be a useful neuropsychological instrument in the assessment of children (Seidel & Joschko, 1991), its relatively poor sensitivity seriously limits its theoretical and clinical usefulness in for use with adult brain-injured patients.

The frustrating problem of research in the area of traumatically brain-injured persons is that we often know relatively little about the anatomy of their injury or about the specific nature of their impairments. Yet, in some way, damage caused by the traumatic event frequently disrupts their lives by reducing their ability to concentrate, causing them to ignore events, or by impairing them in other ways which might be described as reduced attention (Posner & Rafal, 1987). From a general cognitive framework, the present research suggests that we should not view any cognitive task as a whole but consider the elementary mental operations needed to perform that task. In addition, clinicians need to show sensitivity to the subjective complaints of their patients and consider potential moderating factors when interpreting performance on the cognitive tasks used to assess attention and other deficits. Further research into the relationship between subjective complaints and objective measures of attention, distractibility and learning could enhance the clinical utility of both subjective and objective measures. It is this type of multi-level analysis that will be of most use to the patient, the family and clinical practitioners in predicting the patient's ability to function.

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Appendix A: Continuous Performance Test Administration Instructions

Modified from SCAT Administration Instructions (Seidel, 1988).

Subjects are seated comfortably with their dominant hand (writing hand) and arm resting table top at approximately two inches below their elbow. Screen brightness and contrast are adjusted to a comfortable level and the screen is placed approximately two feet from the subject. The subject is told to rest their index finger on the space bar, but is not to depress the space bar until appropriate. Examiner should sit out of view of the subject during testing, but beside the subject for provision of instructions. The following instructions are given in the appropriate order, depending on the counterbalanced condition and can be modified if necessary.

X-task

Select the X-task on the menu and input the subject information. Gently cover the keyboard.

(Display Letters). "Before we begin, I want you to tell me the names of all the letters here on the screen; start with this one" (point to the letter 'A' and allow the subject to read on or continue to point sequentially at all of the letters. If there are any letters misread or unknown, note this and then call out the letters in the following order: "Z, C, H, A, X, E, Q, P, K, U, S" requiring the subject to correctly point to the letter named. If they are unable to identify all of the letters, discontinue testing.

"Now the computer will present one of these letters at a time in the center of the screen and if it is the letter 'X'" (point) "I want you to press the space bar all the way down as fast as you can. If it is any other letter just keep your finger resting lightly on the space bar. Remember only press the space bar if it's the letter 'X' and as fast as you can. Then rest your finger on the bar and wait for the next letter. Okay? Let's try some practice."

(Continue with the practice letters. During practice immediately point out any incorrect responses and missed targets.)

After practice read aloud the feedback screen. (If the subject responded to all the 'X's and responded no more than 1 time to a non-'X', begin the task; otherwise repeat the practice. If after 3 practice sessions the subject continues to fail, but appears to understand the test, (e.g. can state the task requirements) continue testing; otherwise discontinue testing.

(After practice). "Now we are ready to begin. Remember to press the space bar all the way down and as fast as you can, but only if you see the letter 'X'. Also remember to try and keep your finger lightly on the space bar at all other times. There will be lots of letters so try to keep your eyes on the screen and try not to talk until we are finished. I will answer any further questions then. Are you ready? Let's begin." (Start the task).

During the task if the subject is obviously not looking at the screen remind them to do so, but only twice. If this continues frequently after the reminders make a note of this. If the subject talks during the task instruct him/her to continue with the task and that you will answer their questions after it is over.

AX-task

Select AX-task on the menu and input the subject information. Gently cover the keyboard if not already done so.

"Now you are going to do something that is a little different than before." (Display letters). "The computer is still going to put one of these letters on the screen at a time, but this time only press the space bar if you see the letter 'X' if the letter 'A' was right before it. So I want you to wait until you see the letters 'A' and then 'X' right after each other in that order, then press the space bar all the way down and as fast as you can. Remember to keep your finger lightly on the space bar at all other times. Let's try some practice" (begin presentation of practice letters).

(Again during practice point out any incorrect responses and missed targets.)

After practice read aloud the feedback screen output. (If the subject responded to all the 'A-X's and responded no more than 1 time to non 'A-X's begin the task; otherwise repeat the practice. If after 3 practice sessions the subject continues to fail, but appears to understand the test, (e.g., can state the task requirements) continue testing; otherwise discontinue testing.

(After practice). "We are now ready to begin. Remember to press the space bar all the way down and as fast as you can, but only after you have seen the letters 'A' and then 'X' in that order. Remember there will be lots of letters so try to keep your eyes on the screen and try not to talk until we are finished. I will answer any further questions then. Are you ready? Then let's begin.

During the task if the subject is obviously not looking at the screen remind them of this, but only twice. If this continues frequently after the reminders make a note of this. If the subject talks during the task instruct him/her to continue playing the game and that you will answer their questions after it is over.

<u>Distracter Conditions</u>

Select appropriate distracter task (XD or AXD) from the menu and input the subject information.

Instructions for the XD and the AXD conditions are the same as for the X and AX conditions, with additional mention made for auditory component.

"In addition to responding to the appropriate letters on the screen, you will hear some letters played through the head phones. Try to ignore those letters, and press the space bar only when you see an 'X' (or 'X' preceded by an 'A'). Do not respond when you hear the letter 'X' (or 'X' preceded by an 'A')."

Subjects are provided practice trials for those conditions in which they are first exposed to a target type. For example, for a subject receiving the X, AX, XD, AXD task order, practice trials are only provided for the X and AX conditions. Similarly for the subject receiving the XD, AXD, X, AX presentation order, practice trials are only provided for the XD, and AXD. In this case, the distracter tape is not played during the practice trials. SCAT Administration Instructions (From: Seidel, 1988).

Appendix B: Brief Description of Neuropsychological Tests Included

D2 Test (Brickenkamp, 1981)

This paper and pencil cancellation test is designed to assess sustained attention and visual scanning ability. It is composed of 14 lines of letters with a target consisting of the letter "d" with two marks above, below, or one mark above and one mark below. Distracters consist of the letter "p" with one to four marks and the letter "d" with one mark. The examinee is to mark as many target letters per line as is possible within 20 seconds. Scores include of total number of letters considered (regardless of errors), errors of omission, errors of commission, percentage of errors, as well as the distribution of errors. This test has good reliability and validity, and correlates with only the Digit Symbol test of the WAIS-R, suggesting that it is relatively independent of factors normally associated with intelligence. This test does not tend to load on factors of motor speed, motor coordination or motor discrimination (Brickenkamp, 1981; cited in Strauss & Spreen, 1991).

Paced Auditory Serial Addition Task (PASAT; Gronwall, 1977)

Described in detail in the introduction section of this thesis.

Stroop Test (Golden, 1976)

This test measures the ease with which a person can rapidly shift perceptual set to conform to changing task demands as well as suppress automatic forms of response in favour of an unusual one. The test requires the examinee to rapidly read a list of words (Word-Condition), rapidly name coloured letters (Colour-Condition) and rapidly name the ink colour of colour-words (Colour-Word-Condition; e.g., name the ink colour in which the word "RED" is printed). Of particular interest is the response behaviours when examinees are presented with colour-words printed in mismatched ink (known as the Stroop interference effect). In the Golden (1976) version of the Stroop test, subjects are required to process as many stimulus elements as possible within a 45 second time limit. The number of correct responses, as well as errors are recorded for each of the three conditions. Golden reported that the test is effective in distinguishing between normal control and brain-damaged patients. The interference effect is particularly salient in patients with left-frontal lobe damage as compared to normals and other brain damaged patients (Regard, 1981). Age and measured IQ appear to contribute to Stroop Test performance.

Trail Making Test (Reitan & Wolfson, 1985)

This paper and pencil task is designed to assess the ease with which a person can shift perceptual set to conform to changing task demands. It also relies on psychomotor speed and rapid visual search. Part A of this test requires examinees to connect 25 encircled numbers randomly arranged on an 8.5 X 11 inch page. Part B requires connection of numbers and letters, in alternating order. This test does not correlate with verbal tests (Ehrenstein, et al., 1982; cited in Strauss & Spreen, 1991) and is highly sensitive to brain damage (desRosiers & Kavanaugh, 1987). Scores on Trails B appear to be more sensitive to brain dysfunction, as they require more information processing than trails A. Scores are highly correlated with level of education and an educational adjustment is usually applied to raw scores.

Wechsler Adult Intelligence Scale - Revised (WAIS-R; Wechsler, 1981)

Arithmetic Subtest:

This test includes 14 orally presented, timed arithmetic "story" problems and is thought to measure arithmetic reasoning, ability to comprehend verbal instructions, concentration and freedom from distractibility. This test is influenced by level of education.

Digit Span Subtest:

This test measures memory for series of digits, forward and backward, increasing in length up to 7 digits. Digit span is thought to be related to auditory recall, attention, and freedom from distractibility.

Digit Symbol Subtest:

This test requires examinees to mark, in a series of boxes, symbols presented in association with the numbers 1 through 9. It measures speed and accuracy, ability to learn an unfamiliar task, and visuo-motor dexterity.

Wechsler Memory Scale-Revised (WMS-R; Wechsler, 1987)

Attention / Concentration Index:

Consists of the Mental Control, Digit Span and Visual Memory Span subtests of the WMS-R. Digit Span is identical to Digit Span described in the context of the WAIS-R. The Mental Control subtest of the WMS-R requires verbal production of the alphabet, and counting backwards from 100 by 3's. This subtest gives a crude index of mental flexibility. The Visual Memory Span test is similar to the digit span task, with the exception that stimuli consist of .5 inch squares randomly placed on a 5.5 X 8.5 inch card. The examiner points to a series of the squares, and requests the examinee to point to the same squares, in the same order (Visual Span Forward). In the Backwards condition, examinees are asked to point to the same squares as the examiner, but in the reverse order.

The Attention / Concentration Index was derived by performing a principle component analysis on the entire standardization sample for the WMS-R. With the effects of age partialled out, the analyis yeilded two factors: a general memory and learning factor, and a attention/concentration factor. No studies specifically relating the clinical utility of the attention/concentration factor of the WMS-R to brain injury were reviewed. However, several studies cited by Wechsler (1987) suggest that brain injured patients display depressed scores on all of the subscales of the WMS-R.

Appendix C: Informed Consent Form

CONSENT FORM FOR PARTICIPATION IN THE STUDY ENTITLED
"Assessment of Attention Deficits in Closed-Head-injured Patients
Using Computerized Attention Tasks."

I understand that the purpose of the present study is to evaluate the usefulness of two computerized attention tasks in determining the presence and nature of attention problems in persons who have suffered a closed head injury. Each of these tasks requires detection of certain letters and numbers that are presented on a computer screen, and I will be required to respond by quickly pressing the space bar on the computer key pad. I understand that there are several similar tasks, each of which will be explained to me by the examiner. These tasks take approximately 1 hour to complete. I understand that the researcher will review data from my neuropsychological assessment file, and that approval to do so has been granted by Dr. Hern, and the Greater Victoria Hospital Society research approval committee.

I understand that my participation is completely voluntary and that I am free to withdraw from this study at any time, without explanation. I also recognize that I will be paid an honorarium of $10.00 for my participation.

Any data collected in this study will remain strictly confidential. Furthermore, my name will not be attached to any published results, and my anonymity will be protected by using a code number to identify my results.

I understand that whether I choose to participate or choose not to participate will have no bearing on my status within the rehabilitation program and will not be used to grade or assess my progress in any way.

I understand that this research has been approved by the University of Victoria Committee on Research and Other Activities Involving Human Subjects, and by the Research Approval Committee of the Greater Victoria Hospital Society. I understand that there are no foreseen risks involved with this study, but if I have any complaints, I may submit them to either of above mentioned committees.

Date:_____________________

Signature: _____________________

Experimenter:_____________________

Appendix D: Subject Debriefing Form

Assessment of Attention Deficits in Closed Head-injured Patients
Using Computerized Attention Tasks

The study that you have participated was designed to evaluate the usefulness of two computerized attention tasks in determining the presence and nature of attention problems in persons who have suffered a closed head injury.

The first task, called the Seidel Computerized Attention Task or SCAT, looks at a person's ability to sustain attention for an extended period of time. Staying alert and being able to pick out specific letters, or combinations of letters requires a degree of attentional effort. This kind of attention is used every day for a variety of long and tedious tasks. It is expected that over the course of the session, a person's level of attention will decrease. The SCAT considers both the accuracy and the speed of the person's response. Generally, both of these get poorer as the task progresses. Having a person look first for Xs, and then for A-X combinations, makes the task a bit more difficult, and looks at characteristics such as how impulsive a person's response might be, or the ability to not respond.

The second set of tasks is called the California Comprehensive Assessment Program, or CalCAP. The CalCAP tasks are much like those of the SCAT, but are presented more quickly, and require a higher degree of concentration. Some of the subtests look at the ability to respond to a single item, such as the number '7', and some of these tasks are quite difficult, such as responding when 2 of 3 forms are the same. These tasks also look at other features such as language ability, and ability to quickly look at different parts of the screen. As with the SCAT, the person's responses on the CalCAP tasks are looked at for accuracy and speed of response. Again, many of the types of attention that the CalCAP is designed to assess, are important in the real world.

The SCAT and the CalCAP have not previously been used with persons who have sustained a head injury. It is important to continually look for new ways of assessing cognitive deficits in this group of individuals. The results from these tasks will be compared to performance on other measures of attention to see if they are measuring the same process. This comparison will also provide a clearer understanding of the nature of attention. It is felt that attention is an common and extremely important problem in head-injured patients. Memory problems, problems following along in a conversation, or doing two tasks at once, may all be the result of an underlying attention problem. For that reason, it is important to clearly understand both intact and damaged attention abilities.

Since attention appears to be such an important part of everyday functioning, and an important part of other cognitive abilities (concentrating, remembering, listening, etc.), it is hoped that these tasks will be useful for tracking progress of people who have sustained a head injury.

Thank you for taking the time to participate in this study, and if you have any further questions about the study or the results, do not hesitate to ask the examiner, or myself.

Jim Sawchyn , University of Victoria, 721-7564

Vita

Surname: Sawchyn	Given Names: James Matthew
Place of Birth: Saskatoon, Canada	Date of Birth: December 13, 1969

Educational Institutions Attended:

University of Victoria	1992-1995
University of Saskatchewan	1987-1991

Degrees Awarded:

B.A. (Honours)	University of Saskatchewan	1991

Honours and Awards:

Natural Sciences and Engineering Research Council (PGS-A)	1992-94
University of Victoria President's Scholarship	1992-94
University of Saskatchewan Undergraduate Scholarship	1990-91