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Performance on the Test of Everyday Attention and Standard Tests of Attention following Severe Traumatic Brain Injury*

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ABSTRACT

The Test of Everyday Attention (TEA) was designed to address some of the limitations of established measures of attention. However, very few studies have examined its clinical utility. A group of 35 patients who had sustained a severe TBI were compared with 35 age- and education-matched controls on the TEA, Stroop, SDMT, WMS-R Digit Span, Ruff 2s and 7s Selective Attention Test, and PASAT. Of the TEA subtests, only the Map and Telephone Search subtests of the TEA produced significant differences between the two groups, suggesting a deficit in visual selective attention following TBI. Principal components analysis revealed a four-component / factor structure of attention, largely consistent with previous studies. A logistic regression found that the TEA Map Search and Modified Colour-Word subtest of the Stroop were best able to discriminate between the TBI and control groups. When the TBI group was divided into Early (<1 year post injury) and Late (>2 years post injury) groups, there was an additional deficit on the Lottery (sustained attention) subtest in the Early TBI group, indicating that there is some recovery in attentional function beyond 1 year post injury.

Difficulties with attention are frequently reported by individuals who have suffered traumatic brain injuries (TBI) (McKinlay, Brooks, Bond, Martinage, & Marshall 1981; van Zomeren & van den Berg, 1985; Zoccolotti et al., 2000). These difficulties have a major impact upon recovery and rehabilitation and are characterised by increased distractibility (Schmitter-Edgecombe & Kibby, 1998), a tendency to become overloaded when dealing with more than one thought at a time (Lezak, 1995), and difficulties with staying 'on task' (Whyte, Schuster, Polansky, Adams, & Coslett, 2000). Research examining attention following TBI has, in most instances, used the behavioural / task level typology of focussed, divided, and sustained attention, with numerous studies finding deficits in each of these areas following severe TBI (Godefroy, Lhullier, & Rousseaux, 1996; Hartman, Pickering, & Wilson, 1992; Loken, Thornton, Otto, & Long, 1995; Stuss, Pogue, Buckle, & Bondar, 1994; Whyte, Polansky, Fleming, Coslett, & Cavullucci, 1995). However, there are also studies that have questioned whether these findings reflect reduced

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speed of information processing rather than genuine deficits in attention (Ponsford & Kinsella, 1992; Spikman, van Zomeren, & Deelman, 1996; van Zomeren & Brouwer, 1987). In addition, only modest correlations have been found between established tests of attention and both the reports of patients and their significant others (Ponsford & Kinsella, 1991). Thus, there have been continuing problems with the assessment of attention following TBI.

A number of limitations have been identified with established measures of attention which may be contributing to these problems, namely, their multifactorial nature, poor ecological validity, and lack of theoretical basis. First, the multifactorial nature of many established tests of attention is a significant confound in the interpretation of the results that are obtained from these measures. Many of these tests rely upon the mental manipulation of complicated verbal or mathematical concepts, as well as making significant demands upon short-term memory (Sohlberg & Mateer, 1989). For example, although the Symbol Digit Modalities Test (SDMT; Smith, 1973), has been used as a test of divided attention (Ponsford & Kinsella, 1992), it also requires complex visual scanning and tracking abilities (Shum, McFarland, & Bain, 1990), in addition to motor speed and memory (Lezak, 1995). Similarly, the Paced Auditory Serial Addition Test (PASAT; Gronwall, 1977), often cited as a measure of divided attention (Kinsella, 1998; van Zomeren & Brouwer, 1987), relies heavily upon speed of information processing (Ponsford & Kinsella, 1992). Thus, where deficits in 'attention' have been found on established neuropsychological measures, it has been difficult to determine whether these deficits are the result of problems with specific attentional processes or the other cognitive processes that are also involved in these tasks. In fact, a number of studies that have used a range of tests such as the Stroop (Golden, 1978; Stroop, 1935), SDMT (Smith, 1973), PASAT (Gronwall & Sampson, 1974), and Letter Cancellation Tasks (Ponsford & Kinsella, 1992), have failed to find any specific attentional deficits in persons who have sustained a TBI. Instead, they have concluded that these deficits can be explained solely in terms of a reduced speed of information processing (Ponsford & Kinsella,1992; Spikman et al., 1996).

The failure of established tests of attention to correlate either with the subjective reports of individuals with TBI or their carers has sometimes been attributed to the fact that many of these tests lack ecological validity (Kerns & Mateer, 1998). Ecological validity refers to the ability of the assessment task to 'mimic' the types of tasks that individuals are faced with in their everyday life and is particularly important in the rehabilitation context. Sloan and Ponsford (1995) argue that current measures of attention are not sufficiently sensitive to assess the various aspects of attention involved in everyday life. They suggest that some attentional problems may only become apparent in more complex and less structured 'real world' settings, and over longer periods of time, than are provided in conventional assessment situations. Indeed, Kerns and Mateer (1998) state that "... psychometric assessment systematically reduces just those variables that challenge attentional resources and capacities in real life situations" (p. 165). Ecologically valid tests that assess attention in more demanding situations are therefore needed.

Another concern with established measures of attention is that the majority of them are not based on any particular theory of attention (Sohlberg & Mateer, 1989). To date, attention has largely been investigated within the clinical literature at the task / behavioural level typology of focussed, divided, and sustained attention. Such an approach, however, is not based upon any particular theory of attention, as evidenced by the fact that what one author regards as a test of selective attention is considered by another to be a measure of sustained attention (Shum et al., 1990). The absence of clear links between an attentional model and assessment measures is hardly surprising given that, until recently, there was little consensus regarding the basic features of any theory of attention within the literature. However, recent developments, based mainly upon the findings of neuroimaging and lesion studies of Posner and colleagues (Posner, Cohen, & Rafal, 1982; Posner, Inhoff, Friedrich & Cohen, 1987; Posner, Walker, Friedrich, & Rafal, 1984), have culminated in a model of attention that is now being utilised in the development of both clinical and experimental measures of attention (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994, 1996). According to Posner and Peterson (1990), this model, consists of at least three separate attentional systems; a *selection* or *executive* system responsible for selecting relevant stimuli and inhibiting irrelevant ones, a *vigilance* system responsible for maintaining readiness to respond, and an *orientation* system, responsible for engaging, moving and disengaging attention. While Posner (1980) has developed the Covert Orienting of Attention Task (COAT) task to assess the orientation system of his model of attention, he has not addressed the selection or vigilance systems. However, the emergence of this model, along with a growing awareness of the limitations of current neuropsychological measures when predicting attentional function in everyday life (Sbordone, 1998), has resulted in a move towards the development of theoretically-based and ecologically valid assessment procedures that are suitable for use in clinical practice (Hart & Hayden, 1986).

The Test of Everyday Attention (TEA; Robertson et al., 1994) is a primary example of such a test. This test was based upon Posner and Peterson's (1990) model of attention, and includes subtests designed to assess the *selection* and *vigilance* systems identified within this model. Moreover, the content involves more ecologically valid tasks and incorporates relatively familiar materials or concepts, such as maps and telephone directories. Kinsella (1998), in a review of the literature on the assessment of attention following TBI, suggests that the TEA offers a much needed addition to the range of assessment tasks available to the clinician. Of particular importance, is that the TEA includes a dual task condition. Robertson (1995) has highlighted the importance of including dual task conditions within the assessment of attention, suggesting that such conditions have the potential to 'unmask' attentional deficits that would otherwise go undetected. More recently, Crawford, Sommerville, and Robertson (1997) have extended the clinical utility of the TEA by providing methods for analysing individual subtest profiles.

Following the development of the TEA, Robertson et al. (1994; 1996) carried out a principal components analysis of both the TEA and a range of established neuropsychological tests (Stroop, Trails B, Wisconsin Card Sorting Test, Backward Digit Span, d2 Cancellation Task, PASAT) in order to identify the factors that may underlie these measures. This analysis was based on a group of 154 healthy controls and revealed the factors of *visual selective attention/speed*, *attentional switching*, *sustained attention*, and *auditory–verbal working memory*, each of which were defined by specific subtests of the TEA and established tests of attention (Robertson et al., 1994). Furthermore, Robertson et al. (1994) concluded that the factor structure of the TEA accords well with the Posner and Peterson's (1990) model of attention, with the *visual selective / speed*, *attentional switching*, and *auditory–verbal working memory* factors equating to Posner's selection system, and the *sustained attention* factor equating to Posner's vigilance system (Robertson et al., 1994).

In a subsequent study, Robertson et al. (1996) compared groups of patients with stroke, early Alzheimer's disease, progressive supraneuclear palsy, and moderate and severe TBI, with their normative sample. Of particular relevance here is the fact that they compared a group of 15 moderate and severe TBI subjects ($M = 14.6$ months post injury) with their normative sample. The moderate to severe TBI group performed significantly worse than controls on the Map Search, Telephone Search, Telephone Search While Counting, and Lottery subtests. These findings were taken by Robertson et al. (1996) to provide evidence of selective and sustained attentional problems in individuals with TBI.

Despite the potential benefits of the TEA over other tests of attention, there have been surprisingly few other studies that have examined the performance of TBI groups on the TEA or compared it to other tests of attention. In fact, the only known published papers come from the work of Chan and colleagues (Chan, Lee, & Hoosain, 1999; Chan, 2000) who, using a Cantonese version of the TEA, claimed to replicate the four-factor structure reported by Robertson et al. (1994, 1996) in a sample of 49 normal controls. However, while the subtests that constituted the first factor were essentially the same as those in the Robertson et al. (1994, 1996) analysis, there were noticeable differences in the subtests that constituted the remaining three factors (details of these differences are provided in a table within the discussion). Of particular note was the fourth factor, which Chan et al. (1999) termed *divided attention*. However, the Telephone Search While Counting subtest (dual task decrement) was the only test that loaded on this factor, which raises some concerns about the interpretation of this factor. In a subsequent study Chan (2000) found a group of 21 mild-moderate TBI subjects ($M = 41.4$ months post injury) to be impaired, relative to controls, on the majority of TEA subtests. It was concluded from this study that the TEA was able to identify problems with *sustained*, *selective*, and *divided attention*, and *attentional* switching within the mild-moderate TBI population. Of note, however, is the fact that the Chan (2000) study was based on a sample who specifically presented with subjective complaints of attentional difficulties in their day to day lives.

While there has been an increasing focus upon the difficulties associated with established tests of attention, it has also been suggested that attentional deficits may be hidden by the averaging of group data and that we should not treat TBI as an homogenous group, as is done in many research designs (Zoccolotti et al., 2000). Often, studies will include subjects who are 6–12 months post injury and who, are therefore, still likely to be within a more active phase of recovery and rehabilitation, with subjects who may be 2 or more years post injury. It is generally accepted that the majority of recovery following TBI occurs within the first 6 months post injury and that recovery tends to plateau within the second year (Lezak, 1995; Sbordone, Liter, & Pettler-Jennings, 1995). Therefore, in order to address this issue of time-since-injury, the current study, in addition to comparing TBI and Control groups, further divided the TBI group into two distinct groups in terms of time since injury. It was felt that such a division would provide important additional information relating to the persistence of attentional deficits following TBI. Differences between early TBI and Control subjects may otherwise go undetected when treating TBI subjects as an homogenous sample.

To summarise, there are significant limitations with established measures of attention, particularly in terms of their ecological validity and theoretical basis. The TEA, however, seems to hold some promise as an assessment measure, not only because it has attempted to address issues of ecological validity but because it is also one of the few, if not the only, clinical test that has been built upon a specific model of attention. It is, therefore, surprising that the TEA has not received more prominence in the research literature, particularly in terms of evaluating its efficacy as a complimentary or alternative instrument in the assessment of attention following TBI. As a result, the present study examined the attentional deficits of a group of persons who had sustained a severe TBI using both the TEA and a range of established tests of attention (i.e., Stroop, SDMT, Digit Span, Ruff 2s and 7s Test of Selective Attention, PASAT). The aims of this study were to (1) examine the ability of the TEA and a range of established tests of attention to detect specific (i.e., focussed, divided, sustained) attentional deficits following TBI; (2) examine the relationship between the TEA and these more established measures of attention, and in particular the factor structure underlying these measures; (3) determine which measure, or combination of measures, best discriminated between the two groups; and (4) determine whether there are differences in the attentional deficits of persons who are in the early and late stages of recovery following a TBI.

METHOD

Participants

A group of 35 participants with severe non-penetrating TBIs and 35 controls took part in this study. Demographic and clinical data for these groups are displayed in Table 1. TBI participants were recruited from consecutive admissions, over a 3-year period, to a multidisciplinary outpatient rehabilitation program. Severity of injury was classified by the lowest recorded Glasgow Coma Scale (Teasdale & Jennett, 1974) in the first 24 hr post injury [GCS < 8] and/or a Post-Traumatic

Table 1. Means and Standard Deviations for Demographic and Clinical Data for the TBI and Control Groups.

	TBI	Controls	Early TBI < 12 months since injury	Late TBI > 24 months since injury
N	35	35	21	14
Age (years)	28.9 (11.5)	30.2 (10.3)	26.8 (10.4)	32.0 (12.7)
Gender				
Male	28	20	18	10
Female	7	15	3	4
Education (years)	12.0 (1.5)	12.6 (2.0)	12.1 (1.4)	11.9 (1.6)
Premorbid IQ estimate (NART–R)	95.4 (8.6)**	101.1 (9.1)	95.0 (8.6)	95.4 (9.0)
Glasgow Coma Scale	5.7 (3.1)		5.3 (2.8)	6.7 (3.8)
Post-traumatic amnesia (days)	43.2 (37.9)		44.4 (43.4)	40.4 (23.4)
Time since injury (days)	833.3 (990.3)		235.5 (94.2)	1729.9 (1052.8)

$^{**} = p < .01$ TBI vs. Control Group comparison.

Amnesia period of > 24 hr (Julia Farr Post-Traumatic Amnesia Scale; Forrester & Geffen, 1995). Where JF-PTA scores were not available, retrospective reports were used. The results of CT scans were available for 33 of the 35 TBI participants. Of the CT scans available, 24 detected some form of frontal lobe pathology. Of the remaining 9 participants, temporo-parietal pathology was detected in 3 participants, thalamic pathology in 2 participants, basal ganglia pathology in 1 participant and, a diagnosis of 'assumed' diffuse axonal injury in 3 participants. TBI participants varied in terms of time since injury, enabling them to be divided into two distinct groups, with 21 participants being within 1 year post injury and 14 participants being at least 2 years post injury. Demographic data for these groups are also provided in Table 1.

The 35 control participants were individually matched to the TBI sample on the basis of age, and years of education. Participants with a history of major psychiatric disorder, intellectual disability, or other neurological disorders were excluded from the study, as were those who had a hemiplegia of their dominant hand, whose native language was not English, or who had a documented history of substance abuse.

Tasks

Test of Everyday Attention (TEA)

Map Search. This is a test of visual selective attention in which participants are required to search for designated symbols on a coloured map for a 2-min period (Robertson, Ward, Ridgeway, & Nimmo-Smith 1994). The score is the number of symbols found within a 2-min period (maximum possible score is 80).

Elevator Counting. In this test of sustained attention, participants are asked to imagine that they are in an elevator whose floor-indicator is not functioning. They, therefore, have to establish which 'floor' they have arrived at by counting a series of tape-recorded tones. Seven strings of tones are presented, with the subject's score indicating the number of strings correctly counted (maximum score = 7).

Elevator Counting with Distraction. This task, in addition to involving auditory selective attention, also draws upon auditory-verbal working memory. Participants have to count the same pitched tones that were used in the last subtest but this time they have to ignore the interspersed high pitch tones which have been introduced as distractors. Once again, the score indicates the number of strings counted correctly, giving scores ranging from 0 to 10.

Visual Elevator. The Visual Elevator subtest is considered to be a measure of attentional switching. Participants are asked to count a series of drawings of elevator doors that are presented in rows on the pages of a presentation booklet. The task is self-paced. The drawings of the elevator doors are interspersed with large up- or down-pointing arrows, indicating that the direction of counting should change in line with the arrow (i.e., up or down). Two separate scores are derived from this subtest: the first score represents the number of visual strings counted correctly (maximum score = 10), while the second score is a timing score calculated by dividing the total time taken for the correct items by the total number of switches for the correct items. Lower values represent a superior performance to higher values on this timing score.

Auditory Elevator with Reversal. This task is also a measure of attentional switching and is presented at a fixed speed on audio tape. Participants are required to count strings of 'medium' pitched tones. Interspersed with these 'medium' pitched tones are both high (indicating that the subject must switch to counting up) and low tones (indicating that the subject must switch to counting down). The score represents the number of strings of tones counted correctly (maximum = 10).

Telephone Search. This is a visual selective attention task in which participants must look for designated key symbols and ignore other symbols, while searching entries in a simulated classified telephone directory. The score is calculated by dividing the total time taken by the number of symbols detected. The maximum number of symbols that can be detected is 20. Lower values represent a superior performance to higher values on this subtest.

Telephone Search (Dual Task). While this task loaded on the sustained attention factor in the factor analysis of Robertson et al. (1994), it is also considered a measure of divided attention (Chan, 2000). In this task, the subject must again search the telephone directory while simultaneously counting strings of tones presented by a tape recorder. This subtest yields a 'dual task decrement' score which is calculated by subtracting the time per target score of the previous subtest from the time per target score on the current subtest, which has been weighted for accuracy of tone counting. Lower and negative values represent a superior performance to higher values on this subtest.

Lottery. In this subtest, which is considered to be a measure of sustained attention, the subject listens to a series of numbers presented by a tape recorder. All numbers are in the form of two letters followed by three numbers. Participants are instructed to write down the two letters preceding all numbers that end in 55. These are considered 'winning' numbers. There are 10 'winning' numbers randomly included during the 10-min presentation. The participants score is the number of correctly recorded numbers (maximum = 10).

Stroop Colour Word Test (including Bohnen modified subtest)

The Stroop is mainly considered to be a measure of selective attention (Lowe & Mitterer, 1982). The test is made up of four subtests (Bohnen et al., 1992; Golden, 1978). First, the subject is asked to read aloud 100 randomized colour names, printed in black type on a card (e.g., red, green, blue, etc.), as quickly as possible. In the second subtest, the subject is asked to name the colours of 100 coloured sequences of four x's (i.e., 'xxxx') printed on a card in the same array as the words in the first subtest. In the third subtest, the subject is again required to read aloud 100 colour names printed on a card. However, each word is printed in a coloured ink that does not match the word meaning (e.g., the word red may be printed in blue). The subject is asked to name the colours that the words are printed in as quickly as possible, while ignoring the word meaning. The magnitude of the difference between the number correct on the second and third subtest provides an index of the interference effect. It is this interference effect that is considered to be a measure of selective attention. The final subtest, developed by Bohnen et al. (1992), is an extension of the three original Stroop subtests described above. Previous studies have found that the Stroop interference effect has not been able to differentiate between TBI and control groups (Ponsford & Kinsella, 1992; Stuss et al., 1985). However, Bohnen et al. (1992) found that the interference effect generated by the introduction of this fourth subtest was able to differentiate even mild TBI participants from controls. Using the same response sheet as in subtest 3, 20 items were randomly selected and small rectangles (0.8×2.0 mm) drawn around each of these words. As with the first three subtests, and consistent with the Golden (1978) version of the Stroop, participants were given 45 s to produce as many correct responses as they could. The magnitude of the difference between this subtest and the second (colour-naming) subtest is calculated to determine the interference effect which, as with the interference effect described previously, is an indicator of selective attention deficits. The scores in each subtest represent the number of words read correctly within the 45-s time limit.

Symbol Digit Modalities Test (SDMT)

The SDMT (Smith, 1973) principally assesses complex visual scanning and visual tracking, as well as providing an indicator of sustained visual attention (Lezak, 1995; Shum et al., 1990). With the assistance of a key to show which symbol corresponds with which number, participants were given 90 s to fill in the blank spaces below a series of symbols. Both oral and written versions of the test were presented (in a counterbalanced order across participants). The score is the total number of squares completed correctly on each trial.

Digit Span

The forward and backward span subtests of the revised Wechsler Memory Scale (WMS – R, Wechsler, 1987) were presented. While the forward span is considered a measure of the efficiency of attention (freedom from distractibility), backward span draws more upon working memory (Lezak, 1995). In addition, it has been suggested that the reversing operation in the backward span test is dependent upon internal visual scanning processes (Weinberg, Diller, Gerstman, & Schulman, 1972). The score on each of these subtests represented the maximum number of digits that could be recalled (maximum scores: Forward = 8; Backward = 7).

Ruff 2s and 7s Selective Attention Test

Participants were given 15 s to cross out as many 2 s and 7s as they could which were embedded in three lines of either alphabetic or numeric characters (Ruff, Evans, & Light, 1986). They were instructed to start from the left side of the top line and proceed to the second and third lines in a similar fashion. Each line consisted of 50 characters and there were 10 target numbers embedded within each line (i.e., 2 or 7). After 15 s, participants were given the command 'next' signifying that they were to move immediately onto the next block of three lines. There were 20 blocks in total, 10 made up of capitalised alphabetical characters and 10 made up of numerals. The score was the total number of digits correctly cancelled out over the 20 blocks.

Paced Auditory Serial Addition Test (PASAT)

While the PASAT (Gronwall & Sampson, 1974) was designed initially as a measure information processing capacity, it is also widely considered to be a test of divided attention (Kinsella, 1998). Participants were presented with a random series of auditory tape-recorded digits (1–9) and instructed to add pairs of numbers such that each number is added to the one immediately preceding it. The task is presented at four different pacings, with a 2.4, 2.0, 1.6, or a 1.2-s interstimulus interval. The total number of correct responses (maximum possible = 60) were computed for each pacing.

National Adult Reading Test – Revised (UK)

In order to control for pre-morbid IQ differences between the two groups, the National Adult Reading Test – Revised (NART–R, UK) was administered. The NART–R, UK (Crawford, 1992) is a variant of the widely used NART (Nelson, 1982), which like the NART, requires participants to read aloud a list of 50 phonetically irregular words. Error scores are then converted to estimated Full Scale IQ scores using the conversion tables provided by Crawford (1992).

Procedure

The data were gathered as part of a larger study investigating deficits in attention following TBI (Bate, Mathias, & Crawford, 2001). The Ishihara (1972) screening test was used to exclude any participants with colour vision deficiencies from being administered the Stroop, a test which relies heavily upon intact colour vision. Test presentation was counterbalanced to control for any effects of order. Total testing time was approximately 110 min.

RESULTS

Matching Variables

One-way ANOVAs revealed that while the TBI and Control Groups had been successfully matched for age and education, there was a significant difference between the two groups in estimated pre-morbid IQ ($F(1, 68) = 7.15, p = .009$) (refer to Table 1). As a result, pre-morbid IQ estimate (based upon the NART – R error score) was entered as a covariate into all subsequent group comparisons. When the TBI group was divided into Early and Late subgroups, both TBI groups were again successfully matched to the controls on all matching variables except pre-morbid IQ estimate which was again used as a covariate in all subsequent analysis.

Statistical Analyses

Univariate F ratios were calculated for the TEA and other measures of attention in order to determine whether there were differences between the TBI and Control groups on these tests (Aim 1). The problem of making multiple comparisons was noted and a Bonferroni correction was considered. However, because the tests were designed to provide different measures of the construct of 'attention', and given the expected relationship between the variables, such a correction was thought to be unnecessary. A repeated measures ANOVA was additionally used to examine the scores from each condition of the PASAT. Pearson correlation coefficients were then calculated, and a principal components analysis carried out, to determine the relationship between the TEA and the established neuropsychological measures (Aim 2). A logistic regression was also completed in order to determine which combination of attentional measures best discriminated between TBI and Control groups (Aim 3). Following these analyses, TBI subjects were divided into two separate groups, with one group having sustained their injury less than 1 year ago (designated the Early group) and the other group sustaining their injury more than 2 years ago (designated the Late group). A series of one-way ANOVAs, using planned (simple) contrasts (Early vs. Controls; Late vs. Controls), were then run to examine differences between the Early, Late, and Control groups across all of the attentional measures (Aim 4). All data were analysed using SPSS version 10.0 (SPSS, 1999).

Group differences on attentional measures

Means and standard deviations for the TBI and control groups for each of the tests of attention are provided in Table 2. When the subtests of the TEA were analysed, only the Map Search [$F(1,67) = 20.4$, $p = .000$], Visual Elevator (timing score) [$F(1,67) = 4.3$, $p = .043$] and Telephone Search [$F(1,67) = 15.7$, $p = .000$] produced significant differences between the two groups. The Map and Telephone Search subtests are thought to primarily measure *visual selective attention* (Robertson et al., 1994), while the Visual Elevator subtest is considered to be a measure of *attentional switching*. The remaining tests of *sustained attention* (Lottery, Elevator Counting, Telephone Search while Counting) and *auditory–verbal working memory* (Elevator Counting with Reversal, Elevator Counting with Distraction) did not show any significant group differences.

While all of the subtests of the Stroop were administered (see Table 2 for means), only the Colour-Word and Modified Colour-Word subtests, along with the interference scores (i.e., Colour-Word minus Colour, and Modified Colour-Word minus Colour) were analysed, as the word reading (Word) and colour naming (Colour) subtests are not considered to be specific measures of attention. There was a significant difference between the two groups on the Colour-Word [$F(1, 66) = 15.8$, $p = .000$] and Modified Colour-Word [$F(1, 66) = 29.6$, $p = .000$] subtests. Interestingly, there were no significant differences between the two groups on either of the interference scores. However, highly significant differences were found between the two groups on both the Oral [$F(1,67) = 24.4$, $p = .000$] and Written [$F(1,67) = 24.6, p = .000$] versions of the SDMT (refer to Table 2). In contrast, there were no differences between the two groups on either the Forward or Backward Digit Span subtests of the WMS – R. Significant differences between the TBI and control groups were, however, found on the Ruff 2s and 7s Selective Attention Test (total score) [$F(1,67) = 18.3$, $p = .000$].

While there were no significant differences between the two groups at the 2.4-s and 2.0-s rate of the PASAT, significant differences occurred between the two groups on the 1.6-s [$F(1,62) = 5.7$, $p = .020$] and 1.2-s [$F(1,62) = 7.6$, $p = .008$] pacing rates. A Group (TBI vs. Controls) by Presentation Rate (2.4, 2.0, 1.6, and 1.2-s rate) repeated measures ANOVA was subsequently run to further examine the effects of the increased speed across the four PASAT delivery rates. While there was a significant effect for Group ($F(1,62) = 4.47$, $p = .039$), neither the main effect for Presentation Rate nor the Presentation Rate by Group interaction was significant. Thus, while both groups produced fewer correct responses at each incremental increase in the presentation speed, this reduction was not significant (refer to Table 2). In addition, there was no differential impact on the two groups in response to an increase in presentation rate.

In summary, when comparing TBI and Control groups on the subtests of the TEA, only the Map Search, Visual Elevator (timing score), and Telephone Search subtests produced significant differences between the groups. Of the established neuropsychological measures, the Colour-Word and Modified Colour-Word subtests of the Stroop, both the written and oral versions of the SDMT, and the 1.6 and 1.2-s pacing rates of the PASAT produced significant group differences. However, given the ‘marginal’ significance of the Visual Elevator (timing score) and the PASAT (1.6 s) condition, it is suggested that these results be interpreted with some caution.

Relationship Between the TEA and Established Measures of Attention

The correlations between the TEA subtests and the established neuropsychological measures for the combined TBI and Control groups are provided

Table 2. Means, Standard Deviations, and Significance Levels for Each of the Measures of Attention, With the NART – R Included as a Covariate.

	TBI (n = 35)		Control (n = 35)		Early TBI (n = 21)		Late TBI (n = 14)	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
TEA								
Map search	64.0***	(14.3)	77.1	(3.7)	64.1***	(13.4)	63.9**	(16.0)
Elevator counting	6.8	(0.5)	6.7	(0.7)	6.8	(0.5)	6.9	(0.4)
Elevator counting with distraction	8.9	(1.4)	9.3	(1.3)	8.7	(1.5)	9.1	(1.3)
Visual elevator (Accuracy)	8.5	(1.2)	9.0	(1.0)	8.3	(1.3)	8.9	(0.9)
Visual elevator (Time)	4.2*	(1.3)	3.3	(1.1)	4.2	(1.4)	4.3	(1.2)
Elevator counting with reversal	6.9	(2.9)	8.2	(1.9)	7.1	(2.9)	6.6	(3.0)
Telephone search	3.5***	(1.0)	2.6	(0.4)	3.6***	(1.1)	3.5*	(1.0)
Telephone search while counting (dual-task decrement)	2.3	(3.3)	1.2	(2.1)	2.4	(3.7)	2.1	(2.6)
Lottery	8.3	(1.8)	9.3	(1.4)	7.9*	(1.8)	8.9	(1.5)
Stroop								
Word (W) [a]	80.4	(17.0)	104.4	(19.4)	82.5	(16.0)	77.4	(18.7)
Colour (C) [a]	60.7	(10.9)	75.7	(13.1)	59.7	(11.0)	62.4	(11.0)
Colour-Word (CW)	36.8***	(8.5)	47.5	(9.6)	35.7***	(6.9)	38.6*	(10.8)
Modified colour-word (MCW)	33.0***	(6.7)	44.3	(7.8)	32.8***	(7.2)	33.2***	(6.0)
Interference effect (CW minus C)	– 23.9	(9.2)	– 28.3	(9.4)	– 24.0	(10.0)	– 23.8	(8.1)
Modified interference effect (MCW minus C)	– 27.8	(9.7)	– 31.5	(8.5)	– 26.9	(10.0)	– 29.2	(9.5)
SDMT								
Written Correct	42.4***	(10.4)	58.6	(12.6)	40.2***	(9.8)	45.6**	(10.8)
Oral Correct	49.8***	(12.3)	67.8	(13.7)	46.6***	(11.6)	54.6**	(12.0)
WMS-R Digit Span								
Forward Span	6.4	(1.1)	6.8	(1.1)	6.5	(1.0)	6.3	(1.3)
Backward Span	4.9	(1.1)	5.4	(1.2)	4.8	(1.2)	5.0	(1.2)
Ruff Selective Attention Test	209.3***	(45.3)	262.5	(44.7)	200.2***	(47.7)	223.0*	(39.0)
PASAT								
Total correct								
2.4	36.0	(11.2)	43.1	(12.0)	36.0	(11.3)	36.1	(11.5)
2.0	33.6	(11.0)	40.8	(10.6)	33.2	(11.9)	34.2	(10.0)
1.6	27.9*	(9.0)	36.7	(10.1)	27.9*	(6.7)	27.9	(11.7)
1.2	22.0**	(8.4)	29.5	(6.0)	22.0*	(8.5)	22.0*	(8.5)

Note: $p < .05$, $^{**}\ p < .01$, $^{***}\ p < .001$ (all comparisons are with the control group).
[a]Significance levels for these subtests were not reported given that they are not considered specific tests of attention.
TEA = Test of Everyday Attention; SDMT = Symbol Digit Modalities Test; WMS – R = Wechsler Memory Scale – Revised; PASAT = Paced Auditory Serial Addition Test.

in Table 3. Notably, Elevator Counting, considered to be a test of *sustained attention*, and Elevator Counting with Distraction, considered to be a test of *auditory–verbal working memory* (Robertson et al. 1994, 1996), did not correlate with any of the established measures of attention. This was in contrast to the remaining six TEA subtests which correlated with the majority of the established neuropsychological measures. Of the other measures of attention, only limited correlations were found between the Digit Span (both Forward and Backward) and TEA subtests (refer to Table 3).

In an attempt to replicate the findings of previous analyses (Chan et al., 1999; Robertson et al., 1994, 1996) a principal components analysis was carried out. Both TBI and Control groups were included in the analysis as it was felt that, for

Table 3. Correlations Between TEA Subtests and Established Neuropsychological Measures of Attention.

	Map Search	Elevator Counting	Elevator Counting with Distraction	Visual Elevator (correct)	Visual Elevator (timing score)	Elevator Counting with Reversal	Telephone Search	Telephone Search while Counting (Dual)	Lottery
Stroop Colour-Word	.533**	.133	.229	.264*	– .620**	.350 **	– .542 **	– .242 *	.396 **
Stroop Modified Colour-Word	.504**	.168	.243*	.337**	– .715**	.441**	– .550**	– .244*	.393*
Stroop Interference Effect	– .044	– .029	.036	– .168	.241*	– .065	.189	.117	– .350**
Stroop Modified Interference Effect	– .142	– .015	.019	– .138	.240*	– .037	.256*	.148	– .411**
SDMT (written)	.644**	.116	.208	.356**	– .605**	.362**	– .724**	– .361**	.329**
SDMT (oral)	.606 **	.124	.213	.381*	– .600 **	.342 **	– .701 **	– .375 **	.370 **
WMS-R Forwards Digit Span	.080	.168	.049	.139	– .318**	.141	– .093	– .255*	.370**
WMS-R Backwards Digit Span	.116	.075	.103	.301 *	– .382 **	.193	– .154	– .321 **	.374 **
Ruff Selective Attention Test	.621**	.064	.065	.391**	– .571 **	.312 *	– .694 **	– .302 **	.404 **
PASAT (2.4 s)	.328**	.124	– .007	.346**	– .593**	.404**	– .441**	– .186	.325**
PASAT (2.0 s.)	.321**	.048	– .020	.374 **	– .602 **	.365 **	– .453 **	– .244 *	.362**
PASAT (1.6 s.)	.313**	.150	.040	.290*	– .547**	.315*	– .464**	– .224	.337**
PASAT (1.2 s.)	.318**	.192	.078	.211	– .566**	.312*	– .446**	– .229	.377**

** $p < 0.01$ level (two-tailed).
* $p < 0.05$ level (two-tailed).
SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test.

the component structure to have clinical relevance, it had to represent the continuum of performance across both the control and TBI populations. In addition, correlations between the subtests for the Control group alone were largely consistent with when the two groups were combined. A non-orthogonal rotation (oblimin) was used in the current analysis as it was felt that

Table 4. Principal Components Analysis (oblimin rotation) of TEA subtests and established neuropsychological tests of attention.

	Factor 1 Visual Selective Attention	**Factor 2** Attentional Switching	**Factor 3** Sustained Attention	**Factor 4** Divided Attention
Map Search	.946	−.054	−.218	−.023
Telephone Search	−.895	−.033	−.029	.234
Stroop (CW)	.584	−.257	.217	.228
SDMT (Oral)	.761	−.146	.157	.120
Ruff 2 s and 7 s Selective Attention Test	.816	.071	.116	.040
Lottery	.082	−.054	.690	−.258
Visual Elevator (correct)	.210	.252	.581	.152
Backwards Digit Span	−.166	−.109	.809	.090
PASAT (2 s)	.342	.081	.569	.091
Elevator Counting with Distraction	.060	−.900	−.181	−.016
Elevator Counting with Reversal	.091	−.537	.357	.046
Elevator Counting	.054	−.075	.018	.862
Telephone Search while Counting (dual-task decrement)	−.294	−.226	−.232	.495
Eigenvalue	4.97	1.35	1.34	1.05

Note: SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test.

the factors could not be considered to be independent of each other. However, following the oblimin rotation, and in order to more closely replicate the principal component analyses carried out by Robertson et al. (1994, 1996) and Chan et al. (1999), a varimax (orthogonal) rotation was also carried out. There were no differences in the factor structure between the two rotations, and only the loadings varied slightly. The results of the oblimin rotation are, therefore, reported. The principal components analysis (oblimin rotation), which accounted for 66.9% of the total variance, revealed a four-factor structure comprising *visual selective attention*, *attentional switching, sustained attention*, and *divided attention* (refer to Table 4). Only one score was used from each subtest, as highly correlated tests can lead to the production of tenuous factors (Robertson et al., 1996). A subject to variable ratio greater than 5: 1 was achieved. While the factor structure broadly corresponds with the principal components analyses reported previously (i.e., Chan et al., 1999; Robertson et al., 1996), these results should be interpreted cautiously given the relatively low subject number ($N = 70$).

Tests Which Best Differentiate Between the Groups

While the first set of analyses revealed that a number of variables individually differentiated between the two groups, these tests have considerable shared variance, as highlighted by the many significant correlations between measures (refer to Table 3). In order to overcome the problem of excessive overlap between these measures and determine which measure, or combination of measures, best discriminated between the two groups, a logistic regression was carried out using the nine measures that revealed significant differences between the two groups. Variable selection was set with an F for entry at .05, and for removal at .10. The logistic regression, which predicted group membership (TBI vs. Controls) with 89.1% accuracy, found that the Map Search subtest of the TEA ($B = .63$, Wald = 6.2, $p = .013$) and the Modified Colour-Word subtest of the Stroop ($B = .56$, Wald = 5.6, $p = .018$) best differentiated between the two groups. Thus, of all the measures examined here, the TEA Map Search and the Modified Colour-Word subtest of the Stroop, both of which assess *visual selective attention*, provide the most discriminating and

Table 5. Comparison of Factor Analyses from Three Separate Studies.

	Roberston et al. 1996	Chan et al. 2000	Current study
Visual Selective Attention	Map Search Telephone Search Stroop Cancellation Task (d2 Total)	Map Search Telephone Search Stroop SDMT (oral) Elevator Counting with Reversal	Map Search Telephone Search Stroop SDMT (oral) Ruff 2 s & 7 s Selective Attention Test
Attentional Switching	Visual Elevator (correct) Wisconsin	Visual Elevator (time) Elevator Counting with Distraction	Elevator Counting with Reversal Elevator Counting with Distraction
Sustained Attention	Lottery Elevator Counting Telephone Search While Counting (dual-task decrement)	Lottery Elevator Counting Backwards Digit Span	Lottery Visual Elevator (correct) Backwards Digit Span PASAT (2 s)
Auditory-Verbal Working Memory	Elevator Counting with Reversal Elevator Counting with Distraction Backwards Digit Span PASAT (2 s)		
Divided Attention		Telephone Search While Counting (dual-task decrement)	Telephone Search While Counting (dual-task decrement) Elevator Counting

economical assessment of attention deficits in persons who have sustained a TBI.

Time Since Injury (Early vs. Late)

In order to determine whether there were differences in the attentional problems of persons who have sustained a TBI based on time since injury, the TBI sample was divided into two groups. The first group included subjects who were less than 12 months post injury (Early group), while the second group included subjects who were more than 2 years post injury (Late group). Table 2 contains the means and standard deviations for each of the attentional measures for both of these groups, together with the control group data. As with the previous analyses, pre-morbid IQ estimate was entered as a covariate into each of the analyses. Univariate ANOVAs using planned contrasts (Early vs. Controls, Late vs. Controls) were carried out on each of the measures. The planned contrasts revealed that significant differences occurred between the Early TBI and Control groups on the Map Search ($t = -3.91$, $p = .000$), Telephone Search ($t = 3.75$, $p = .000$), and Lottery ($t = 2.41$, $p = .019$) subtests (refer to Table 2). When comparing the Late TBI and Control groups significant differences were again found on the Map Search ($t = -3.48$, $p = .001$) and Telephone Search ($t = 2.64$, $p = .010$) subtests, but not on the Lottery subtest (refer to Table 2). Thus, it appears that there may be some recovery in sustained attention function (as measured by the Lottery subtest) beyond the first year post injury.

Analyses of the established measures of attention (using planned contrasts) revealed significant differences between the Early TBI and Control groups on the Stroop Colour-Word ($t = -4.01$, $p = .000$), Modified Colour-Word ($t = -4.95$, $p = .000$), Written ($t = -5.10$, $p = .000$) and Oral ($t = -5.34$, $p = .000$) versions of the SDMT, Ruff Selective Attention Test ($t = -4.51$, $p = .000$), PASAT (1.6-s rate) ($t = -2.10$, $p = .042$) and PASAT (1.2-s rate) ($t = -2.40$, $p = .020$). Planned contrasts comparing the Late TBI and Control groups also found significant differences on the Stroop Colour-Word ($t = -2.33$, $p = .023$), Modified Colour-Word ($t = -3.85$, $p = .000$), Written ($t = -2.92$, $p = .005$) and Oral ($t = -2.67$, $p = .009$) versions of the SDMT, Ruff Selective Attention Test ($t = -2.37$, $p = .021$), and PASAT (1.2-s rate) ($t = -2.14$, $p = .037$) [refer to Table 2]. However, there was no difference between the Late TBI and Control groups on the PASAT (1.6-s rate).

To summarise, when the TBI group was divided into two groups based on time since injury, the Early group showed deficits in *visual selective attention* (Map Search & Telephone Search) and *sustained attention* (Lottery). Persons who had sustained a TBI but who were more advanced in their recovery (Late group), on the other hand, only showed deficits in *visual selective attention* (Map Search & Telephone Search), suggesting that there is some recovery in *sustained attention* beyond the first year post injury. Analysis of the established measures of attention revealed that there were significant differences between the Early and Control groups on a number of these measures (i.e., Colour-Word, Modified Colour-Word, SDMT, Ruff Selective Attention Test, PASAT (1.6-s and 1.2-s rate). When the Late and Control groups were compared, significant differences were again found on all of these measures except the PASAT (1.6-s rate), again suggesting that there may be some recovery of function in the cognitive processes underlying this task.

DISCUSSION

The current study was designed to examine the attentional deficits of persons who had sustained a severe TBI using both the TEA and more traditional tests of attention. Overall, the results of this study revealed that the severe TBI group performed more poorly on the Map Search, Telephone Search, and Visual Elevator (timing score) subtests of the TEA, suggesting a deficit in *visual selective attention*, and to a lesser extent *attentional switching,* following TBI. While these findings were consistent with those of Robertson et al. (1994, 1996), these authors found additional differences between the TBI and Control groups on the Telephone Search while Counting (*divided attention*) and Lottery (*sustained attention*) tasks. These latter findings may be explained by the fact that Robertson et al. (1996) used an older TBI group ($M = 37.5$ years compared to 28.9 years), shorter post injury interval ($M = 14.6$ months compared to 28 months), and a smaller sample size ($n = 15$ compared to $n = 35$). However, unlike Robertson et al. (1996), the current study controlled for the effects of pre-morbid IQ, as this factor had the potential to affect test performance. When the same analyses were re-run without the inclusion of pre-morbid IQ as a covariate, additional significant differences were found on the Elevator Counting with Reversal and Lottery subtests. Thus, controlling for pre-morbid IQ estimate provided a more conservative set of results.

There were also notable differences between the findings of the current study and those of Chan (2000), who found deficits on all but the Elevator Counting subtest in their TBI subjects. However, it must be noted that the Chan (2000) study was based on subjects who were complaining of post-concussive symptoms and attentional problems in their daily lives; possibly increasing the likelihood of finding more attentional problems. In addition, the Chan (2000) study used a Cantonese version of the TEA, and contained a modified version of the Lottery subtest. The comparability of this version with the original TEA has yet to be established.

The performance of both TBI and Control subjects on a range of established tests of attention was generally consistent with the findings of previous studies (Ponsford & Kinsella, 1992; Spikman et al., 1996). An analysis of the individual measures found that while the performance of TBI subjects on the Colour-Word and Modified Colour-Word subtests of the Stroop was significantly lower than Controls, there were no significant differences between the two groups on either of the interference measures. These interference measures are thought to assess attentional deficits, as the Word, Colour, and Colour-Word subtests principally measure speed of information processing (Ponsford & Kinsella, 1992; Spikman et al., 1996). Thus, the Stroop did not detect attentional deficits in this TBI sample.

Consistent with the findings of Ponsford and Kinsella (1992), the SDMT discriminated between TBI and healthy control subjects. Unfortunately, due to its multi-factorial nature, the finding of reduced performance on this task cannot be used to distinguish between specific attentional deficits and other cognitive deficits (e.g., speed of information processing) in TBI subjects. Digit span (forwards and backwards) was also unable to discriminate between the two groups. Consistent with this finding, Lezak (1979) found that while Digit Forwards scores were depressed in the first few months following TBI, these scores subsequently returned to normal levels. However, a number of other studies have found that Digit Span Backwards remains impaired, even following less severe injuries (Barth et al., 1989; Uzzell, Langfitt, & Dolinskas, 1987).

Finally, the PASAT revealed significant differences between the two groups at the fastest timing rates (1.6 and 1.2 s). Interestingly, the repeated measures ANOVA revealed that increasing the rate of presentation was no more detrimental to the TBI than the Control group. Although, contrary to what was expected, this finding was consistent with the findings of Ponsford and Kinsella (1992). Given the well-established finding of reduced speeds of information processing following TBI (Ponsford & Kinsella, 1992; Spikman et al., 1996; van Zomeren, Brouwer, & Deelman, 1984), we would have expected larger deficits between the groups as the pacing rate was increased. It is possible that increasing the rate of presentation served to focus the TBI group's attention, so that competing stimuli (either external or internal) were less likely to distract them from the task. Consistent with this, Bate, Mathias, and Crawford (2001) reported anecdotal accounts of TBI subjects who found, using different tests, that the introduction of a secondary task assisted them to better focus their attention upon the primary task.

Although the PASAT has been described as measuring divided attention, like the SDMT, it is highly multi-factorial in nature (Crawford, Obonsawin, & Allan, 1998), relying heavily upon working memory and arithmetic calculation skills and, as such, does not enable us to determine with certainty that attentional problems alone account for group differences in performance. Thus, while the Colour-Word, Modified Colour-Word, SDMT, Ruff 2-s and 7-s Selective Attention Test, and PASAT revealed significant differences between the TBI and Control groups, the limitations of these measures (e.g., multi-factorial nature) make it difficult to determine whether reduced performance on these tasks is caused by specific attentional deficits, reduced speed of information processing, or other cognitive deficits. Indeed, all of the tasks that revealed differences between the two groups were timed tasks. Where timing was a less significant component, differences between the two groups were less likely to be found (e.g., Elevator Counting). Of all the measures used, only the Visual Elevator subtest (Accuracy Score) from the TEA and the Forward and Backward Span subtests of the WMS – R were free of external time restraints, and none of these showed significant group differences.

The relationship between the TEA subtests and the established neuropsychological measures was examined using correlational analysis. Elevator Counting and Elevator Counting with Distraction did neither correlate with any of the established measures of attention, nor differ between groups. This was in direct contrast to the remaining six TEA subtests which correlated with the majority of the established measures of attention. A principal components analysis, which included subtests from the TEA as well as more established measures of attention, produced a four-factor structure which was largely consistent with the analyses reported by both Robertson et al. (1994,

1996) and Chan et al. (1999) (Table 5). First, there was clear evidence for a factor constituting *visual selective attention.* The second factor (*attentional switching*) contained the Elevator Counting with Reversal subtest, a task with clear face validity in relation to this factor. However, in contrast to the analyses of Robertson et al. (1996) and Chan et al. (1999), the *attentional switching* factor in the current study did not include the Visual Elevator task. Instead, this Visual Elevator subtest loaded on the third factor, *sustained attention*. Consistent with the analyses of Chan et al. (2000), the fourth factor (*divided attention*) contained the Telephone Search while Counting Task (dual-task decrement) and as a result, was labeled divided attention. While this departed from the work of Robertson et al. (1996), who's fourth factor (Elevator Counting with Reversal and Elevator Counting with Distraction) was labeled *auditory–verbal working memory*, it is consistent with the earlier work of Robertson et al. (1994) who originally included the Telephone Search while Counting task as a test of *divided attention*.

Although there was significant commonality between the principal components analysis in the current study and the previous analyses of Robertson et al. (1994, 1996) and Chan et al. (1999), there were some loadings in the current study that were not consistent with the conceptual nature of the factors. For example, while the Elevator Counting test loaded on the divided attention factor in the current study, conceptually it is more aligned with sustained attention (Table 5). In addition, the Visual Elevator (Correct) test, which loaded on the sustained attention factor, could be considered to be more aligned conceptually with alternating attention. As a result of these discrepancies, it is suggested that some caution be taken in the interpretation of the factor structure, particularly given the multifactorial nature of most of the tasks.

The logistic regression carried out in the current study found that of all the subtests used in this study, Map Search and the Modified Colour-Word subtest of the Stroop best discriminated between the two groups. However, while such a reductionist approach uses only those tasks that maximally discriminate between the two groups, reliance on just these measures will not provide a sufficiently broad range of tests to cover the identified components / factors of attention. In addition, while a particular test may not have been able to identify group differences, this does not automatically rule out its clinical utility. The larger standard deviations amongst TBI subjects on a number of the subtests (e.g., Telephone Search while Counting) provides testament to the sensitivity of these measures in detecting variations in performance following TBI. As both theoretical constructs and factor analyses have identified four components of attentional function, it is suggested that an adequate assessment of attention would require a minimum of two subtests from each of these factors.

The division of the TBI Group into two subgroups (i.e., < 1 year post- injury; > 2 years post injury) revealed an additional difference between the Early TBI group and the Control group on the Lottery (*sustained attention*) task. Such a finding suggests the persistence of sustained attention deficits in the first 12 months following TBI, but that there is some recovery of *sustained attention* function beyond this point. Further confirmation of this hypothesis is being sought by the current authors in a longitudinal study of TEA performance following TBI. When the Early and Late groups were compared to Controls on the established neuropsychological measures, the two TBI groups differed from controls on virtually all of the same measures. The only exception was the PASAT (1.6-s rate), where the significant difference between the Early and Control groups, but not between the Late and Control groups, suggested some recovery of function in the cognitive processes underlying this task.

When evaluating the findings of the current study, there are a number of issues that should be considered. First, while the TEA provides some tasks that relate more closely to everyday activities, it is still subject to some of the criticisms of existing measures of attention; namely, the subtests are multifactorial and the test is still presented within a highly structured environment, limiting its ecological validity. The Map Search and Visual Elevator subtests, in particular, appear to draw on a range of cognitive processes in addition to attention. However, the introduction of a dual task (Telephone Search while Counting) is an important addition to the range of assessment tools available to the clinician. While there was a notable difference between the mean scores of the Early TBI and the Control groups on the dual task, the large variation in TBI performance, resulted in a non-significant group difference. The fact that significant differences between TBI and Control groups were not established does not rule out the dual task as an important clinical assessment tool.

The decision to control for pre-morbid IQ estimate also warrants further discussion. As noted previously, the TBI and control groups differed in terms of pre-morbid IQ estimate but not education. This raises the question of whether NART – R estimates of pre-morbid ability are compromised by TBI. Certainly, there is little discussion of this possibility in the literature. Perhaps more likely is the possibility that there may be a selection bias that occurs when recruiting healthy volunteers who, in our experience, tend to be female and of slightly higher intelligence. Such a bias is further compounded by some of the risk factors associated with TBI, namely, male gender, and lower levels of employment and socioeconomic status (Rimel, Jane, & Bond, 1990). The fact that education, but not pre-morbid IQ, was matched in the current study, may merely reflect the situation that 'years of education' is more an indicator of students being encouraged to stay at school longer, rather than an index of academic achievement. In this study the decision to control for pre-morbid IQ was based upon the assumption that pre-morbid IQ had the potential to influence performance on the tests of attention. In addition, it was felt that the pre-morbid IQ differences between the two groups were likely to reflect a selection bias in our sample, rather than the possibility that the NART – R was an invalid estimate of pre-morbid IQ in the latter stages of recovery following severe TBI. The effect of this decision was to provide a more conservative estimate of the impact of severe TBI on attention.

In summary, the TEA was originally designed to provide a more ecologically valid and theoretically based approach to the study and assessment of attention than existing measures of attention. While previous studies (Chan et al., 1999; Robertson et al., 1996) have identified a factor structure that confirms the theoretical base of the test, few studies have attempted to replicate this finding or examined its clinical utility with a severe TBI group. A principal components analysis of the TEA in the current study supported these previous studies in identifying the factors of *visual selective attention*, *attentional switching*, *sustained attention*, and *auditory–verbal working memory/divided attention*. Consistent with the previous studies of Robertson et al. (1996) and Chan (2000), the current study found deficits in *visual selective attention* within the TBI group. While two tests (Map Search and the Modified Colour-Word subtest of the Stroop) were identified as being able to maximally discriminate between the two groups, the importance of devising a clinical assessment protocol that incorporates measures from each of the components of attention must be remembered. It is, therefore, suggested that any assessment of attention incorporate a minimum of two tests from each of these factors. TBI subjects who were within the first 12 months post injury presented with additional deficits in sustained attention that were not apparent in TBI subjects who were more than 12 months post injury, perhaps representing some recovery in attentional function beyond 1 year post injury. Finally, while the TEA represents a welcome addition to the assessment of attention, a number of the subtests draw upon multifactorial cognitive processes. As a result, it is difficult to attribute deficits in performance on these subtests to attentional processes alone.

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