Investigating Selective Attention after Mild to Moderate Traumatic Brain Injury using Perceptual Load Theory

Christopher Waters

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Christopher Waters
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School of Social Sciences and Psychology
Victoria University
Melbourne, Australia

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ABSTRACT

This study used Lavie's (1995, 2010) perceptual load theory to investigate selective attention deficits after mild to moderate Traumatic Brain Injury (TBI). This theory predicts that when the load involved in a task does not exceed perceptual resources (low load), there is spare capacity for irrelevant distractors to be processed. This leads to distractor interference, with incompatible distractors causing maximal interference compared to neutral and compatible distractors. When perceptual resources are exceeded (high load) differential distractor interference effects are reduced or eliminated. Twelve mild to moderate TBI patients and 12 neurologically intact controls completed two computer-based tasks which manipulated perceptual load, as well as neuropsychological tests of attention. In computer task A target letters flanked by coloured shapes were presented with distractors that were incompatible, neutral or compatible with the target. Computer task B was similar but involved more ecologically relevant targets in the form of line drawings of cups and glasses. Participants were instructed to respond to targets when they appeared with coloured shapes (single feature; low load) or specific shapes of specific colours (conjunction of features; high load) thus manipulating perceptual load by verbal instruction alone. Patterns of responses were consistent with hypotheses; however, no statistically significant differences were found between distractor types under low load in either computer task. Whereas there were no significant differences between groups on RT measures, TBI patients made significantly more errors on the computer tasks and showed poorer performances on neuropsychological tests of selective attention than did controls. Small sample sizes and possible confounding effects of cognitive load may have contributed to the lack of statistically significant results. Future research with mild/moderate TBI patients may benefit from varying display set size to manipulate load instead of the verbal instructions used in the current study.

DECLARATION

I, Chris Waters, declare that the Doctor of Psychology (Clinical Neuropsychology) thesis entitled "Investigating Selective Attention after Mild to Moderate Traumatic Brain Injury using Perceptual Load Theory" is no more than 40,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: Date: 8/April/2011

Submitted with emendations – April 2011

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DEDICATION

I would like to dedicate this thesis to my wife and two beautiful boys.

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CHAPTER 1 - INTRODUCTION

1.1. Early and late selection theories of attention

The ability to remain focussed on a task without being affected by interference from irrelevant distractors is fundamental to any coherent cognitive function (Lavie, 2005). Recent research has shown that merely instructing people to focus on goal-relevant stimuli and ignore goal-irrelevant stimuli does not prevent irrelevant distractors from being processed (Lavie 1995, 2001, 2010; Lavie & Cox, 1997; Lavie & Fox, 2000; Lavie & Tsal, 1994). The word 'focus' in this context is used to describe the ability to select for attention only those stimuli that are relevant to the goal of a task. Research into the mechanisms involved in selective attention has lead to long-standing debate amongst researchers (Driver, 2001) about whether task-irrelevant distractors are processed early or late in the attentional process.

Researchers such as Broadbent (1958) have proposed that focussing attention on task-relevant stimuli blocks task-irrelevant distractors from early perceptual processing. This has been referred to as an 'early' selection effect (Driver, 2001). According to early selection theory, irrelevant stimuli should not influence task performance because they have not been fully processed. However, others have found that task-irrelevant distractors are processed and that focussing attention on task-relevant stimuli ameliorates rather than prevents distractors from influencing relevant behavioural responses (Deutch & Deutch, 1963). This has been referred to as the 'late' selection effect (Driver, 2001). Early selection theories assume that perception has a limited capacity where irrelevant distractors are filtered out early in the process, and subsequently are not processed. Late selection theories assume that perception is automatic and that both targets and distractors are simultaneously processed. Selection of target information occurs only after the full processing of all stimuli.

Kahneman and Treisman (1984) suggested that the change in emphasis from early to late selection theories may have been due to changes in the methodology being used to investigate selective attention. Evidence for the early selection view came from research that typically overloaded participants with relevant and irrelevant stimuli in relation to a task and required them to make complex responses. Evidence for the late selection view of attention typically came from methods utilising more simple detection or identification responses to stimuli presented on its own or with just a few task-irrelevant distractors (Lavie & Tsal, 1994). More recently, researchers have been investigating a hypothesis aimed at resolving the apparent discrepancies between early and late selection theories.

1.2. Perceptual load theory

Lavie and Tsal (1994) provided an extensive review of the literature on both sides of this debate and proposed an alternative perspective that accounted for the apparent discrepancy between 'early' and 'late' selection views. This discrepancy hinges on the question of whether distractors are filtered out early in the perceptual processing of a task due to limited capacity, or whether relevant targets are selected only after both target and distractor have been automatically processed. Lavie (1995) proposed the perceptual load hypothesis which asserts that perception has limited capacity, and automatic processing of all stimuli occurs until it runs out of capacity.

Working from the premise that perceptual processing is a finite resource, Lavie and Tsal (1994) proposed that early selection occurs when the perceptual load of processing task-relevant stimuli approaches or exceeds the limit of the available resources. In contrast, late selection occurs when perceptual processing resources are not exceeded, leaving spare capacity for automatic processing of task-irrelevant stimuli, and resulting in distractor interference (Lavie & Tsal, 1994).

Lavie (1995) proposed that the degree of perceptual load should be considered as a necessary condition for selective attention. Importantly, the degree of interference from task-irrelevant distractors is modulated by task demands. When the task is easy, attentional resources are available to be allocated to irrelevant information, leading to distractor interference (this corresponds with the 'late' selection view as distractors are processed). Conversely, when the task is difficult, there are limited resources available to be allocated to irrelevant information; thus the extent of distractor interference is reduced (corresponding with the 'early' selection view as distractors are blocked from being processed).

Lavie (1995) suggested that most of the selective attention research supporting the 'late' selection view came from experiments that predominantly utilized low perceptual load tasks, and cited as evidence research that used small display set sizes of usually just two different stimuli: a target and a distractor (e.g. Erikson & Erikson, 1974, Kahneman & Henik, 1981). She sought to demonstrate this in her influential 1995 paper, which described a series of experiments designed to manipulate perceptual load.

Lavie (1995) demonstrated that high load displays lead to selective attention consistent with early selection theories, and that low load displays leave spare capacity for distractors to be processed, consistent with late selection theories. Participants responded to the identity of a target letter that always appeared in the central region of the display. A distractor that was either incompatible, neutral or compatible with the target response was located above or below the central target letter. Reaction times (RTs) to target letters and errors were measured in relation to the distractor type and task load (high or low load).

In Lavie's experiment 1 (see Figure 1 below), the target and distractors were letters. Load was manipulated by increasing the relevant display set size of items among which the target appeared. The low load condition involved a display of two stimuli (target letter in centre region of the display and a single distractor letter either above or below the center), whereas the high load condition involved a larger display set (target letter set at different positions amongst five other letters with a single distractor either above or below the center region). Neurologically intact participants were asked to respond to target letters by pressing a corresponding key on a key board (separate keys for each target) and only one target per display was present. Lavie (1995) found distractor interference effects only under the low load condition. In addition to this, the compatible distractors appeared to facilitate target recognition, regardless of set size. Lavie (1995) concluded that the results supported her hypothesis that load involved in target processing mediates the processing of irrelevant distractors.

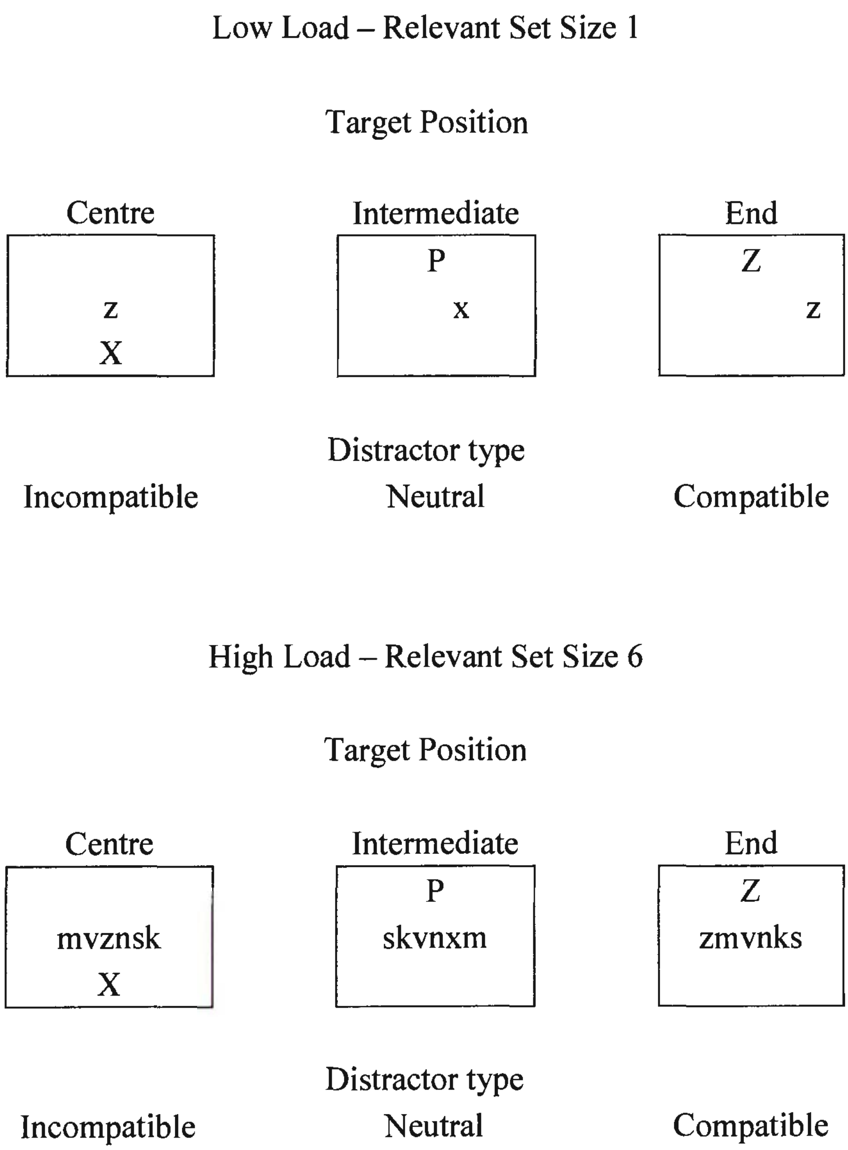

Figure 1: Examples of stimuli used by Lavie (Experiment 1; 1995).

Calling on feature integration theory (Treisman & Gelade, 1980; Treisman & Sato, 1990), Lavie (1995) proposed that mere perception of single features is load-free and only the conjunction of features imposes perceptual load, as it requires a greater focussing of attention. In other words, manipulating load can be achieved by specifying a search based on a single feature of the target, such as a specific colour (low load, resulting in high interference) or a conjunction of two features, such as the combination of a specific colour and shape (high load, resulting in low interference; Lavie, 1995).

Lavie (1995, Experiment 2a) manipulated perceptual load in an identical display by instructing participants to process an additional flanking shape presented alongside the target letter by focussing on different combinations of flanker features depending upon load manipulation. Both the target letter and additional shape were presented in the central region of the display. Irrelevant distractors that were incompatible, neutral or compatible with the target letter were displayed either above or below the central region. In this experiment, a response to a target letter was dependent on the colour of the shape flanking the target in the low load condition, and on a conjunction of shape and colour in the high load condition. The low load condition required a response when the colour of the shape was blue ('go') and no response was required when the colour was red ('no-go'). In the high load condition a response was required when the shape was either a blue square or a red circle ('go'), and there was no response required for any other combination of features ('no-go). Lavie (1995) reported that the requirement to process just the color feature (low load condition) left extra capacity that "spilled" over to the irrelevant distractors, resulting in distractor interference, and that the processing of irrelevant distractors was reduced (evidenced by less interference leading to faster RTs and fewer errors) when processing of conjunctions of features (high load condition) was required. Lavie concluded:

> "Thus, manipulating selective attention by instruction alone can load the relevant information processing sufficiently for the elimination of irrelevant distraction, without any change in the stimuli". (Lavie, 1995, p461.)

In a recent review of research into selective attention and perceptual load, Lavie (2010) noted a growing body of evidence showing that the processing of irrelevant distractors can be reduced if not prevented (early selection) when processing of relevant stimuli involves high perceptual load, and that distractors are perceived when the perceptual load is low (late selection) (Lavie, 1995 & 2001; Lavie & Cox, 1997; Lavie & Fox, 2000). Studies using varying experimental paradigms such as 'response competition' used by Lavie (1995), and priming (Lavie & Fox, 2000) with a range of methods for varying load show converging evidence that distractor effects are reduced if not eliminated under high perceptual load in targeting processing (Lavie, 2010).

1.2.1. Cognitive load manipulations

Lavie (2010) has also proposed that distractor processing depends also on mental processing or cognitive load. Lavie, Hirst, de Fockert, and Viding (2004) investigated whether a more active second mechanism of attentional control is required for rejecting irrelevant distractors when they are perceived, as in conditions of low perceptual load. This form of cognitive control over selective attentional processes requires higher level executive cognitive control functions, such as working memory, that actively maintain attention on task relevant stimuli and prevent irrelevant distractors from influencing behaviour even though they are perceptually processed (Lavie et al., 2004). Behavioural studies have shown that high working memory load does reduce the capacity to actively direct attention to relevant stimuli and that this results in increased processing of irrelevant distractors under conditions of low perceptual load (Lavie et al., 2004). That is, high cognitive load such as increased working memory demand, leads to increased processing of irrelevant distractors and thus distractor interference effects when compared to the effects of high perceptual load. Lavie (1995, Experiment 2a) manipulated perceptual load by instruction alone. This may have introduced a level of cognitive load into the demands of the experimental task; however, there did not appear to be any effect of cognitive load on the results of that experiment.

In summary, Lavie's perceptual load theory attempts to explain visual selective attention mechanisms that limit perceptual processing of irrelevant stimuli under conditions of high perceptual load. Lavie et al., (2004) noted this mechanism to be passive in nature. That is, irrelevant distractors are simply not perceived because there is no capacity left within the perceptual resources as they are fully utilised when the perceptual load of a task is high.

1.3. Brain structures associated with attention

Attention relies on complex interactions among many neural regions (Posner, 2004), and several researchers have highlighted the involvement of distributed brain systems such as the frontoparietal network of connections that mediate attentional processes (Posner & Petersen, 1990; Saalman, Pigarev, & Vidyasagar, 2007). In a landmark paper, Posner & Petersen (1990) sought to understand the cognitive operations and neuronal activities involved in attention as a functional system for control over more automatic mental processing. In reviewing a broad range of research they identified three major cognitive components to attention (orienting to sensory events, detecting signals for conscious processing, and maintaining an alert state) and proposed the underlying neuronal networks for these different aspects of attention.

Where overt orienting relates to foveation of a stimulus to improve processing in terms of acuity, it is possible to covertly orient to the location of a stimulus without moving the eye or head in order to focus it on the fovea. Posner and Petersen (1990) note the involvement of the posterior parietal lobe, the lateral pulvinar nucleus of the posteriolateral thalamus, and the superior colliculus in orienting attention to a location. Damage to these areas affects the covert shifting of attention from visual stimuli. They suggest a sequence for the processing of information involved in orienting attention where the parietal lobe first disengages attention, followed by the midbrain moving attention to a new target location, with the pulvinar then involved in processing data from that new location (Posner & Petersen, 1990).

The ability to prepare and sustain an alert state in order to process priority signals is an important attentional function. Posner and Petersen (1990) noted that attentional alertness depends heavily on the integrity of the right cerebral hemisphere (from studies of visual neglect), and norepinephrine pathways involving structures associated with the posterior attention system (posterior parietal lobe, pulvinar, and superior colliculus).

Posner and Petersen (1990) also identified the importance of the anterior cingulate gyrus to the operations involved in detecting signals for conscious processing. The anterior cingulate has connections with the posterior parietal lobe and dorsolateral prefrontal cortex suggesting involvement in language based attentional tasks (anterior connections) as well as the posterior attention system. Recent advances in neuroimaging have helped to map the brain regions involved in visual attention and Posner (2004) has acknowledged a greater contribution from frontal (e.g. frontal eye fields) and subcortical structures in visual attention than suggested by his original posterior attentional network.

Another well established neuroanatomical account of attention has been proposed by Mesulam (1981, 2000). Based on a review of unilateral neglect studies, Mesulam (1981) developed a model of an integrated network for the modulation of directed attention within extrapersonal space. The model included four cerebral regions including the posterior parietal lobe, limbic regions (cingulate gyrus), frontal lobe (e.g. frontal eye fields, inferior frontal gyrus) and the ascending reticular activating system (ARAS). These regions are also interconnected via connections to the thalamus, striatum and superior colliculus. Each region provided its own functional contribution to the network that when damaged leads to different clinical manifestations of the syndrome of unilateral neglect.

According to Mesulam's model, the posterior parietal lobe is thought to provide an internal sensory map of extrapersonal space. Unlike the primary sensory cortex that maps to specific regions of the body, it has been described more like a sensory representation "...encoded in terms of strategies aimed at shifting the focus of attention to a behaviourally relevant target" (Mesulam, 2000, p.225). One of its main roles in the attentional network is to compute strategies for the flexible shifting of attention between salient targets. Contributions from the frontal eye fields (and possible adjacent premotor cortex) involve generating the specific sequences involved in motor programs for exploration, scanning, reaching, fixating, and shifting the focus of attention. Mesulam (2000) noted that less is known about the role of the cingulate gyrus, and suggested that as part of the limbic system it plays a role in identifying the motivational relevance of events and in sustaining the level of effort required during attentional tasks. Nuclei of the ARAS (intralaminar thalamic nuclei, brain-stem raphe nuclei, nucleus locus coeruleus, substantia nigra, nucleus basalis) project to the posterior parietal lobe, frontal regions, and cingulated gyrus suggesting ARAS involvement in the activation state of the attention system (Mesulam, 2000). Meulam contends that the attentional system functions as an integrated network that processes inputs in a parallel fashion. Each component is not only responsible for its own specialised functions but also contributes to the overall integrity of the attentional network.

1.3.1. Functional imaging of attentional processes

The advent of new functional brain imaging and stimulation techniques provides further information about brain activity during attentional tasks, and allow a more fine-grained understanding of the fractionation of the attentional process both behaviourally and neuroanatomically. In an interesting study looking at whether the cognitive processes of attention (e.g. alerting, orienting, selection) are actually separable independent functional units, Fan et al. (2005) used event-related fMRI to explore three aspects of attention as measured by the Attention Network Test (ANT). These researchers hypothesised that separable patterns of activity would be found with specific attentional functions loading heavily on segregated anatomical areas. Although there was some overlap found between these networks, they found support for generally separable networks including activation in frontal, parietal and thalamic areas (alerting), activation of right superior parietal and temporal parietal junction areas (orienting), and activation in the anterior cingulate cortex and lateral frontal regions when selecting a target amongst either congruent or incongruent flankers (Fan et al., 2005).

Trans-magnetic stimulation (TMS) can induce temporary interruption of brain activity and has been used by researchers to further our understanding of which areas of the human brain are involved in attention (Chambers & Heinen, 2010). The ability of TMS to interrupt functioning in specific brain regions has allowed researchers to investigate dissociations between cortical regions that other methods have not (Chambers & Heinen, 2010). Hilgetag et al. (2001) used TMS over the right posterior parietal cortex to temporarily induce spatial inattention to the ipsilateral side, similar to brain injured patients with spatial neglect. TMS has also been able to further researchers' understanding of attention across multiple modalities. For example, Chambers, Payne and Mattingly (2007) suggest that some parietal activity is critically involved in spatial orienting for the visual modality but not for touch. This is in contrast to neuroimaging studies which previously suggested the involvement of fronto-parietal and temporal regions in spatial selection across sensory modalities (Macaluso, Frith, & Driver, 2002),

Rees and Lavie (2001) in their comprehensive review of functional imaging studies of attention and visual awareness suggest that visual awareness needs additional contributions from frontal and parietal cortices as well. Moreover, activation in frontal and parietal areas is influenced by changes in visual awareness (Nobre et al., 1997). Rees and Lavie suggest this further strengthens the hypothesised link between attention and awareness.

An accepted model of visual awareness relates to the ventral ('what') and dorsal ('where') visual pathways (Zillmer & Spiers, 2001). In this model visual information is relayed from the thalamus to the primary visual cortex in the occipital lobe and then to secondary association cortex. It is then analysed in parallel streams through the dorsal parietal areas and ventral temporal areas (Carlson & Buskist, 1994). These pathways are thought to represent a functional specialization of the dorsal stream for processing spatial information and of the ventral stream for object identification (Zillmer & Spiers, 2001). Ventral activity has been correlated with the contents of visual awareness (Logothetis & Schall, 1989), and damage to this stream leads to impaired object identification although spatial awareness may be preserved.

In their review, Rees and Lavie (2001) suggest that to associate the ventral pathway with visual awareness alone may be misleading. They cited animal studies where areas of the parietal and frontal cortex were ablated and chronic blindness resulted despite intact primary visual cortex (Nakamura & Mishkin, 1986; Nakamura, Schein, & Desimone, 1986; Sperry, Myers, & Schrier, 1960). In addition to this, human studies have demonstrated that patients with unilateral neglect (showing a lack of awareness of contralesional stimuli) had damage to the inferior parietal cortex (usually in the right hemisphere) (Feinberg & Farah, 2003). They noted that loss of visual awareness can occur even when ventral visual cortex remains intact and that this suggests an active input into visual awareness from dorsal frontal and parietal cortex (Rees & Lavie, 2001).

Rees and Lavie's (2001) review also considered recent research into a component of visual neglect known as visual extinction. Some patients with right inferior parietal lesions with visual extinction can identify the presence of an object presented to either the right or left visual field; however, when presented with objects in both fields simultaneously, they are unaware of the object in the left visual field (Feinberg & Farah, 2003). Functional MRI studies have shown that although the stimulus in the left field is 'unseen and extinguished' (Rees, Wojciulik, Clarke, Husain, Frith, & Driver, 2000), it still activates primary and extrastriate visual cortex in the same way that was elicited when only the left visual field stimulus was presented (Rees et al., 2000). It appears that the presence of neural activity in visual cortex in direct relation to an object is not enough for visual awareness of the object, at least in right parietal patients with visual extinction (Rees & Lavie, 2001).

Beck, Rees, Frith, and Lavie (2001) used a change blindness paradigm to investigate the neural correlates of conscious detection in normal participants. Rees and Lavie (2001) describe change blindness as the phenomenon where detecting change in two successively presented images is difficult when an intervening event is briefly interposed between the two presentations. Beck and colleagues were able to show that areas of ventral visual cortex were activated by the presentation of a changed stimulus even though the changes went undetected by participants. In addition to this, when the changes were detected by participants, there was enhanced activity within visual cortex and additional bilateral activation in areas of frontal and parietal cortex. As well as providing support for the concept that ventral stream activity is necessary but not sufficient for awareness, Rees and Lavie (2001) noted that frontal and parietal activation is consistently seen when stimuli are consciously detected compared to undetected stimuli. They go on to suggest that:

> "The strong anatomical overlap between the parietal plus dorsolateral prefrontal activations that correlate with awareness in those studies, and areas typically associated with the control of attention, suggests a close functional relationship between attention and awareness." (Rees & Lavie, 2001, p1351.)

The above section provides a summary of important neuro-anatomical structures and connected circuitry involved in visual attention and awareness. Not only are the visual cortices involved in visual attention, but parietal and frontal lobe structures and pathways connecting these brain areas are also intricately involved in human ability to select relevant targets within the environment. The following discussion explores the modulation in neural activity involved in visual attention when perceptual load is experimentally manipulated.

1.3.2. Perceptual load and the modulation of neural activity

Functional magnetic resonance imaging (fMRI) studies conducted since Lavie's 1995 experiments have demonstrated that manipulations of perceptual load modulate localised brain activity in the occipital lobe. Rees, Frith, and Lavie (1997) used fMRI to track activity in the visual cortex associated with the perception of motion, and then had participants perform a task under conditions of low versus high perceptual load on either a moving or static background that was irrelevant to the task. Neural activity in posterior visual cortices selective for processing motion was not evoked under conditions of high load, but was evoked only under conditions of low perceptual load (Rees et al., 1997). Similarly, Rees, Frith, Lavie and Driver (1999) found that neural activity usually evoked by written words was not evoked under conditions of high perceptual load.

Grill-Spector and Malach (2001) found that stimulus-specific fMRI signals in the visual cortex to irrelevant but repetitive background stimuli were attenuated only when the relevant stimuli were processed under conditions of low load. In the high load condition, the adaptation or 'response suppression' usually associated with repeated stimuli was absent. Lavie (2005) noted that this finding implies that full engagement of attentional capacity in a high load task mediates the brain's ability to discriminate between novel and repeated backgrounds. Pinsk, Doniger, and Kastner (2004) found that increasing perceptual load of a relevant task not only reduced activity related to irrelevant distractors, but also enhanced target related activity.

These studies provide evidence supporting Lavie's perceptual load theory at the level of cortical activity. They demonstrate that high perceptual load in a relevant task modulates if not eliminates neural activity related to irrelevant distractors. The next section takes a brief look at applying perceptual load theory when these brain structures are rendered dysfunctional.

1.4. Perceptual load and neuropsychological patients

At least two studies of neuropsychologically impaired individuals utilising the perceptual load theory have been reported. For example, patients with right parietal damage resulting in left neglect are consistently distracted by stimuli in their right visual field. Lavie and Robertson's 2001 study of patients with left neglect found that not only was manipulating perceptual load effective in reducing distraction by irrelevant stimuli in the right field, but the change in load needed to produce this effect was minimal compared to the change in load needed to cause the same effect in normal controls. This suggests that patients with left neglect experience a reduced attentional capacity which is easily exhausted by increases in perceptual demand. Such a pattern was also reported in another study of a patient with bilateral damage to the frontal and temporal regions (Kumanda & Humphreys, 2002). Effecting a small increase in load by adding single letters to the display resulted in a significant reduction in the level of distractor interference from irrelevant stimuli. Lavie (2005) suggested that small increases in task load were enough to overload the available attentional capacity (which was reduced in these patients compared to normal controls), thus reducing the impact of irrelevant stimuli on task performance.

From these studies it would appear that even relatively small increases in perceptual load exhausts attentional capacity in patients with damage to right parietal (Lavie & Robertson, 2001), frontal, and possibly temporal regions (Kumanda & Humphreys, 2002). When perceptual load is manipulated with these patients, distractibility is significantly reduced under the high load condition. This suggests that if real world manipulations of perceptual load could be produced, these patients may benefit from being less susceptible to irrelevant distractors in day to day activities. Perhaps these capacity limits can be used to benefit other groups of patients who have reduced attentional capacity due to traumatic brain injury (TBI), such as those associated with closed head injuries (CHI).

1.5. Traumatic brain injury

Traumatic brain injury (TBI) and head injury (HI) have been referred to as synonymous terms generally meaning injury to the brain. Head injury can also be used to include injuries to other head structures such as the face or jaw (Lezak, Howieson & Loring, 2004). Here we will use the terms TBI or HI to refer to trauma that has injured the brain, such as closed head injury (CHI).

Mild TBIs make up a significant proportion of all head injuries treated in hospitals. The World Health Organization (WHO - Cassidy, Carroll, Peloso, Borg, von Holst, Holm et al., 2004) conducted a systematic review of international studies and estimated that 70-90 percent of hospital treated adults with TBI could be classified as mild. The incidence of mild TBI is probably higher if those injuries not treated at a hospital are taken into account. Demakis and Rimland (2010) found that quick resolution of symptoms was the most common reason for not seeking treatment amongst a group of undergraduate students who retrospectively reported having had a mild TBI.

In Australia, the average rate of TBI in 2004-2005 was 107 per 100,000 population (Australian Institute of Health and Welfare, 2007). The highest rate (23% of all TBIs) occurred in individuals aged 15-24 years. Across all age groups there were higher rates for males compared to females, with males comprising over two thirds (69%) of all reported TBIs.

The Australian statistics are consistent with international findings where estimates indicate that twice as many men than women suffer a TBI (Banich, 2004; Hannay, Howieson, Loring, Fischer, & Lezak, 2004). Motor accidents have been reported as the main cause of TBI in adolescents and young adults (Sohlberg and Mateer, 2001). High incidence of TBI has also been recorded in the very young and elderly (over 65 years) with falls as the major cause of these injuries (McCrae, 2008; Sohlberg, & Mateer). Other causes include sport related injuries and assaults. Alcohol is reported to be involved in over half of the injuries either due to intoxication of the instigator of the injury, the recipient of the injury, or both (Banich, 2004).

Approximately 80 percent of cases are classified as mild TBI, with moderate to severe cases making up the remaining 20 percent (McCrae, 2008; Sohlberg & Mateer, 2001). TBI is viewed as having a major impact on health services (McCrae, 2008; Saatman, Duhaime, Bullock, Maas, Valadka, & Manley, 2008). The prevalence rates of TBI exceed that of both stroke and epilepsy (Sohlberg & Mateer, 2001) and are reported to be higher than the combined rate of Alzheimer's disease, multiple sclerosis, and Parkinson's disease (Banich, 2004).

However, epidemiological studies on the prevalence of TBIs are thought to under-represent the true prevalence of brain injuries due to a number of difficulties in obtaining reliable data (Saatman et al., 2008; McCrae, 2008). These include inconsistent diagnostic criteria, heterogeneous inclusion criteria between studies, and the preponderance of studies relying on hospital admissions (Demakis & Rimland, 2010; Saatman et al., 2008). For example, studies relying on hospital admissions are likely to bias the data collected to include more moderate to severe injuries, and to underestimate the number of mild TBIs (McCrae, 2008).

1.5.1. Classification of severity in traumatic brain injury

Classification of severity of TBI is important as it provides not only diagnostic but also prognostic information, as well as a guide to treatment and rehabilitation. A number of different tools have been devised to allow clinicians to rate severity; however, most have poor sensitivity in assessing mild TBI.

The Glasgow Coma Scale (GCS) developed by Teasdale and Jennett (1974) is a widely used measure of TBI severity (Lezak et al., 2004). The GCS gives an indication of the level of responsiveness of the patient at the time of the injury.

A rating out of 15 is based on three domains of function; eye opening, verbal response, and motor response, deriving a numerical rating of post injury status ranging from the mildest confusional state through to deep coma. Lower scores are indicative of greater TBI severity (see Table 1). Coma duration is also used as an important indicator of injury severity. Coma duration of 20 minutes or less is considered mild, duration of up to 36 hours is considered moderate, and coma greater than 36 hours is considered severe (Fischer et al., 2004; McCrae, 2008).

Other commonly used measures for rating the severity of TBI and predicting outcome include the length of loss of consciousness and posttraumatic amnesia (PTA; Fischer et al., 2004; McCrae, 2008). PTA has been defined as the period following a head injury that a patient is unable to register experience, and is often declared to have ceased after the patient has been able to register and recall continuous memories of their experience over an extended period (Fischer et al., 2004). The Westmead PTA Scale (Shores, Marosszeky, Sandaman, & Batchelor, 1986) provides a standardized set of procedures used to track the duration that a patient is in PTA. The scale first asks seven questions designed to assess the patient's level of orientation with one point given for each correct answer. Then the patient is shown three pictures of objects and asked to remember these along with the examiner's face and name. The same three faces are used until a perfect score of 12 is reached. After this, different objects are used until the patient achieves a score of 12 on three consecutive days. The patient is deemed to be out of PTA on the first of the three consecutive days they obtain perfect scores.

The length of PTA has been used as an indicator of injury severity with PTA of 60 minutes or less indicating mild TBI, PTA of less than 24 hours indicating moderate TBI, and PTA for periods greater than 24 hours indicating severe through to very severe TBI (Fischer et al., 2004). However, difficulties arise using these measures as well. McCrae (2008) noted the difficulty in estimating the length of time a patient is unconscious. There may be a lack of reliable witness to describe the event and observe the length of time associated with loss of consciousness. In relation to PTA, resourcing constraints at hospitals may limit the availability of screening for PTA. In addition, many mild TBI sufferers may not even attend hospital for treatment, or are discharged from emergency departments without assessment of PTA (McCrae, 2008). These difficulties are particularly pertinent to mild TBI as ratings of moderate or severe cases are more likely to be admitted to hospital and monitored for diagnostic, treatment and prognostic reasons (Fischer et al., 2004).

Classification of TBI severity remains problematic, particularly in assessing mild TBIs. In 2007, the National Institute of Neurological Disorders and Stroke (NINDS in the United States) convened a committee looking at the development of a valid classification system for TBI with the aim of linking patterns of brain injury to specific therapeutic interventions (Saatman et al., 2008). Saatman et al., (2008) and others (McCrae, 2008; Lezak et al., 2004) note that the GCS has good utility when classifying TBI cases that are moderate and severe, and that for these cases the GCS provides useful information during the acute care phase and also in predicting outcome. However, its usefulness is limited due to the heterogeneity of TBI aetiology (Saatman et al., 2008). Complicating factors such as multiple facial fractures or sedation using drugs can impact or even make it impossible to perform GCS ratings on admission to hospital (McCrae, 2008). Also, different injuries to the brain may be assessed using the GCS as having the same level of severity, but the GCS gives no indication of the causes for the dysfunction and therefore leaves out valuable diagnostic information (Saatman et al., 2008). The NINDS paper also noted that the clinical categorisation of symptom severity is only one way to classify TBI's (Saatman et al., 2008). Other ways to classify TBI noted by the NINDS committee included: pathoanatomic classifications that describe the location and anatomical features of the injury; physical mechanisms looking at the way an injury was sustained (e.g. impact or inertia induced injuries); and pathophysiological classification looking at the physiological processes involved in TBI and recovery. However, the use of other classifications systems also have limitations to their use (Saatman et al., 2008) and despite the limitations of the GCS, it remains one of the most commonly used classifications of TBI in hospital settings (McCrae, 2008).

In many cases, the absence of a single rating scale that takes into account the complex nature of TBI diagnosis and severity ratings makes it necessary for skilled medical specialists to make clinical judgements as to the severity, treatment choices and prognosis of TBI cases using combinations of these indicators (McCrae, 2008). Table 1 provides a common format for combining GCS, PTA estimates and length of loss of consciousness to make ratings of TBI severity (Fischer et al., 2004; McCrae, 2008).

Table 1. Severity Indicators of Traumatic Brain Injury

	SEVERITY CLASSIFICATION		
MEASURE	MILD	MODERATE	SEVERE
Glasgow Coma Scale	13-15	9-12	3-8
Duration of Coma	<20 minutes	< 36 hours	>36 hours
Posttraumatic Amnesia	<60 minutes	1-24 hours	>24 hours

(Sources: Fischer et al., 2004; McCrae, 2008)

1.5.2. Mild traumatic brain injury

Using traditional severity measures as outlined previously, mild TBI has been estimated to account for between 70-90 percent of all treated cases of TBI (McCrae. 2008) and therefore represents the vast majority of TBI injuries. Prevalence rates have been estimated to lie between 100-300 per 100,000 population by a World Health Organization's Collaborative Centre Task Force on Mild Traumatic Brain Injury report (Holm, Cassidy, Carroll, & Borg, 2004). However, estimates for mild TBI also suffer from limitations to epidemiological studies due to factors such as differing diagnostic criteria and classifications systems.

One debate has centred around the pathoanatomical classification of mild TBI where current technology commonly used in general hospital settings may not be readily able to identify injury to the brain (Lezak et al., 2004). For example, Mittenberg, Canyock, Condit, and Patton (2001) estimated that approximately 38 percent of patients displaying neurological symptoms consistent with mild TBI fail to show any abnormalities on CT scan. Several recent studies have compared conventional MRI techniques with diffusion tensor imaging (DTI) in professional boxers (e.g., Chappell, Ulag, Zhang, Heitger, Jordan, Zimmerman et al., 2006; Hopkins, Beck, Burnett, Weaver, Vicroroff & Bigler, 2006; Zhang, Heier, Zimmerman, Jordan, & Ulag, 2006). Findings from these studies noted the presence of subtle white matter abnormalities on DTI imaging that was undetected by conventional MRI imaging. Even those boxers without neurological impairment were shown to have white matter pathology on DTI imaging (Chappell et al., 2006). These studies demonstrate that newer, more sensitive MRI methods such as DTI detect white matter abnormalities that conventional MRI scanning does not detect (Bigler, 2008).

Another area of contention within mild TBI research concerns the aetiology of postconcussion syndrome (PCS) following mild TBI (Meares, Shores, Taylor, Batchelor, Bryant, Bagulay et al., 2008). According to the International Classification of Diseases (ICD-10, diagnostic criteria 310.2) PCS occurs following a head injury that may have included a loss of consciousness, and requires the presence of a cluster of three or more categories of symptoms, including but not limited to: headaches, dizziness, fatigue; irritability, depression, anxiety; subjectively reported poor concentration and/or memory difficulties; insomnia; reduced alcohol intolerance; or pre-occupation with these symptoms and a fear of brain damage with hypochondriacal concern and adoption of sick role (see Appendix A for full listing of ICD-10 criteria). However, in their study, Meares et al. (2008) found that PCS was not found to be specific to mild TBI patients and that there were high rates of PCS in both the mild TBI participants and a group of non-brain injured trauma controls. They concluded that the use of the term PCS may be misleading as it incorrectly implies the presence of a brain injury (Meares et al., 2008).

The classification of brain injury severity is controversial in that there is not a single rating scale that is universally accepted. Whereas the GCS and PTA scales have better utility in predicting outcome for more severe TBIs, they have limited ability to predict functional outcomes in mild brain injuries. Syndromes such as PCS do not appear to be sufficiently distinct to differentiate patients who have had a head injury from those with other orthopaedic injuries. Although there are limitations to these rating scales and terms such as PCS, they provide some valuable information and are still used in clinical settings.

1.5.3. Mechanisms of impact in TBI

There are many ways in which the brain can be damaged in TBI. Zillmer and Spiers (2001) classify TBI according to damage to the skull, describing two groups. The first group consists of Closed Head Injuries (CHI), which are commonly associated with a blow to the head without penetrating the skull. The second group is known as Penetrating Head Injuries (PHI) where the skull and brain are penetrated by an object (Zillmer & Spiers, 2001). The present discussion will focus mainly on the mechanisms involved in CHIs.

1.5.3.1. Primary injury effects

Hannay, Howieson, Loring, Fischer, and Lezak (2004) describe in detail the effects of two stages of brain damage involved in CHI. The first stage or primary injury occurs at the time of impact, and involves a number of different processes.

Diffuse Axonal Injury (DAI) in CHI

One of the main mechanisms of damage in TBI is force inflicted on the brain as a result of rapid acceleration followed by rapid deceleration (Banich, 2004; Bigler, 2008; Hannay et al., 2004; Sohlberg & Mateer, 2001). When this occurs the brain moves within the skull and can result in neuronal twisting and shearing of axons, as well as focal damage if the brain impacts with the inside of the skull (Hannay et al., 2004). Different types of blows to the head can cause differing forces within the skull such as linear and rotational forces that can shear, stretch and rupture axons and white matter tracts (Banich, 2004). These injuries tend to be diffuse as they can affect large areas of white matter. The amount of damage varies in different locations, with anterior regions and deeper structures being more susceptible to damage than more posterior regions (Hannay et al., 2004).

These diffuse injuries to large areas of white matter tracts effectively disconnect the cortex from subcortical structures (Hannay et al., 2004). Although these diffuse injuries are not easily detected by conventional imaging technology, they often reveal themselves later as the loss of neural tissue, which can lead to enlarged ventricles and loss of volume in structures such as the corpus callosum (Banich, 2004). For example, MR spectroscopic studies (Cohen, Inglese, Rusinek, Babb, Grossman, & Gonen, 2007) showed the presence of subtle brain volume loss in mild TBI. As discussed previously, more contemporary MRI techniques such as DTI have been able to detect subtle white matter changes in mild TBI (e.g. Zhang et al., 2006).

In addition, post-mortem brain studies have shown the presence of diffuse axonal injuries in mild TBI patients who died of other causes (Blumbergs, Scott, Manavis, Wainwright, Simpson, & McLean, 1994). Another post-mortem study of a man who had persistent post concussive syndrome conducted 7 months post-injury revealed evidence of hemosiderin (a marker of cell damage) and residual inflammatory reaction that was taken as evidence of subtle white matter damage to the brain that was undetected while the man was alive (Bigler, 2004).

Neurometabolic cascade

Many of the clinical symptoms in moderate to severe TBI are thought to be due to the destruction or shearing of axons, as described above. However, in mild TBI following CHI, this may not be the only cause of symptoms. Recent research has demonstrated that in mild TBI, neurons may not be destroyed, but instead are rendered dysfunctional due to pathophysiological sequence of events known as the neurometabolic cascade (Iverson, 2005; Iverson, Lang, Gaetz, & Zasler, 2006). In addition to this, histopathological processes including cell loss, cytoskeletal changes, inflammatory cellular reactions, and biochemical markers of cell death have been seen in mild TBI (Anderson, Brown, Blumbergs, McLean, & Jones, 2003). This cascade of physiological events includes ionic shifts, altered metabolism, impaired connectivity and changes in neurotransmission with the damaged neurons is thought to be independent of diffuse axonal injury (McCrae, 2008).

Vascular injuries

CHIs can create haemorrhages within and around the meninges and brain tissue as a direct result of impact. Bigler (2008) noted that mechanical forces involved in TBI can stretch the internal carotid and structures involved in the circle of Willis, as well as other vasculature structures within the brain including the dura. Petechial haemorrhages occur largely in the frontal and temporal lobe white matter due to tearing and rupturing of small blood vessels within these regions. Tearing of larger blood vessels can occur due the same forces that cause DAIs (Hannay et al., 2004).

Focal lesions in CHI

Bigler (2008) noted the ease at which the brain can be transiently impaired through mechanical deformation and stated that common neurological structures must be affected. Orbito-frontal and temporal poles of the frontal and temporal lobes are particularly susceptible to damage in CHI as they are supported by areas of the skull that have bony processes that can damage the cortex as the brain makes contact and moves over them (Hannay et al., 2004). Contusions in the cortex can occur with gyral crests being most susceptible. Focal lesions occur as the brain is moving within the enclosed skull and comes into contact with it. Injuries at the site of a blow to the head are called coup injuries. As the brain literally bounces off the skull it can then travel in the opposite direction and make contact with the opposite pole of the skull, causing further damage. This is known as a contrecoup injury (Hannay et al., 2004). For example, if someone is pushed backwards, and their head hits the ground, a coup injury in the occipital areas might be sustained, as well as a contrecoup injury at frontal sites. Vascular structures on the surface of the brain are also vulnerable (Hannay et al., 2004).

Bayly, Cohen, Leister, Ajo, Leuthardt, and Genin (2005) used pre and post MRIs to observe brain deformation when the head had been dropped by just 2 cm in human participants. They found that the brain's centre of mass continues to move as the skull decelerates, placing the structures that bind the brain to the base of the skull under mechanical load. The brain rotates about this central base with anterior structures becoming compressed, and posterior structures are stretched. The superior-frontal surface of the brain compresses against the top of the cranium. In a review of modern imaging techniques investigating post-concussive syndrome, Bigler (2008) noted that the brainstem "...experiences shortening and shear as the posterior and inferior parts of the brain continue rotating downward and forward" (p. 5). The mechanical forces associated with mild TBI leave common brain regions susceptible to damage including the hypothalamic-pituitary pathways, fornix, corpus callosum, upper brain stem, as well as the orbital frontal and medial temporal lobes (Bigler, 2008).

Viano, Casson, Pellaman, Zhang, King, and Yang (2005) used complex models of the brain to simulate head injuries reconstructed from players' head impacts video-taped from actual American National Football League games. They reported that the largest strains due to the deformation of the brain occurred in the fornix, midbrain and corpus callosum and these forces were present for all participants who were concussed. They also reported that early strain in the orbital-frontal and temporal regions correlated with dizziness. Cognitive and physical symptoms associated with concussion were correlated to measurable displacement of the hippocampus, caudate, amygdala, anterior commissure and midbrain (Viano et al., 2005).

1.5.3.2. Secondary injury effects

Hannay et al. (2004) describe secondary injuries as a result of physiological processes following the initial impact. Some of these processes include elevated intracranial pressure (ICP), oedema, hypoxia and ischaemia, and infections (Kolb & Cioe, 2004). Swelling can have focal or generalized effects and can increase ICP which can lead to increased pressure on other adjacent brain structures and in turn increases the risk of further damage to brain tissue (Hannay et al., 2004). These effects are life threatening and can place pressure on the brain stem causing major disruption to vital functions such as respiration, and can lead to death without some form of intervention. With the advent of improved medical and surgical procedures, more patients are surviving these potentially life threatening processes involved in TBI.

In summary, traumatic brain injuries have multiple effects on the integrity of brain tissue, many of which lead to temporary and often permanent functional disturbances as a direct and/or indirect result of the traumatic brain injury. The next section briefly reviews the neuropsychological effects of TBI, particularly its impact upon attention.

1.6. Attention and TBI

Attention deficits have been cited as one of the most common cognitive deficits associated with TBI (Belanger et al., 2005; Belmont, Agar, & Azouvi, 2009; McCrae, 2008; Tombaugh, Stormer, Rees, Irving, & Francis, 2006; Whyte, Flemming, Polansky, Caallucci, & Coslett-Branch, 1998; Ziino & Ponsford, 2006). Sohlberg and Mateer (2001) report that these difficulties involve increased susceptibility to distractions, difficulties responding to simultaneously presented stimuli, and problems with shifting mental set. Others note that slowed mental processing and reaction times have a generalised impact on attention (Tombaugh et al., 2006) and contribute to poor concentration, distractibility, and difficulty dividing attention between simultaneous tasks (Hannay et al, 2004). Patient-reported difficulties with "short term memory" following mild TBI have been associated with the combined effects of reduced attention span (Geary et al., 2010), and heightened distractibility rather than memory dysfunction (Howieson & Lezak, 2002). In studies using a variety of tests of attention, researchers note the presence of attentional deficits amongst TBI patients. The following provides a brief review of some of the recent research into the effects of TBI on attentional processes.

Chan (2000) used a modified version of the Test of Everyday Attention (TEA) and standard neuropsychological tests of attention with a group of TBI patients and controls. He reported that TBI patients showed deficits on tests assessing sustained attention, selective attention, divided attention, and on attentional switching tasks. In a confirmatory factor analysis of the TEA (Cantonese version) with data from 92 TBI patients experiencing post-concussive symptoms, Chan and Lai (2006) found a three factor model as the best fit for the data. This model included visual selection, sustained attention, and attentional switching. The inclusion of a fourth factor for divided attention as would be suggested from the earlier study of Chan (2000), did not improve the fit of the model.

Bate, Mathias, and Crawford (2001) assessed a group of 35 patients with severe TBI and 35 matched controls with the Test of Every Day Attention (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) and other neuropsychological tests of attention. They found that TBI patients performed significantly worse on the Map Search and Telephone Search subtests of the TEA suggesting visual selective attention deficits following TBI.

In another study looking at visual selective attention after severe TBI, Scmitter-Edgecombe and Kibby (1998) manipulated conditions of high to low target-distractor similarity in a visual search task with 20 severe TBI participants and 20 matched controls. When participants were required to search for the target, the TBI group required significantly longer to find the target in both the low and high target-distractor conditions. When not required to search for the target, TBI participants took significantly longer than controls when the similarity between target and distractors was high. The authors concluded selective attention disadvantages for the TBI group when visual search is required, and when the target and irrelevant distractors are visually similar (Scmitter-Edgecombe & Kibby, 1998). Ziino and Ponsford (2006) also found selective attention deficits in a group of TBI patients, although they found a relationship exists between subjective fatigue and performance on higher order attentional tasks.

In an innovative study looking at the impact of high and low levels of distraction on prospective memory, Knight, Titov, and Crawford (2006) used a virtual shopping precinct evenly divided into high and low distraction zones. Twenty severe TBI patients and matched controls (n=20) "walked" down the virtual streetscape while completing ongoing and prospective memory tasks. TBI patients performed poorly on the ongoing task (completing a checklist of 10 errands), and prospective memory task (responding appropriately to targets as they repeatedly appeared) when compared to controls. This suggests that real-life memory functions are impacted upon by increased levels of distractibility following severe TBI.

Others have also found significant susceptibility to distraction among patients with TBI compared to controls (Whyte et al., 1998; Whyte, Schuster, Polansky, Adams, & Branch Coslett, 2000). Using analysis of videotapes and coding for off-task behaviour, Whyte et al. (2000) compared 20 moderate to severe TBI patients with 20 matched controls. These researchers found that the TBI group was less attentive than controls regardless of whether distractors were present or not.

McAvinue, O'Keefe, McMackin, and Robertson (2005) investigated the processes of sustained attention (ability to remain on task without being distracted) and error awareness in TBI participants. Using a simple continuous performance go/no-go test (Sustained Attention to Response Task - SART), McAvinue and colleagues found TBI participants were significantly impaired in sustained attention and error awareness compared with controls. After accounting for severity of injury, the degree of error awareness in TBI participants was moderately correlated with sustained attentional capacity. These results were confirmed in a second experiment with an independent sample of TBI patients and controls (McAvinue et al., 2005).

Attention deficits are noted to be common even in mild TBI (Belanger et al., 2005; Vanderploeg et al., 2005; Van Donkelaar, Langan, Rodriguez, Drew, Halterman, & Osternig, 2005). For example, Paré, Rabin, Fogel, and Pépin (2009) compared 37 mild TBI patients with 79 healthy controls on a dual-task paradigm used to assess divided attention. Participants were assessed within one week of injury and again at three month follow-up. Pare and colleagues found that the mild TBI group had slower reaction times than controls and this difference was maintained as the tasks became more challenging across both baseline and at three month follow up.

Another study investigated deficits in the alerting, orienting and executive components of attention as measured by the Attentional Network Test (ANT) in a group of twenty undergraduates who had sustained a mild TBI and matched controls (Van Donkelaar et al., 2005). In this study, researchers found no difference between groups on the alerting measure of the ANT and concluded that this aspect of attention was unaffected by mild TBI in this sample. They found evidence for mild TBI to partially influence the executive component (to select the appropriate target from within either congruent or incongruent flankers). Mild TBI in this sample had the most marked effect on the orienting component (ability to locate a target with or without spatial cues).

The above discussion has highlighted that attentional deficits associated with mild to severe TBI consist of several separable yet overlapping components (e.g. alerting, orienting, executive control - Van Donkelaar et al., 2005). In addition to this, the underlying neuropathology of TBI can differentially affect these attention components (Fernandez-Duque & Posner, 2001). In summary, the structures most likely to be damaged and the mechanisms of damage most likely to occur in TBI and mild TBI are those that will affect at least some part of the attentional process, given the neuroanatomical distribution of the attentional system. Given the likely occurrence of attentional deficits, rehabilitation of attention is an important aspect of recovery following TBI.

1.6.1. Other neuropsychological deficits following TBI

Beyond the impact upon attention, there are numerous other cognitive, emotional, behavioural, sensory and motor sequelae of TBI (Sohlberg & Mateer, 2001; Prigatano, 1999; Ponsford, 2004).

1.6.1.1. Emotional sequelae of mild TBI

Depression and anxiety are often seen in people who have suffered a mild TBI (Hovland & Raskin, 2000; Ponsford, 1995; Wrightson & Gronwall, 1999). Mooney, Speed, and Shepherd (2005) investigated variables related to poor outcome after mild TBI and found that poor recovery when compensation or litigation was involved appeared to be explained more by depression, pain, and performance on tests of malingering than by the injury itself. Raskin and Stein (2000) reported that although depression may be associated with functional difficulties, it does not appear to contribute to cognitive impairments in mild TBI sufferers. However, Bigler (2008) has suggested that emotional dysregulation may come about from disruption/damage to medial temporal lobe and basal forebrain regions. Viano et al. (2005) also noted the effect of TBI upon the amygdala. These studies suggest that the emotional component of recovery from TBI can have a neurogenic basis.

A number of postconcussional symptoms contribute to the emotional distress experienced by mild TBI patients (McCrae, 2008). These include sleep disturbance and irritability (McAllister & Flashman, 1999), fatigue (Belmont, Agar, and Azouvi, 2009; Ponsford, Willmott, Rothwell, Cameron, Kelly, Nelms, et al., 2000; Stulemeijer, van der Werf, Bleijenberg, Biert, Brauer, & Vos, 2006) as has acute awareness of deficits and reduced mental efficiency (Hannay et al., 2004; Ponsford, 1995).

1.6.1.2. Motor and sensory sequelae of mild TBI

Slowed psychomotor processing speed is one of the most common changes in motor functioning following mild TBI (Barrow, Collins, & Britt, 2006; Crawford, Knight, & Alsop, 2007; De Monte, Geffen, May, McFarland, Heath, & Neralic, 2005; Tombaugh, Rees, Stormer, Harrison, & Smith, 2007). This is proposed to be due to white matter disruption which slows information transfer between different brain regions. Slow responding to cognitive tasks involving interhemispheric integration has been noted even in mild TBI (Mathias, Beall, & Bigler, 2004) and has been attributed to damage to the corpus callosum and anterior commissure (Inglese, Makani, Johnson, Cohen, Silver, Gonen et al., 2005; Mathias, Bigler, Jones, Bowden, Barrett-Woodbridge, Brown et al., 2004).

Typical sensory and perceptual symptoms reported after mild TBI include light and noise sensitivity, dizziness, diplopia, nausea and headache (Bennet & Raymond, 1997; Gronwall, 1991; McCrae, 2008).

1.6.1.3. Behavioral and cognitive sequelae of mild TBI

Along with emotional regulation difficulties described earlier, dysfunction associated with mild TBI typically includes problems with attention, memory, planning and problem solving, initiation, impulsivity, and self-awareness (Lundin, de Boussard, Edman, & Borg, 2006; Sohlberg & Mateer, 2001). Behavioral sequelae of TBI vary depending on a number of factors including the age of the patient, premorbid characteristics, as well as site and severity of the injuries sustained (Sohlberg & Mateer, 2001). Sohlberg and Mateer note that although specific deficits such as aphasias, apraxias, unilateral neglect and visuo-spatial difficulties may result from localized lesions, these are not typical features of mild TBI caused by closed head injury, where damage appears to be more diffuse. McCrae (2008) reported the discrete lesions that can occur in the frontal and temporal lobes as these areas of the brain are most susceptible to damage caused by the acceleration / deceleration forces associated with CHI.

A meta-analysis of mild TBI studies conducted by Zakzanis, Leach, and Kaplan (1999) noted that commonly reported deficits included executive difficulties, delayed recall, memory acquisition, and attention. Mathias et al. (2004) suggested that these cognitive functions should be targeted when mild TBI patients undergo neuropsychological assessment. For example Mathias and colleagues (2004) found mild TBI patients demonstrated deficits in attention, non-verbal fluency, verbal memory, and slowed information processing when compared with controls.

Several studies have suggested that while these cognitive deficits occur immediately post injury, they have dissipated within one to three months post-injury for most patients (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005, Ponsford et al., 2000), with a subset of patients experiencing prolonged difficulties after three months and up to one year post injury. (Kashluba, Paniak, Blame, Reynolds, Toller-Lobe, and Nagy; 2004; Kwok, Lee, Leung, and Poon, 2008; Paniak, Reynolds, Phillips, Toller-Lobe, Melnyk, and Nagy, 2002; Vanderploeg, Curtiss & Belanger, 2005).

More recently, researchers have been able to indentify structural changes following mild TBI that has not been possible with less sensitive but common neuroimaging conducted in treatment centres (e.g. Zhang et al., 2006). Geary, Kraus, Pliskin, and Little (2010) designed a study to investigate the disparity between recent neuroimaging advances that have identified subtle brain changes and white matter integrity in mild TBI patients and subjective complaints of memory difficulties that are often not confirmed by traditional neuropsychological assessment. They found that a group of non-litigating mild TBI patients (at least 6 moths post injury) performed significantly poorer on the first trial of a verbal learning task than matched controls. There was no significant difference between the groups on total learning or memory composite measures such as those traditionally interpreted in standard neuropsychological assessment. Moreover, using diffuse tensor imaging (DTI) the authors report that the first trial of the learning task was associated with changes in the unculate fasciculus (which connects temporal and prefrontal regions) and the left superior longitudinal fasciculus (involved in visual awareness, maintenance of attention, initiating motor behaviour, and language). Geary and colleagues suggest this may represent an anatomical correlate for the poor performance on the first learning trial.

Vanderploeg, Curtiss, and Belanger (2005) studied the long-term neuropsychological outcomes of Vietnam veterans who had experienced a mild TBI. The average length of time post injury was eight years. They noted that mild TBI patients can have poor long-term outcomes on subtle aspects of attention and working memory.

The examples above highlight that most cognitive deficits associated with mild TBI appear to be due to diffuse rather than focal injuries. They tend resolve relatively quickly within the first three months of injury. However, some patients have persisting difficulties and these subtle changes can be detected up to eight years post-injury in some cases (Vanderploeg et al., 2005).

1.7. Rehabilitation of attention

The attention difficulties commonly seen following TBI and their impact on an individual's ability to function have been targeted by comprehensive rehabilitation programs such as Sohlberg and Mateer's (2001) Attention Process Training (APT). Sohlberg and Mateer noted the importance of using a broad approach in TBI rehabilitation programs that integrates pre-injury factors (for example, personality, education, and socio-economic factors), with post injury factors (for example, type and location of injury, cognitive, physical, emotional and behavioural factors). It has also been argued that a holistic approach to TBI rehabilitation is needed to help patients adapt to life post injury, re-integrate back into the community and to improve perceived quality of life (Cicerone, Mott, Azulay, & Friel, 2004; Prigatano, 1999). Sohlberg and Mateer's APT approach to the rehabilitation of attention involves cognitive (attention) remediation within the larger context of a holistic rehabilitation program for TBI. Cicerone and colleagues reported a randomized control trial comparing a standard interdisciplinary neuro-rehabilitation program with a more 'comprehensive holistic neuropsychologic' rehabilitation program. They found that the holistic rehabilitation approach was associated with greater confidence in being able to manage the emotional and cognitive symptoms that are the result of TBI (Cicerone, Mott, Ajulay, Sharlow-Galella, Ellmo, Paradise et al., 2008). Cicerone and colleagues suggested that this may due to the holistic rehabilitation approach emphasising the "...self-regulation of cognitive and emotional processes" (p. 2239) as a core component of rehabilitation.

Attention deficits are common after even mild TBI (Hannay et al., 2004). Neuropsychological and cognitive rehabilitation programs often focus on remediation of attention difficulties or strategies to help compensate for attentional deficits (Cicerone et al., 2008; Ponsford et al., 2000; Prigatano, 1999; Sohlberg and Mateer, 2001). Sohlberg and Mateer have developed a clinically useful model of attention processes which includes: a) focussed attention (basic responding to stimuli such as looking in the direction of a noise), b) sustained attention (being able to maintain attention over time during continuous activity), c) selective attention (freedom from distractibility), d) alternating attention (mental flexibility), and e) divided attention (responding to two tasks simultaneously).

Sohlberg and Mateer (2001) describe four approaches used when addressing deficits in attention following TBI. These include: a) the use of cognitive exercises to remediate and improve attention (Attention Process Training), b) the use of self-management strategies and environmental supports to compensate for attentional deficits, c) the use of aides to help keep track of important information, and d) psychosocial support. These approaches facilitate the integration of social, behavioural and emotional issues that are associated with cognitive deficits (Sohlberg & Mateer, 2001).

Attention Process Training is based on the assumption that stimulating specific processes via repetitive exercises leads to improvement in attention (Sohlberg & Mateer, 2001). The exercises, which usually resemble laboratory tasks, are often presented via computer, and are selected to target specific components of attention with which the patient is having difficulty. A sample exercise for training sustained attention may require a patient to listen for certain words presented in an audio recording and respond when the target word has been identified. For selective attention, target stimuli may be required to be selected from a number of irrelevant stimuli such as a moving background.

Another of Sohlberg and Mateer's (2001) approaches to the rehabilitation of attention is the use of self-management compensatory strategies or external supports designed to reduce the effects of attention deficits. Self instructional routines can be designed to help the individual remain focussed on a task or activity. They include strategies such as orienting procedures (e.g. setting a watch to beep at regular intervals and then asking the question "Am I on task?" when it beeps), and pacing (e.g., doing difficult tasks early in the day to avoid the effects of fatigue on attention) (Sohlberg & Mateer, 2001).

Case studies and small group studies provide some support for the utility of APT. Palmese and Raskin (2000) reported using APT-II with three individuals with mild traumatic brain injury who had persisting difficulties in attention including divided attention, sustained attention and selective attention. These difficulties were targeted using APT-II. The training program was tailored to each individual's cognitive profile and was hierarchical in design, building upon those attentional and cognitive skills that remained relatively intact. It involved the manipulation and repetition of stimuli (auditory and visual), with tasks becoming progressively more complex. Participants underwent 10 weeks of cognitive retraining (APT-II) followed by six to seven weeks of educational computer programmes, educational videos about brain injury, and mental games and puzzles. All three individuals were reported to have shown some degree of improvement from pre- to post-testing. The authors reported maintenance of benefits up to six weeks without the retraining programme, but acknowledged that the changes may not have been specific to the APT-II programme (Palmese & Raskin, 2000). Another study reported case studies of two severe TBI patients undertaking training using Sohlberg and Mateer's APT (Pero, Incoccia, Caracciolo, Zoccolotti, & Formisano, 2006). Pero and colleagues reported improved functioning for both patients as measured on a functional scale evaluating attention. In particular, they reported improvements in selective attention (Pero et al., 2006).

The above discussion highlights the complicated processes involved in attention that are often interrupted following TBI. Researchers have found widespread utility for rehabilitation programs that utilise a holistic approach that takes into account both pre and post injury factors (Cicerone et al., 2008). Clinical models for the rehabilitation of attention such as Sohlberg and Mateer's Attention Process Training focus on processes such as focussed, sustained, selective, alternating, and divided attention to guide rehabilitation efforts.

1.8. Perceptual load theory and rehabilitation of selective attention

One specific attentional process that is targeted in programs such as Attentional Process Training is selective attention. Sohlberg and Mateer (2001) emphasise that treatment models should be grounded in attention theory; however, when it comes to selective attention, there has been decades of dispute about the mechanisms involved (Driver, 2001; Lavie & Tsal, 1994). As discussed previously in section 1.2. Lavie and Tsal (1994) argued that the apparent differences between early and late selection theories could be adequately explained by perceptual load theory. Lavie (1995) convincingly demonstrated that high load displays lead to selective attention consistent with early selection theories, and that low load displays leave spare capacity for distractors to be processed consistent with late selection theories.

Although there is a growing body of evidence supporting the perceptual load hypothesis, both with neurologically intact participants (e.g., Lavie, 1995; Lavie & Cox, 1997) and some neuropsychological patients such as those described in section 1.4 (Kumanda & Humphreys, 2002; Lavie & Robertson, 2001), no research to date has used perceptual load paradigms to investigate the attentional difficulties associated with mild to moderate TBI. If reduced distraction from irrelevant stimuli can be predicted by manipulating the perceptual load of a relevant task, then this theory may be useful for informing rehabilitation strategies for those that have difficulty with attention and are easily distracted, such as those with mild to moderate TBI.

1.9. Rationale for the current study

The aim of this thesis was to investigate the relationship between selective attention difficulties associated with mild to moderate TBI and perceptual load. Attention difficulties are amongst the most debilitating deficits demonstrated by TBI patients. Selective attention difficulties have a detrimental impact on patients' ability to inhibit inappropriate responses, resulting in difficulty selecting the correct goal from many possibilities in the environment. Patients may also become distracted by objects in their environment which are irrelevant to their course of action (Ries & Marks, 2005), and these deficits present a significant obstacle to a return to independent living.

Experimentally, selective attention and distractibility may be assessed by measuring how sensitive the individual is to irrelevant stimuli (distractors) in the environment while they attempt to 'focus in' and select a pre-determined target stimulus. In neurologically intact participants, irrelevant information in the environment is processed by the visuomotor system and alters actions to the goal. Response times to targets increase and accuracy is reduced when distractors are present (Erikson & Erikson, 1974; Lavie & Tsal, 1994). Distractor interference paradigms, moreover, have proved useful in investigating cognitive function in neurological populations, in particular anarchic hand syndrome and left-sided neglect (Kritikos, Breen, & Mattingley, 2005; Riddoch, Humphreys, & Edwards, 2000).

Importantly, the magnitude of interference from distractors is modulated by task demands. When the task is easy and does not fill attentional capacity, attentional resources are available to be allocated to irrelevant information, leading to distractor interference. Conversely, when the task is difficult and requires full attention, there are limited resources available to be allocated to irrelevant information; thus the extent of distractor interference is reduced (Lavie & Tsal, 1994). One commonly used method of manipulating the level of difficulty (or load) of the task is to specify searching for the target based on a single feature, such as a specific colour (low load, high interference) or a conjunction of two features, such as the combination of a specific colour and shape (high load, low interference; Lavie, 1995).

Lavie (1995) manipulated the perceptual load of visual selective attention tasks using reaction time paradigms with relatively simple stimuli (letters and coloured circles and squares). In these experiments, Lavie demonstrated that perceptual load could be manipulated by instruction alone, without the need to present more visually complex stimuli. However, the ability to generalise this task to everyday experience is limited, because most visual objects are not accompanied by a separate and discrete identifying marker. A more ecologically valid task may be the combination of the target and the identifying marker within the same object, for example, a picture of a cup with a coloured shape on it.

1.9.1. General research aims and hypotheses

The general aim of this research was to investigate whether the perceptual load model (found to be applicable with neurologically intact persons) can also be applied with people who have had a mild/moderate TBI. In order to test this, several computer based tasks were designed to replicate Lavie's (1995) perceptual load experiments. In computer task A of the current research, the computer task used the same simple visual targets and distractors (i.e. separate letters and coloured shapes) as in Lavie's experiment 2a (1995). In computer task B of the current research, a second task used more ecologically valid stimuli in the form of line drawings of drink containers/receptacles (cup, glass, bottle) with coloured shapes, creating a series of single stimuli containing all the necessary information for making a response. Reaction times and errors were measured as dependent variables.

The general hypothesis here was that for people with mild to moderate TBI, distractor congruence would affect reaction times to the relevant target only under conditions of low load. This is because, according to the perceptual load hypothesis, processing of distractors should only occur under conditions of low load. Incompatible distractors are incongruent with the target and evoke response competition leading to slower reaction times and more errors. Neutral distractors evoke no response competition or facilitation as they are not associated with any required response and provide a baseline with which to compare the interference effects (differences in reaction times and error rates) of the incompatible distractors. Compatible distractors are identical in shape to the presented target representing congruence between distractor and target. However, previous research has shown that using identical physical features for both distractor and target can lead to conflicting results, including both interference effects (Bjork & Murray, 1977; Estes, 1972; Santee & Egeth, 1982) and facilitation effects (Erikson, Gottel, St. James, & Fournier, 1989) on relevant target processing. Because of the ambiguous effects associated with compatible distractors, relative differences in reaction time and error rates between incompatible and neutral distractors provide the most robust way to measure the effects of distractor processing under different conditions of perceptual load. The inclusion of compatible distractors in this study was to prevent any predictable relation between the presentation of distractor types and the particular target shown because any such correlations are known to affect performance (Lavie, 1995).

Under conditions of high perceptual load, distractor processing should be minimal or eliminated completely, and should not affect the relative reaction times to the target (Lavie, 2005). In addition to this, the mild to moderate TBI group will be more affected on the computer tasks and tests of attention than controls because of their attentional deficits.

1.9.2. Specific hypotheses

Using two computer tasks (one replicating Lavie's experiment 2a (1995) and another computer task using more ecologically valid stimuli), the broad aim was to investigate whether manipulating perceptual load using only verbal instruction would modulate processing of distractors in a group of mild to moderate TBI patients with selective attention difficulties and a control group. In addition, participants were also administered a brief battery of neuropsychological tests assessing premorbid intellectual functioning, memory and attention. Attention deficits are common following even mild TBI. Therefore, it was hypothesised that TBI participants in this study would display poorer performance on the tests of attention than control participants.

It was further hypothesised that for both computer tasks, the level of perceptual load would predict distractor effects on target processing across both TBI and control groups. Both TBI and control groups should show distractor effects under conditions of low load (single feature detection) as measured by response times and number of errors. Under conditions of low load, perceptual resources are not exceeded and spare capacity should be available for automatic processing of distractors, resulting in slower reaction times with more errors in the presence of incompatible compared with neutral distractors.

Neither the TBI group nor the control group should show differential distractor interference effects under conditions of high load (conjunction of features) as measured by response times and number of errors. Under conditions of high load, perceptual resources should be exceeded with reduced capacity available for processing distractors, resulting in the reduction or elimination of differences in reaction times and error rates in the presence of both incompatible and neutral distractors.

The pattern of responses on the computer tasks should be consistent across both TBI patients and controls; however, it was hypothesised that increased distractor interference effects should lead to slower reaction times and more errors for the TBI group compared to controls due to the TBI group's deficits in selective attention processes.

CHAPTER 2 - METHOD

2.1. Participants

2.1.1. TBI participants

Fifteen patients from the Ballarat Health Services – Acquired Brain Injury Service who were rated as having sustained a mild to moderate TBI by the service's rehabilitation physician were recruited for the study. Participants were excluded from the study based on the following criteria: history of severe TBI (GCS equal or less than 8, LOC greater than 6 hrs, PTA greater than 24 hours); presence of any visual problems including diplopia, field defects or inattention; history of non-insulin dependent diabetes mellitus (NIDDM), epilepsy and other medical conditions known to have associated neurological effects; unable to see stimuli clearly (self-report and discrimination test using computer task stimuli); poor performance on the RAVLT (less than 2 standard deviations below the mean for their age); presence of any hemiplegia or motor control difficulties (self-report); history of psychiatric condition (self-report) or high scores on the HADS anxiety or depression scale at baseline testing.

One female recruit was excluded due to the presence of posttraumatic stress disorder and was undergoing treatment from a clinical psychologist at the time of the study. In addition to this, two male recruits decided to withdraw prior to the initial session because of location and travel difficulties. Therefore a total of 12 participants with mild to moderate TBI were included in the study (4 females, 8 males; age range 20-47 years, M = 32, SD = 8.65).

2.1.2. Control participants

Twelve healthy control participants (7 females, 5 males; age range 21-48 years, M = 35, SD = 9.55) were included in the study. Potential participants were screened according to the following exclusion criteria: Less than 18 years or greater than 50 years of age; history of head trauma or any loss of consciousness; history of non-insulin dependent diabetes mellitus (NIDDM), epilepsy and other medical conditions known to have associated neurological effects; unable to see stimuli clearly (self-report and discrimination test using computer task stimuli); poor performance on the RAVLT (less than 2 standard deviations below the mean for their age); presence of any hemiplegia or motor control difficulties (self-report); history of psychiatric condition (self-report) or high scores on the HADS anxiety or depression scale at baseline testing. No control recruits were excluded on the basis of these criteria.

2.2. Apparatus and materials

2.2.1. Screening interview

Participants completed a semi-structured interview (see Appendix B) which asked for demographic information and relevant history of brain trauma or illness including: date of birth, age, gender, handedness, and years of education. Participants were also screened for the presence of any of the exclusion criteria conditions outlined above.

For the TBI group, participants were asked for the date of injury and their medical files were reviewed for evidence of TBI and severity (GCS and PTA scores, loss of consciousness, imaging reports) as documented by medical staff. Combinations of these indicators were used by the Rehabilitation Specialist (a physician) leading the BHS Acquired Brain Injury Service to determine the severity of the injury. Only those patients given a mild to moderate rating were approached to participate in the study using the following guidelines: Mild TBI (GCS 13-15; PTA less than 60 minutes; duration of coma less than 20 minutes) and moderate TBI (GCS 9-12; PTA less than 6 hours; duration of coma between 1 to 24 hours).

2.2.2. Cognitive tasks

a) Estimated premorbid intellectual functioning

Wechsler Test of Adult Reading (WTAR)

The Wechsler Test of Adult Reading (WTAR; The Psychological Corporation, 2001) is a test commonly used to estimate premorbid intellectual functioning. Participants are required to read aloud a series of 50 irregular words in ascending order of difficulty. The score is the number of words correctly pronounced. The WTAR shows excellent internal consistency with coefficients ranging from .90 to .97 in the U.S. standardization sample across the various age groups, and very good test-retest correlations ($r>.90$). WTAR scores correlated highly with the Verbal IQ ($r=.75$), Verbal Comprehension ($r=.74$) and Full Scale IQ ($r=.73$) indices from the Wechsler Adult Intelligence Scale - Third Edition (WAIS-III, The Psychological Corporation, 1997). The WTAR correlates moderately with the Working Memory ($r=.62$), Performance IQ ($r=.59$), Perceptual Organisation ($r=.56$) and Processing Speed ($r=.47$) indices from the WAIS-III.

The WTAR was administered in accordance with the standard administration procedures. Premorbid intellectual functioning was estimated based on the U.S. normative data incorporating the WTAR standard score and demographic variables (WTAR-Demographics-Predicted WAIS-III and WMS-III Scores for the U.S. Standardization Sample, Ages 20-89) as described in the WTAR manual (The Psychological Corporation, 2001).

b) Selective attention

Test of Everyday Attention (TEA)

The Test of Everyday Attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) was developed and validated as a measure of attentional performance based on Mirsky's model of attention (Mirsky et al., 1991). The TEA assesses different aspects of the attentional system in terms of their impact on daily life, and includes two subtests measuring visual selective attention: Map Search and Telephone Search.

In the Map Search task, participants search for symbols (e.g., a knife and fork sign representing eating facilities) on a colour map of a metropolitan area. This is an age-sensitive subtest which is usable with almost all brain-damaged patients. Participants are given two minutes to search for 80 targets. There are two scores relating to the number of targets identified at one-minute and two-minute time periods. The Telephone Search task requires participants to look for key symbols while searching through pages in a simulated telephone directory. The score for this task is based upon the time taken to identify each target.

The TEA has several alternative forms that have been validated and normed on the same population, allowing normative data to reflect the practice effects seen when participants repeat the same test. In the current study, the TEA was used to assess the TBI patients' current level of daily functioning at both time 1 (Version A) and time 2 (Version B) testing sessions. These subtests were administered in accordance with the standard administration procedures, as described in the TEA manual (Robertson et al., 1994). The TEA manual reports test-retest reliability coefficients between Versions A and B administered 1 week apart as .83, .86 and .86 for Map Search (1 minute), Map Search (2 minute) and Telephone Search scores respectively.

c) Attention, speed and mental flexibility

Trail-making Test

The Trail Making Test (TMT: Strauss, Sherman, & Spreen, 2006) is a measure of speed, attention and mental flexibility. There are two parts to this test. Part A consists of an A4 size piece of paper with a series of 25 numbered circles placed in a predetermined pattern. Participants are asked to draw a continuous line from one circle to the next in ascending order of numbers. Part B is similar but includes the added difficulty of circles labelled with either letters or numbers. Participants are asked to draw a continuous line from one circle to the next but alternate from a number to a letter in the following manner: 1-A-2-B-3 and so on. For both parts A and B, the score is the time taken to complete the task. Test-retest reliability estimates reported in Strauss et al. (2006) for a range of neurological groups ranged from .69 to .94 (Part A) and .66 to .86 (Part B). The TMT has been shown to have good validity for use with a number of populations including TBI patients (Lange et al., 2005), and across different versions of the test (Atkinson et al., 2010). These subtests were administered in accordance with the standard administration procedures, as described in Strauss et al., (2006, p. 656).

d) Verbal memory

Rey Auditory Learning Test (RAVLT)

Rey Auditory Verbal Learning Test (RAVLT: Strauss et al., 2006) is a test used to assess verbal learning and memory. Participants are presented with a list of 15 words spoken at a rate of one word per second. They are then asked to recall as many words as they can. The list is presented five times enabling the participant to learn more words with each presentation. They are then asked to recall the words after a 20 to 30 minute delay. Scoring reflects the number of words recalled at each trial. Strauss et al., (2006) reported high internal reliability for the total score over five trials (coefficient alpha = .90) and test-retest reliabilities ranged from r=.60 to r=.70 for trial 5 and delayed-recall trials. This test was used to assess verbal memory and give an indication of the TBI patients' capacity to remember verbal instructions. It was administered using the standard procedures provided in Strauss and colleagues (2006, p. 784).

2.2.3. Mood

Hospital Anxiety and Depression Scale (HADS)

The Hospital Anxiety & Depression Scale (HADS; Zigmond & Snaith, 1983) was used to screen for the presence and severity of anxiety and depression. The HADS is a self-report inventory asking participants to rate the presence of a range of anxiety and depression related symptoms. This scale is a commonly used measure of symptom severity in hospital and outpatient populations (e.g., Godefroy, Hell, & Spitz, 2010; Hobbs, 2008; Tagay, Herpertz, Langkafel, Erim, Bockisch, Senf et al., 2006).

2.2.4. Computerised perceptual load tasks

2.2.4.1. Computer task A

Computer task A was designed to replicate Lavie's original experiment (Lavie, 1995; experiment 2A) where she used identical stimuli in both the low and high load conditions and manipulated attentional load using a single feature (colour in the low load condition) and a conjunction of features (combinations of colour and shape in the high load condition). Whereas Lavie (1995) used a tachistoscope to present the experimental stimuli and record responses, this study used an IBM compatible computer attached to a VGA colour monitor (set to 1024 x 768 pixels) and the DmDX/DMASTR software developed at Monash University and the University of Arizona (Forster & Forster, 2003). The latencies of responses (reaction time, RT) were collected to the nearest millisecond (ms), and errors were recorded when participants failed to respond or responded to the stimuli with the incorrect hand.

Coloured and black stimuli were presented on a white background on a VGA screen using an IBM compatible Pentium computer. A coloured (red or blue) square or circle and a black letter were presented in the centre of the screen with 0.70° of contour-to-contour separation between them (see figure 2).

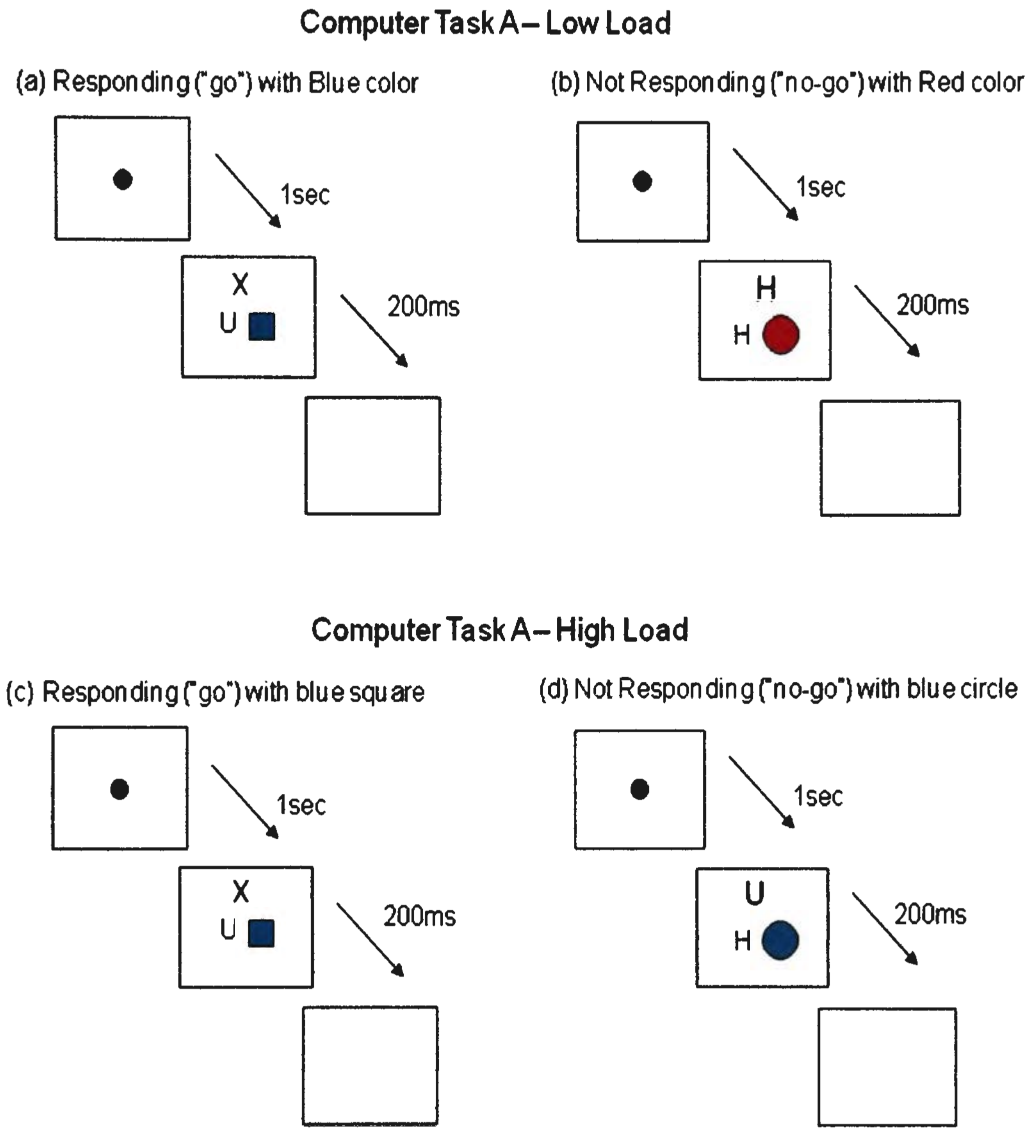

Figure 2: Examples of stimuli used in Computer task A: a) "go" trial for the Low Load condition with a neutral distractor; b) "no go" trial for the Low Load condition with a compatible distractor; c) "go" trial for the High Load condition with a neutral distractor; d) "no go" trial for the High Load condition with an incompatible distractor.

Each of these stimuli appeared randomly but with equal probability either to the left or to the right side of the mid-screen fixation point. The target letter was either the capital letter H or U. A distractor letter larger than the target appeared randomly and equiprobably either above or below the midpoint, separated by 1.30° of visual angle from the nearest contour of the central stimuli. The distractor letter was equally likely to be incompatible with the target (the letter U when the target letter is H, or vice versa), compatible with the target (same letter as the target letter), or neutral in relation to the targets (the letter X, which had no defined response in the experiment).

In the low load (feature demand) condition, the colour of the shape was blue for 75% of the trials and red for 25% of the trials. For each of the colours, the shape was equiprobably a square or a circle. In the high load (conjunction demand) condition, either a blue square or a red circle appeared on 75% of the trials, and either a red square or a blue circle appeared on the remaining 25% of trials. The presentation order of the coloured shapes, their locations, and each of their combinations was randomised using the DmDX/DMASTR software's random function.

2.2.4.2. Computer task B

Computer task B used more ecologically valid stimuli that included all components required for a response decision within the one target object, unlike computer task A which used a coloured shape flanking the target. Using the DmDX/DMASTR software, line drawings (cup, glass or bottle) on a white background were presented on a VGA screen using an IBM compatible Pentium computer (see figure 3). The target (either a cup or a glass) appeared at the centre of the screen. Superimposed on the target object was a coloured shape (red or blue; circle or square). A distractor object larger than the target appeared randomly and equiprobably either above or below the centre, separated by greater than 1 degree of visual angle from the nearest contour of the central stimuli. The distractor was equally likely to be incompatible with the target (a cup when the target shape is a glass, or vice versa), compatible with the target (same shape as the target shape, e.g. cup when the target is a cup), or neutral in relation to the targets (i.e. a bottle with an aqua coloured diamond, where the bottle, colour and diamond shape had no defined response in the experiment leading to a neutral distractor).

In the low load (feature demand) condition, the colour of the shape was blue for 75% of the trials and red for 25% of the trials. For each of the colours, the shape was equally likely to be a square or a circle. In the high load (conjunction demand) condition, either a blue square or a red circle appeared on 75% of the trials, and either a red square or a blue circle appeared on the remaining 25% of trials. The order of the coloured shapes, the objects, and each of their combinations was randomly presented according to the DmDX/DMASTR software's random function.

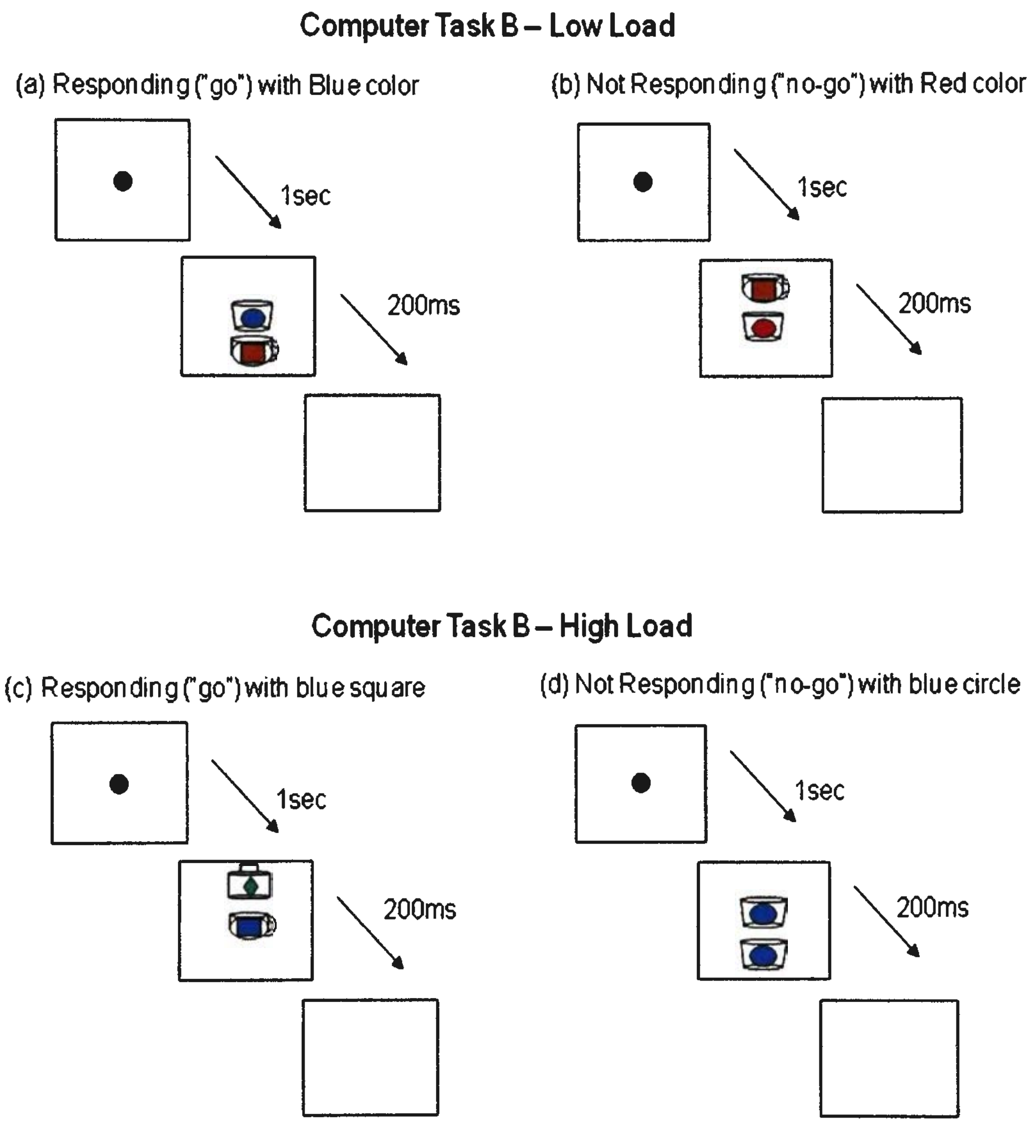

Figure 3. Examples of stimuli used in computer task B: a) "go" trial for the Low Load condition with an incompatible distractor; b) "no go" trial for the Low Load condition with an incompatible distractor; c) "go" trial for the High Load condition with a neutral distractor; d) "no go" trial for the High Load condition with a compatible distractor.

2.3. Procedure

2.3.1. Recruitment

a) TBI participants:

Potential participants were identified by Ballarat Health Services – ABI Service staff Rehabilitation Physician as being in the post-acute phase of recovery following mild to moderate TBI. Participants were informed of the research project by their ABI case-manager and given a copy of the Information to Participants form (see Appendix C) and asked if the Investigator could contact them. Those patients who agreed to the investigator contacting them were contacted by telephone and given further information about aims and demands of the research. They were informed that their participation was anonymous, that they were free to withdraw at any time, and that withdrawing would not impact in any way on any programmes or services they may be involved in through Ballarat Health Services. Those who agreed to continue were given an appointment to attend the Peter Heinz Rehabilitation Centre to commence participation.

b) Control participants:

Participants were recruited from a convenience sample of friends and/or colleagues/associates of the investigators via verbal invitation to participate. They were provided with a copy of the Information to Participants (Healthy Participants) form (see Appendix C) and given the opportunity to clarify any questions they had about the research and their involvement. They were able to choose whether or not to participate in the study, and their participation was not be coerced. They were informed that their participation would remain anonymous, and that they were free to withdraw at any time.

2.3.2. Order of testing

In the **first testing session,** after obtaining written informed consent (see Appendix C for consent form), participants were administered the structured interview and baseline battery, as well as version A of the Map Search and Telephone Search subtests of the TEA. Participants were then randomly assigned to complete either Computer Task A or Computer Task B first. In addition to this, the order of perceptual load (low or high) and hand-to-letter correspondence (Computer Task A) or hand-to-object correspondence (Computer Task B) was also randomly assigned in the first testing session.

In the **second testing session** (approximately 7 days later), participants were administered Version B of the Map Search and Telephone Search subtests of the TEA. Participants who completed computer task A in the first session completed computer task B in the second session (and vice versa for those participants who completed computer task B first).

2.3.3. Administration of computer tasks

Computer task A

Participants were seated in a dimly lit room with their heads supported by an adjustable chin rest 85cm from the VGA computer screen. The chin rest was adjusted for all participants so their eyes were level with the fixation point on the display, and the midline of their bodies was in line with the centre of the VGA monitor.

Before each trial, a black fixation point appeared at the centre of the display for 1000 ms. This was immediately replaced by the target display for 200 ms. Participants were then required to press one of two buttons in accordance with response instructions (the 'shift' keys positioned to either the right or left of the keyboard with either their right or left hand respectively) as fast as they could (‘go’ trials) while avoiding errors and inhibiting responses to some trials (“no-go” trials). Participants were instructed to ignore the distractor.

Each task demand (low or high load) condition was presented in three blocks of 48 trials (for a total of 144 trials per condition), presented in one session per task demand condition. Each session began with 24 practice trials, except when participants received the high load condition first in which case they were allowed 48 practice trials.

Participants were instructed to respond to letter targets in the centre of the screen while ignoring distractors. In the low load condition, participants were instructed to respond only when the target letter (H or U) appeared with a blue-coloured shape. In the high load condition, participants were instructed to respond only when the target letter was accompanied by a shape with the appropriate conjunction of features (blue square OR red circle). They were instructed to respond to the target letter H by pressing the left shift key, and to the target letter U by pressing the right shift key. The instructions were read aloud to the participants and were also displayed on the computer monitor prior to the commencement of each block. The instructions were repeated until the participant indicated they understood the task and were able to demonstrate the correct hand to letter correspondence and response rule.

At the end of the practice trials and immediately prior to the experimental trials, the instructions were again presented to remind the participant of the rules. Participants were then instructed via the monitor to press the spacebar when they were ready to begin the experimental trials. There was no assistance given when the participant was completing the experimental trials.

Each condition of three blocks took 12 minutes to complete. There was approximately five minutes break between conditions. In addition, the practice trials took approximately two to four minutes to complete. In total, the administration of all four conditions took approximately 65 minutes including around five minutes of initial instructions and familiarisation with the task.

Reaction times and number of errors for each condition were averaged across conditions for each participant. Errors were defined as: (a) no response within 2000 ms of presentation of the target, and (b) response with incorrect hand.

Computer task B

With the following exceptions, the procedure for computer task B was the same as that outlined for computer task A:

Participants were instructed to respond to line drawing targets in the centre of the screen while ignoring distractor drawing placed above or below the target. They were instructed to respond to the target drawing of a cup by pressing the left shift key, and to the target drawing of a glass by pressing the right shift key. In the low load condition, participants were instructed to respond only when the target drawing (cup or glass) contained any blue-coloured shape. In the high load condition, participants were instructed to respond only when the target drawing contained either a blue square or a red circle.

2.3.4. Design and data analysis

Analysis of demographic and screening data, and neuropsychological test scores was limited due to the small sample sizes and violation of the assumption of normality for some variables. Because of small sample sizes, the assumption of normal distribution was tested using the Shapiro-Wilks Test (see Appendix D). Independent samples t-tests were used to compare the two groups where the data was deemed to be normally distributed. For comparisons involving variables that could not satisfy the assumption of normal distribution, the non-parametric Kolmogorov-Smirnov Z test was used as this has been noted to have utility over other non-parametric tests (e.g. Mann-Whitney U test) for sample sizes of less than 25 participants (Field, 2005). Pearson's r was used to calculate effect sizes for all comparisons.

Mean RTs and error rates for each participant were computed as a function of two within-subjects variables for Task Load (low or high) and Distractor Type (incompatible, neutral or compatible) and a between-subjects variable for Group (TBI or control). Single data points that were greater than two standard deviations from the mean for that condition were treated as outliers and removed from the data and a new mean was calculated. The General Linear Modelling (GLM) module of SPSSx (version 16) was used to conduct a series of repeated measures factorial design analyses (ANOVA) of these variables. Partial eta-squared ($\eta \rho^2$) was used as a measure of effect size for these analyses.

CHAPTER 3 - RESULTS

3.1. Demographic and neuropsychological data

3.1.1. Demographic characteristics of the sample

Table 2 shows the results of independent samples t-tests and Kolmogorov-Smirnov Z tests which were used to compare TBI participants and control participants on age, education level, Hospital Anxiety and Depression Scale (HADS) and the Wechsler Test of Adult Reading (WTAR).

Table 2. Independent samples t-tests (*t*) and Kolmogorov-Smirnov Z tests (*D*) for age, education, HADS and WTAR scores.

	TBI group (n=12)		*Control group (n=12)*					
	M	*SD*	*M*	*SD*	*t*	*D*	*p*	*r*
Age	32.25	8.65	34.83	9.55	-.695	-	.50	.15
Education	11.75	0.87	14.50	2.32	-3.85	-	.002	.72
HADS Anxiety	9.42	4.42	5.58	1.93	2.753	-	.01	.51
HADS Depression	7.83	4.84	1.50	1.98	-	1.63	.01	.33
WTAR Predicted IQ	98.12	8.49	107.17	8.48	2.597	-	.02	.48

HADS= Hospital Anxiety and Depression Scale; WTAR= Wechsler Test of Adult Reading

As a group, control participants had significantly more years of education $t(22) = -.695$, $p<.05$, and significantly higher predicted IQ $t(22) = 2.597$, $p<.05$ than TBI participants. There was no significant difference in age between the two groups. TBI participants rated significantly higher levels of anxiety $t(22) = 2.753$, $p<.05$, and depression $D = 1.63$, $p<.05$, than control participants.

Clinical information describing the TBI group is presented in Table 3. Physician ratings of severity classified the majority of TBI participants as having mild or mild to moderately severe injuries (75 percent). The remaining participants were classified at moderate severity of injury with no participants being classified beyond this rating. The minimum time of assessment post-injury was 3 months, with the majority of participants being assessed within 12 months of injury.

Table 3. Clinical data for TBI participants.

	Total	
Doctors' rating		
Mild	7	(58%)
Mild-Moderate	2	(17%)
Moderate	3	(25%)
Time since injury (months)		
Median	9.5	
Range	3-240	
Glasgow Coma Scale		
14/15	3	
15/15	3	
Not recorded on file	6	
Posttraumatic Amnesia (hours)		
Median	2	
Range	1-6	
Not recorded on file	3	

For those participants with GCS and PTA scores documented in their medical files, both GCS scores and PTA estimates were well within the mild to moderate range. Documented CT imaging scans were available for 11 participants, with no abnormalities detected for eight participants. Documented changes on imaging scans for the remaining three participants included one participant with mild diffuse cerebral oedema, and small haemorrhages in the dorsal brain stem and left cerebella hemisphere. Another patient had an extradural haematoma in the right parietal and temporal regions, with multiple small left fronto-temporal contusions, and a small extra-axial haematoma in the left fronto-temporal region. The third participant was found to have a depressed fracture of the frontal bone with an intraparenchymal haemorrhage in the left frontal lobe. In addition, this participant also displayed a mild expressive dysphasia, and had a post-traumatic seizure one week post injury.

3.1.2. Differences between groups on neuropsychological measures

Table 4 shows the results of independent samples t-tests and Kolmogorov-Smirnov Z tests which were used to compare TBI participants and control participants on the Trail Making Test parts A and B (TMT A and TMT B), Test of Everyday Attention (TEA) subtests Telephone Search A and B and Map Search A and B, and Rey Auditory Verbal Learning Test (RAVLT).

Table 4. Independent samples t-tests (*t*) and Kolmogorov-Smirnov Z tests (*D*) for cognitive tests.

	TBI group (n=12)		*Control group (n=12)*					
	M	*SD*	*M*	*SD*	*t*	*D*	*p*	*r*
TMT A (time in seconds)	28.33	5.03	25.25	5.40	-1.448	-	.16	.29
TMT B (time in seconds)	64.17	17.60	50.17	12.58	-2.242	-	.04	.43
TEA Map Search A-1min	8.75	2.26	11.33	3.26	2.257	-	.03	.43
TEA Map Search A-2min	8.33	3.26	10.58	3.50	1.630	-	.12	.33
TEA Map Search B-1min	8.42	2.02	10.67	3.71	-	1.021	.25	.21
TEA Map Search B-2min	8.25	2.50	10.42	2.81	1.998	-	.06	.39
TEA Telephone Search A	8.17	2.41	12.00	3.67	3.027	-	.01	.54
TEA Telephone Search B	6.17	3.86	11.50	5.81	2.650	-	.02	.49
RAVLT Trial 1	5.83	1.53	7.25	2.05	-	.61	.85	.13
RAVLT Trial 5	12.58	2.07	13.25	1.77	-	.61	.85	.13
RAVLT Learning	6.75	1.49	6.00	1.95	-	.61	.85	.13
RAVLT Total	48.33	9.06	55.08	8.70	-1.862	-	.08	.37
RAVLT Delayed Recall	11.75	1.71	12.00	2.66	-	.82	.52	.17
RAVLT Recognition	14.25	0.75	14.50	0.91	-	.61	.85	.13

TMT = Trail Making Test; TEA = Test of Everyday Attention - Scale Scores; RAVLT = Rey Auditory Verbal Learning Test

On average, the control group was faster to complete TMT A than the TBI group. Although this difference was not statistically significant $t(22) = -1.448$, $p > .05$, there was a medium effect size, $r = .29$. For TMT B, the mean time to completion was significantly faster for the control group compared to the TBI group, $t(22) = -2.242$, $p = .04$, with a medium to large effect size, $r = .43$.

On average, the control group performed better on all of the Test of Everyday Attention Map Search and Telephone Search subtest measures. These differences were significant for the following subtests: Map Search A – 1 minute (t (22) = 2.257, p = .03, with medium effect size, r = .43); Telephone Search A (t (22) = 3.027, p = .01, with large effect size, r = .54); and Telephone Search B (t (22) = 2.650, p = .02, with large effect size, r = .49). The difference between groups on Map Search B – 1 minute was not significant (D = 1.021, p >.05), and the effect size was small to medium, r = .21. The control group performed better on average than the TBI group on the 2 minute measures of both Map Search A and Map Search B. Although the difference between groups on Map Search A – 2 minute scores was not significant $t(22) = 1.630, p > .05$, there was a medium effect size, r = .33. The difference between groups on Map Search B – 2 minute approached significance (p = .06) and there was a medium effect size, r = .39.

There were no significant differences between groups found for any of the RAVLT scores. However, the RAVLT Total score which is the sum of the five learning trials approached significance (D = -1.862, p = .08) and there was a medium effect size found for this difference, r = .37.

3.2. Computer task A

3.2.1. Computer task A analysis of reaction times (RTs)

The full factorial model including task load, distractor type, group, and presentation order factors was analysed using the GLM repeated measures module of SPSSx (version 16) and showed no effect of the two presentation order variables or any interaction involving these variables (p > .10). The data from the two different presentation order datasets were therefore pooled. A GLM repeated measures analysis (Group X Task Load X Distractor Type) showed there was no main effect for the group variable $F(1, 22) = 1.067, p >$

.10, $\eta p^2 = .05$, or interaction between group and distractor type or task load ($p > .10$). That is, there were no significant differences in mean RTs found between the TBI and control participants. Although visual inspection of Figure 4 (showing mean reaction times (RTs) across all conditions of computer task A for both the TBI and control group) suggests the presence of group differences for the low load task, this was not borne out by the GLM reported above. Despite the absence of a group main effect, additional exploratory analyses were run on the TBI and control groups on their own. There were no main effects or interactions for either group, $p > .05$ for all comparisons (see Appendix E). Data for the two groups were pooled for further analysis.

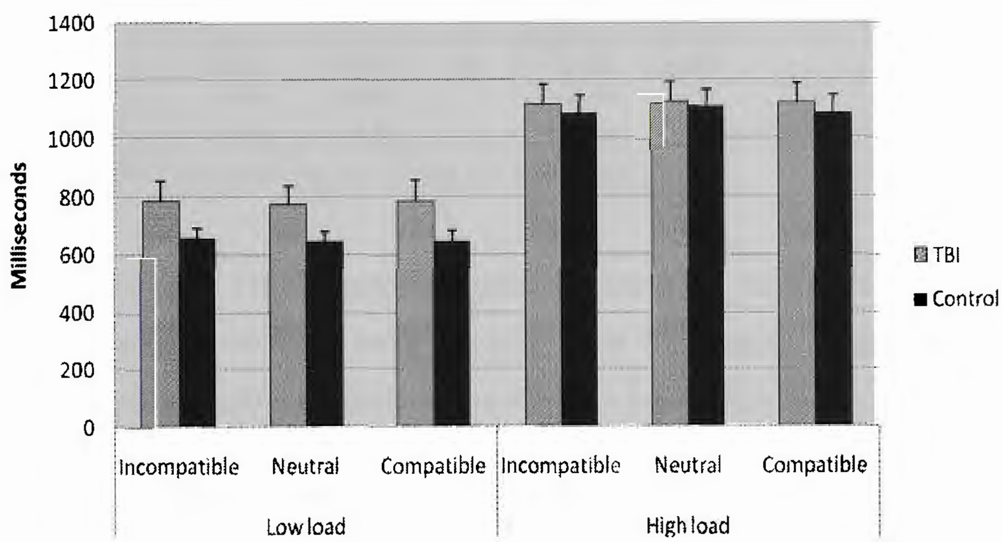

Figure 4: TBI and control participants' mean RTs (bars represent standard error) in milliseconds on Task A according to load (low or high) and distractor type (incompatible, neutral or compatible with the target).

Table 5 shows the mean RTs and error rates for the pooled data. Visual inspection of the means in table 5 comparing incompatible distractors to neutral distractors showed participants were 13 ms slower on average when responding to incompatible distractors when compared with responding to neutral distractors in the Low Load condition. The direction of this difference appears consistent with Lavie's (1995) perceptual load theory and suggests interference effects on RTs from the incompatible distractors. However, in the high load condition, responses to the incompatible distractors were an average 15 milliseconds faster than for the neutral distractors. The trend of incompatible distractors facilitating faster responses was consistent with data reported by Lavie (1995). A similar pattern was seen on mean RTs for the compatible versus neutral distractors across low load (9 milliseconds slower for compatible distractors) and high load conditions (13 milliseconds faster for compatible distractors).

Table 5. Computer task A mean reaction times (in milliseconds), standard errors, and percentage errors for pooled data.

	Distractor Type				
Low Load	I	N	I-N	C	N-C
Mean	720.13	707.08	13	716.07	-8.99
SE	39.08	39.09		41.72	
%Errors	2.65	2.56		1.89	
High Load	I	N	I-N	C	N-C
Mean	1100.89	1116.17	-15	1103.2	12.97
SE	44.94	43.86		43.78	
%Errors	8.99	8.81		9.56	

n=24, I = Incompatible, N = Neutral, C = Compatible

These findings on visual inspection were not borne out by statistical analysis. A GLM repeated measures analysis (Task Load X Distractor Type) of the RT data showed a significant main effect of Task Load, $F(1, 23) = 117.04$, $p < .000$, $\eta\rho^2 = .836$, demonstrating that perceptual load had been effectively manipulated. However, there was no main effect for Distractor Type ($p > .05$). There was no significant interaction between Task Load and Distractor Type, $F(1, 23) = 1.73$, $p > .10$, $\eta\rho^2 = .07$ for this analysis.

3.2.2. Computer task A analysis of errors

As with RT data, the mean percentage of errors was calculated as a function of two within-subjects variables (Task Load - low or high; and Distractor Type - incompatible, neutral or compatible); and three between-subjects variables (presentation order - low or high first; Task A or B first; and group - TBI or control). GLM repeated measures factorial design analysis of these variables showed no effect of the two presentation order variables and no significant interactions involving any of the between subjects variables ($p > .10$). Therefore the two presentation order variables were pooled for further analysis. The differences in percentage errors for Group approached significance $F(1, 16) = 4.096$, $p = .06$, $\eta\rho^2 = .20$, (small effect size) and this variable was included as a between-subjects variable in subsequent analysis.

Figure 5 shows mean errors rates (percentages) across all conditions of computer task A for both the TBI and control groups.

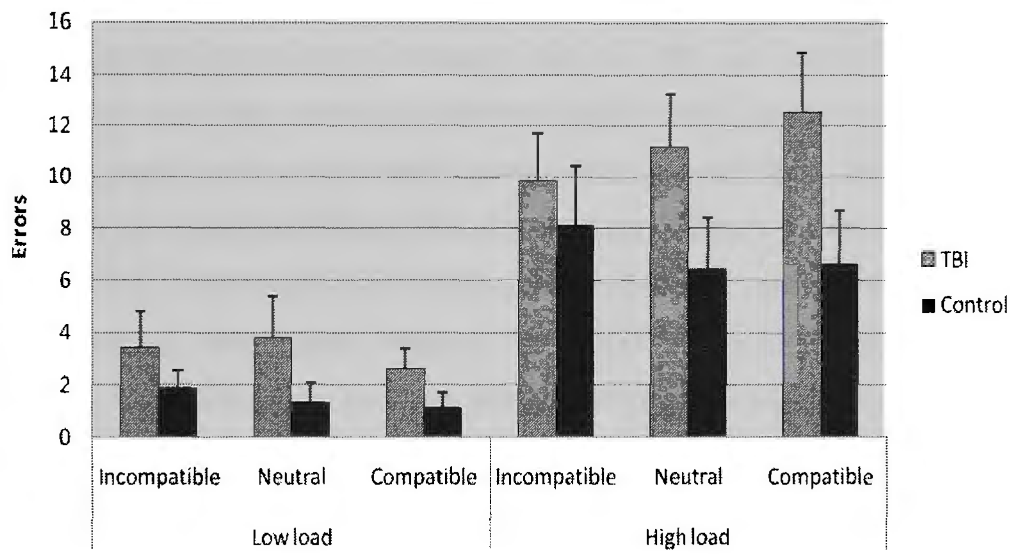

Figure 5: TBI and control participants mean percentage error rates (bars represent standard error) on Task A according to load (low or high) and distractor type (incompatible, neutral or compatible with the target).

GLM mixed repeated measures analysis (Group X Task Load X Distractor Type) found a significant main effect for Task Load ($F(1, 22) = 20.49$, $p = .000$, $\eta\rho^2 = .47$), such that there were more errors in the High Load conditions, demonstrating that perceptual load had been effectively manipulated. Whilst there was a significant main effect for Group ($F(1, 22) = 4.71$, $p < .05$, $\eta\rho^2 = .18$) with TBI participants making more errors than controls, there were no significant main affect for Distractor Type ($F(1, 22) = .02$, $p > .10$, $\eta\rho^2 = .001$). There were no significant interactions in this analysis ($p > .10$ in all cases).

3.2.3. Computer task A Discussion

The broad aim of computer task A was to investigate whether manipulating perceptual load using only verbal instruction would modulate the processing of distractors in a group of mild to moderate TBI patients with selective attention difficulties and a control group. The mild to moderate TBI participants in the current study showed impairment on a number of neuropsychological tests of selective attention when compared to the control group, thus demonstrating the presence of selective attention deficits.

It was hypothesised that for computer task A, TBI and control participants would show a similar pattern of responses across both conditions of load, but that TBI participants would show slower reaction times than controls due to their selective attention deficits. Visual inspection of figure 4 showed a trend in the direction of faster RTs for controls compared to TBI participants in the low load condition, with almost identical mean RTs in the high load condition. However these differences between groups were not statistically significant. In contrast to mean RT data, there was a significant difference found between groups on error data. TBI participants made significantly more errors than control participants, indicating partial support for the prediction that TBI participants would display poorer performance on these tasks.

Another hypothesis predicted that the incompatible distractors in the low load condition (single feature detection) would result in slower reaction times and higher error rates compared with neutral distractors, for all participants. This is because Lavie's (1995) perceptual load theory posits that the low load condition (single feature detection) should not exceed perceptual resources, leaving spare capacity for automatic processing of distractors and predicts that there will be a differential effect of distractors with incompatible distractors causing the most interference because of response competition. Although on average incompatible distractors caused increased interference (resulting in increased reaction times) compared to neutral distractors in the low load task, as predicted by perceptual load theory, the differences were not significant. This was despite the significant main effect for Load indicating that perceptual load had been manipulated. A similar result was found for errors, with no significant differences evident between distractor types in the low load condition.

A final hypothesis for computer task A predicted that distractor effects would be reduced if not eliminated under conditions of high perceptual load. Under conditions of high load (conjunction of colour and shape), perceptual resources should be exceeded leaving no spare capacity to process distractors, thus eliminating differences in RTs depending on distractor types. Visual inspection of the data showed the elimination of the pattern of responses seen in the low load condition, and there were no significant differences between RTs for incompatible and neutral distractors in the high load condition, suggesting support for this hypothesis. However, the absence of any significant results in the low load condition confounds this result making it ambiguous to interpret. This will be elaborated on in more detail in the General Discussion.

3.3. Computer task B

3.3.1. Computer task B analysis of reaction times (RTs)

Mean reaction times (RTs) for computer task B underwent GLM repeated measures analysis for the full factorial model including task load and distractor type as within-subjects variables, with group and the two presentation order factors as between-subjects variables. There was no main effect or interaction found for either presentation order variable ($p > .10$). As in computer task A, the data from the two different presentation order datasets were therefore pooled. A GLM repeated measures analysis (Group X Task Load X Distractor Type) showed there was no main effect for the group variable $F(1, 22) = .935$, $p > .10$, $\eta\rho^2 = .04$, or interaction between group and distractor type or task load ($p > .10$).

Similar to computer task A, Figure 6 (mean reaction times (RTs) across all conditions of computer task B for both the TBI and control groups) suggests the presence of group differences for the low load task. This was, however, not borne out by the GLM reported above. Although there was no group main effect, additional exploratory analyses were run on the TBI and control groups separately. Once again, there were no main effects or interactions for either group, $p > .05$ for all comparisons (see Appendix E). Data were again pooled across groups for subsequent analyses.

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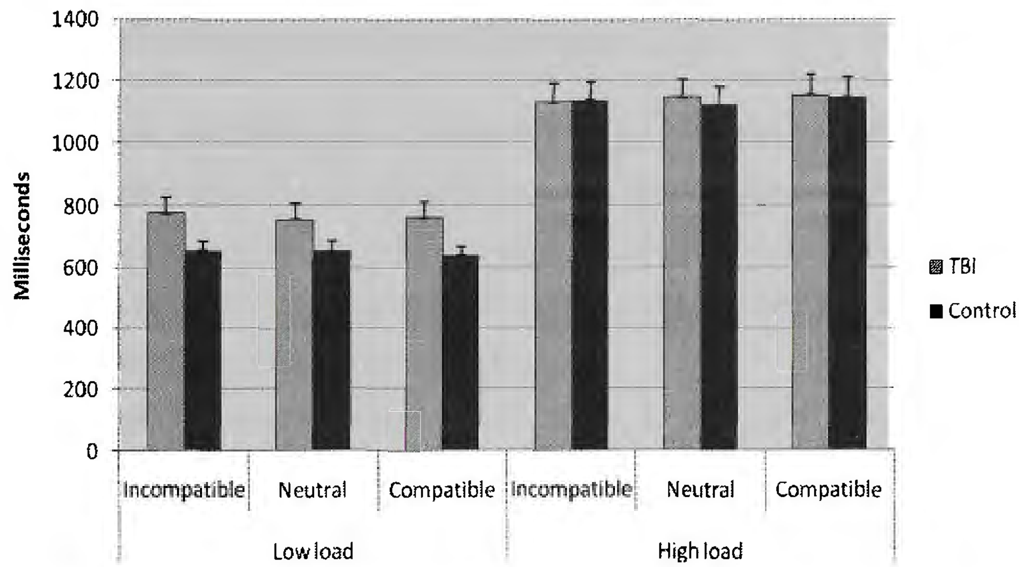

Figure 6. TBI and control participants' mean RTs (bars represent standard error) in milliseconds on Task B according to load (low or high) and distractor type (incompatible, neutral or compatible with the target).

Table 6 shows the mean RTs and error rates for the pooled computer task B data. In the Low Load condition participants were on average 12 ms slower when responding to incompatible distractors when compared to responses to neutral distractors. As in computer task A, the direction of this difference is consistent with Lavie's (1995) perceptual load theory and suggests greater interference effects on RTs from the incompatible distractors. For the high load condition, mean RTs to both incompatible and neutral distractors were almost equivalent (on average 1ms faster for neutral distractors). This was also consistent with Lavie's (1995) findings and suggests support for the hypothesis that there would be no differences on Distractor Type under conditions of high perceptual load.

Table 6. Computer task B mean reaction times (in milliseconds), standard errors, and percentage errors for pooled data.

	Distractor Type				
Low Load	I	N	I-N	C	N-C
Mean	716.23	704.67	12	699.98	4.69
SE	30.97	31.22		30.37	
%Errors	3.41	2.94		2.46	
High Load	I	N	I-N	C	N-C
Mean	1135.31	1134.34	1	1149.79	-15.45
SE	39.99	40.27		44.35	
%Errors	10.23	9.28		10.04	

n=24, I = Incompatible, N = Neutral, C = Compatible

In contrast to computer task A, inspection of RTs for the compatible versus neutral distractors across the low load condition showed a mean difference of 5 milliseconds (slower for neutral distractors). The high load condition showed a mean difference of 15 milliseconds (faster for neutral distractors). This pattern was opposite that seen in computer task A.

GLM repeated measures analysis (Task Load X Distractor Type) revealed similar results to computer task A. There was a significant main effect for Task Load $F(1, 23) = 163.6$, $p < .000$, $\eta\rho^2 = .88$, thus demonstrating that perceptual load had been effectively manipulated in computer task B. However, there was no significant main effect for Distractor Type ($p > .10$), nor a significant interaction between Task Load and Distractor Type ($p > .10$).

3.3.2. Computer task B analysis of errors

As with the analysis of computer task A, the mean percentage of errors was calculated as a function of two within subjects variables (Task Load - low or high; and Distractor Type -incompatible, neutral or compatible); and three between subjects variables (presentation order - low or high first; Task A or B first; and group - TBI or control). GLM repeated measures factorial design analysis of these variables showed no effect of the presentation order variable of low or high load first ($p > .10$) and the data was pooled for this variable in subsequent analyses.

Figure 7 shows mean errors rates (percentages) across all conditions of computer task B for both the TBI and control groups.

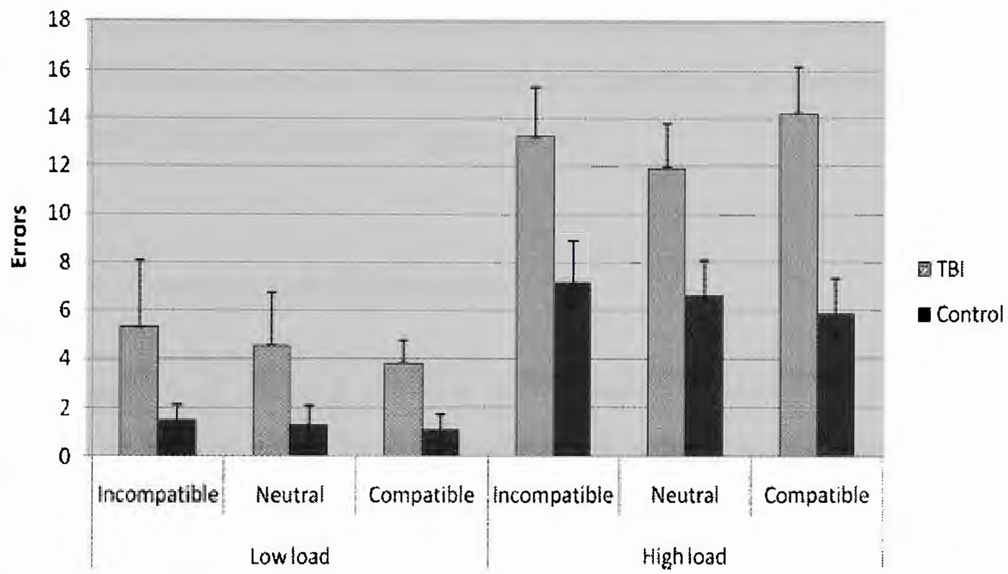

Figure 7. TBI and control participants mean percentage error rates (bars represent standard error) on Task B according to load (low or high) and distractor type (incompatible, neutral or compatible with the target).

There was a significant main effect for the order of presenting Task A or Task B first ($F(1, 16) = 5.31, p = .035, \eta\rho^2 = .25$) with higher error rates associated with Task B being presented first. As this variable was originally designed to counter balance the effects of presenting either Task A or Task B first, this variable was included in subsequent analyses of errors as a covariate to control for this variation statistically. There was a significant difference in percentage errors between groups $F(1, 16) = 12.03, p = .003, \eta\rho^2 = .43$, and this variable was included as a between-subjects variable in subsequent analysis.

A GLM mixed repeated measures analysis (Group X Task Load X Distractor Type) with presentation order (Task A or Task B first) entered as a covariate was conducted. The analysis of within-subjects factors showed there was a significant main effect for Task Load only ($F(1, 21) = 8.173, p < .05, \eta\rho^2 = .28$) demonstrating that perceptual load had been effectively manipulated after controlling for presentation order. There was no significant main effect for Distractor Type in this analysis ($F(1, 21) = .566$, $p > .10$, $\eta\rho^2 = .03$) or interaction between Task Load and Distractor Type, $p > .10$.

For the between-subjects variable and controlling for presentation order of Task A or Task B first (covariate), there was a significant main effect of Group, $F(1, 21) = 11.79$, $p < .05$, $\eta\rho^2 = .36$, such that TBI participants made more errors than controls. There were no significant interactions between Group, Task Load or Distractor Type, $p > .10$.

3.3.3. Computer task B Discussion

Visual analysis of figure 6 shows a similar pattern to computer task A with faster mean reaction times for the control group in the low load condition, with almost identical mean reaction times in the high load condition. However, results from computer task B showed no significant differences between groups on mean RTs, thus failing to provide support for the hypothesis that TBI participants would show slower reaction times than control participants.

As with computer task A, perceptual load was manipulated in task B. Although on average, RTs in task B were slower in the presence of incompatible distractors compared to neutral, the differences were not statistically significant, nor did the impact of distractor type vary depending upon the level of perceptual load, as predicted by Lavie's perceptual load hypothesis. This finding is consistent with the results of computer task A where there was no support for the hypothesis predicting slower RTs for incompatible distractors compared to neutral distractors under conditions of low load. As with computer task A, the high load conditions in task B appear to be associated with the absence of differential interference effects depending upon type of distractor.

The design of the study attempted to control for presentation order effects by randomly assigning to participants to complete either Task A or Task B first.

Task presentation order had a significant effect on error data in computer task B that was not observed in computer task A. This variation was controlled statistically by incorporating this variable into the error analysis as a covariate.

TBI participants made significantly more errors than control participants on experiment B and this trend was in the predicted direction. This provides support for the hypothesis that TBI participant's attentional difficulties would affect performance more than would be seen by control participants.

Similar to the RT data, the analysis of errors showed increased errors in the High Load condition, providing evidence that perceptual load had indeed been manipulated in computer task B. However, there was no support for the hypothesis predicting that incompatible distractors would elicit more errors than neutral distractors under conditions of low perceptual load. As with RTs, the high load conditions in task B appear to be associated with the absence of differential interference effects depending upon distractor type.

3.4. Further exploratory analysis

The above analyses revealed no differences between the groups on RTs, with TBI participants making significantly more errors than controls. Further exploratory analyses were conducted to investigate any differences within the TBI group when divided into mild versus moderate severity ratings. In these analyses, there were seven mild TBI and five moderate TBI participants (see Table 3). Kolmogorov-Smirnov Z tests for independent samples revealed no differences between the mild and moderate TBI participants on any of the cognitive tests (RAVLT, TMT, TEA), or the RT and error measures in both computer task A and B (for all, $p > .05$; see Appendix E). The lack of differences between the mild and moderate TBI participants showed that the TBI participants were a relatively homogeneous group in relation to their performances on cognitive tests and both computer tasks.

Further to this, case-wise analysis of the TBI participants' performance on computer task A showed a relative trend in the direction predicted by Lavie's perceptual load theory for eight participants. That is, three quarters of the TBI participants showed relatively less interference on RT measures in the presence of incompatible versus neutral distractors in the high load condition as compared with the low load condition. This provided another way to divide the TBI participants into two distinct groups: A group that showed a trend in the predicted direction (n=8) and one that did not (n=4). However, comparisons on baseline tests of attention (TEA) and mood (HADS) between these two groups using non-parametric Kolmogorov-Smirnov Z tests for independent samples revealed no statistically significant differences (for all, $p > .05$; see Appendix E).

A similar division of two groups within the TBI participants was identified for computer task B measures. Although there were eight cases that followed the predicted trend, these were not wholly consistent with those cases identified on computer task A. Once again, Kolmogorov-Smirnov Z tests for independent samples between these two groups of cases on baseline tests of attention revealed no significant differences at the $p=.05$ level (see Appendix E).

Non-parametric correlations (Kendall's tau) of the TBI participants' performance on baseline selective attention measures (TEA and Trail Making Tests) and experimental tasks were also conducted. Although there were no significant associations between baseline measures and RT measures for computer tasks, several significant associations were seen between TEA measures and errors on the computer tasks. For computer task A errors, there were significant negative correlations with the low load condition on Map Search 1 minute scores for both versions A and B of the TEA ($\tau = -.53$, $p<.05$ and $\tau = -.49$, $p<.05$ respectively). That is, low scores on the TEA Map Search 1 minute measure were significantly correlated with higher number of errors in the low load condition. Also, for the high load condition there were significant negative correlations on the Map Search 2 minute measures (version A and B) ($\tau = -.50$, $p<.05$ and $\tau = -.53$, $p<.05$ respectively). Poor performance on the Map Search 2 minute measures was associated with making more errors on the high load condition of computer task A. There were no significant correlations found between TEA Map Search measures and error rates for computer task B (see Appendix E).

The TEA Telephone Search version B measure showed a significant negative correlation with the high load conditions of both computer task A (τ = -.66, $p<.05$) and computer task B (τ = -.64, $p<.05$). That is, poorer performance on version B of the Telephone Search test was associated with higher error rates under conditions of high perceptual load across both experimental computer tasks (see Appendix E).

In addition, non-parametric Wilcoxon sign ranked tests comparing TEA measures across time revealed no significant differences. That is, both TBI and control participants' relative performances on the Map Search and Telephone Search subtests of the TEA did not differ across the two testing sessions (see Appendix E), suggesting that the absence of the expected differences in computer tasks A and B was not due to improvements in the TBI participants' selective attention over time, as measured by the TEA.

CHAPTER 4 - GENERAL DISCUSSION

TBI patients report a range of symptoms that can have a marked impact on their lives. These include emotional, behavioural, cognitive, and sensorimotor difficulties. Researchers have noted that attention difficulties are commonly reported by TBI patients, even when the severity of the injury has been classified as mild or mild to moderate (Belanger et al., 2005; Belmont, Agar, & Azouvi, 2009; Chan, 2000; McCrae, 2008). This is not surprising given that many of the neural networks thought to be involved in attention are susceptible to the types of damage that can occur in TBI.

Rehabilitation of attention deficits has been a focus of rehabilitation programs for TBI patients. For example, Sohlberg and Mateer's (2001) Attention Process Training (APT) is a comprehensive rehabilitation program designed to reduce the impact of attention difficulties on the patient's ability to function. One aspect of attention that is the focus of programs such as APT is selective attention. Selective attention deficits lead to increased susceptibility to the impact of irrelevant information in the environment (distractors). This can have a detrimental impact on a patient's ability to inhibit inappropriate responses, resulting in difficulty selecting the correct target from many possibilities in the environment.

Lavie (1995) proposed a useful paradigm for understanding selective processes involved in attention that centres on the observation that perceptual processing has limited capacity. The level of perceptual load or demand involved in a task modulates the level of resources that are available to process information. If the perceptual load is low, perceptual resources will not be exceeded thus leaving spare capacity for processing irrelevant distractors, leading to distractor interference. When perceptual load is high, perceptual resources are exceeded, leaving no spare capacity for the processing of irrelevant information and reducing or eliminating the impact of distracting stimuli on performance. It appears that distractor effects can be reduced if not eliminated under conditions that involve high perceptual load in processing the target (Lavie, 2010). Whilst there has been a growing body of research supporting Lavie's perceptual load theory using neurologically intact populations (Lavie, 1995, 2001, 2005, 2010; Lavie & Fox, 2000; Lavie & Tsal, 1994), and also in some neuropsychological patients (Kumanda & Humphreys, 2002; Lavie & Robertson, 2001), there has been no research investigating the effects of manipulating perceptual load in mild to moderate TBI patients.

This study sought to investigate the potential of Lavie's perceptual load theory (as first investigated in her 1995 paper) to aide understanding of the selective attention deficits associated with mild to moderate TBI. Whereas most studies looking at manipulations of perceptual load have used changes in set size of the stimulus array to increase load, this study used identical stimuli and manipulated load by instructing participants to respond based on a single feature (colour - low load condition) or a conjunction of features (colour and shape – high load condition). There were two experiments in this study using two computer based tasks. Computer task A used stimuli similar to Lavie's experiment 2a (1995), while computer task B attempted to use more ecologically valid stimuli.

Overall, the results for both computer task A (target letters with a coloured shape flanker), and the attempt to incorporate more ecologically valid stimuli (computer task B: line drawings of cups and glasses with coloured shapes superimposed onto the target) were similar. Although perceptual load was effectively manipulated in these experiments, and on average the pattern of results showed the predicted differential effects depending upon the type of distractor (incompatible, neutral or compatible to the target), these differences were not statistically significant for either the TBI patients or control participants. The following discussion addresses the results of the current study with specific reference to previous research where relevant, and considers some reasons why strong support for the hypotheses was not found.

4.1. Clinical, demographic, and cognitive variables

The present study recruited a group of TBI patients who were thought to be representative of the targeted population. As a group, the TBI participants in this study were all classified as having sustained a mild to moderate TBI and all participants were in a post-acute phase of recovery at the time of assessment. There were several significant group differences between TBI and control participants. Although the groups did not differ on age, the control participants as a group had nearly three years more education on average. The controls group's predicted IQ was significantly higher than that of the TBI group (although both groups fell within the conventional "Average" IQ range).

TBI participants in this study endorsed greater levels of depression and anxiety than did control participants. Whereas control participants' self-rated symptoms were in the normal range for both scales, TBI participants showed mild levels of both depression and anxiety. These findings are consistent with previous findings where persisting difficulties following a head injury are often associated with increased levels of emotional distress (Hovland & Raskin, 2000; Mooney, Speed, & Shepherd, 2005; Raskin & Stein, 2000). In addition to this, the current study's TBI participants were recruited from an ABI service that assists patients who are having persisting symptoms following a head injury and who were more likely to have some level of affective distress due to these difficulties.

Given that TBI patients' difficulties with attention have been well documented (e.g Belanger et al., 2005; McCrae, 2008; Ziino & Ponsford, 2006), it was hypothesised that TBI participants would be more affected on standardised, clinical tests of attention than control participants. In general this prediction was shown to be accurate for the participants in the current study. TBI participants were shown to have slower average scores on the Trail-Making Test (TMT) than control participants. There was a medium to large effect size seen for the significant difference between groups on the relatively harder task of TMT Part B, which requires attentional switching. Although the difference between groups on Part A of the TMT was not statistically significant, the difference was associated with a medium effect size in the hypothesised direction, suggesting that a larger sample may have resulted in a significant difference on this measure.

TBI participants' mean scale scores on the Map Search A 1-minute and Telephone Search subtests of the Test of Everyday Attention (TEA) were significantly lower than control participants indicating poorer selective attention in the TBI group. Other TEA measures showed non-significant trends (with small to medium effect sizes) in the predicted direction, such that on average TBI participants showed poorer performance than controls. Bate et al. (2001) found significant differences between a control group and TBI patients on Map Search and Telephone Search subtests of the TEA; however, their sample used patients classified as severe TBI. The present study shows a similar trend between TBI and control participants; however the absence of statistically significant differences is likely to be due to the less severe injuries of the current study's TBI participants (mild to moderate). However, taken as a whole, the significant differences on some of the measures of selective attention, and the average differences on others, showing better performance for the control participants provides support for the prediction that TBI participants would display poorer performance on tests of attention.

The current study found no significant differences between groups on any of the indices of the Rey Auditory Verbal Learning Test (RAVLT). This was in contrast to a study by Geary et al., (2010) who compared mild TBI patients with controls and found significantly poorer performance on the first trial of a similar verbal learning task for TBI participants. Geary and colleagues suggested this was a possible area of impairment found in mild TBI patients that was not identified in traditional neuropsychological assessment. They also suggested an anatomical correlate for this deficit in verbal attention may be the unculate fasciculus and the superior longitudinal fasciculus. On average the TBI patients in the current study registered fewer words than that controls after the first trial of the RAVLT; however, the difference was not significant and the effect size was small.

4.2. Computer-based perceptual load tasks

Previous research has found that the level of perceptual load involved in the processing of a target modulates distractor interference across different types of distractors (e.g. incompatible, neutral or compatible distractors; Lavie, 1995). Because incompatible distractors are incongruent with the target and evoke response competition, they lead to greater interference which is measurable as slower reaction times and higher error rates. In contrast, neutral distractors evoke no response competition or facilitation as they are not associated with any required response. Responses in the presence of neutral distractors provided a baseline with which to compare the interference effects (differences in reaction times and error rates) of the incompatible distractors.

According to perceptual load theory, processing of distractors should only occur under conditions of low load (Lavie, 1995; Lavie & Tsal, 1994). Therefore, incompatible distractors should result in slower reaction times and higher error rates compared to neutral distractors only under conditions of low perceptual load. As perceptual load increases, attentional resources are filled, leaving little attentional capacity to be filled by task-irrelevant information such as distractors. Therefore, in high load tasks where perceptual load is increased, the differential effects of incompatible and neutral distractors are eliminated. As discussed in section 1.9.1, previous research involving compatible distractors using identical physical features for both distractor and target can lead to conflicting results showing both interference and facilitation effects from distractors (e.g. Bjork & Murray, 1977; Erikson et al., 1989) and makes interpreting these effects ambiguous.

In the current study, the general hypothesis was that for both mild to moderate TBI and control participants, the type of distractor (incompatible, neutral, or compatible) would affect responses to the relevant target only under conditions of low load. That is, incompatible distractors would result in slower reaction times and more errors when compared with neutral distractors under conditions of low perceptual load. Under conditions of high perceptual load, distractor processing should be minimal and therefore distractor type should not affect responses to the target (i.e. no differences in reaction times or error rates between incompatible and neutral distractors).

Both computer tasks demonstrated effective manipulation of perceptual load and the pattern of mean RTs across distractor types showed a trend in the predicted direction. That is, mean RTs were slower for incompatible distractors compared with neutral distractors in the low load conditions of both computer tasks A and B. This was consistent with Lavie's experiment 2a (1995). For example, in computer task A of the current study, the mean RTs for incompatible distractors were 13ms slower than for neutral distractors, under conditions of low load. The comparative difference in Lavie's study was 16ms slower for incompatible distractors. Under conditions of high load, both studies showed faster reaction times for incompatible distractors versus neutral distractors (15ms for computer task A of the current study and 7ms in Lavie's (1995) experiment 2). However, the current study did not show statistically significant differences in mean reaction times or percentage errors between the three distractor types (incompatible, neutral or compatible) under the low load condition.

Whilst the direction of the differences in mean RTs is consistent with perceptual load theory, the statistical homogeneity of responses for all three distractors under low perceptual load found here is not consistent with previous research. In a neurologically intact population, Lavie (1995) found significant distractor interference effects only under the low load condition. In particular, Lavie found significant slowing of reaction times and higher error rates in the presence of incompatible distractors compared to neutral distractors only under conditions of low perceptual load. This effect has been found in several studies (Grill-Spector & Malach, 2001; Lavie, 2001; Lavie & Cox, 1997; Lavie & Fox, 2000; Lavie & Tsal, 1994; Rees et al., 2000), and across a range of display types that manipulated load using similar stimuli to the current experiment (computer task A) and also varying set size (target on its own (low load) or amongst several flankers (high load).

Across both computer tasks A and B, the current study also showed no differences in mean reaction times or percentage errors between the distractor types under conditions of high load. This was consistent with the hypothesis and also with previous research (Grill-Spector & Malach, 2001; Lavie, 2001; Lavie & Cox, 1997; Lavie & Fox, 2000; Lavie & Tsal, 1994; Rees et al., 2000). The lack of significant differences between distractor types under conditions of high perceptual load looks consistent with Lavie's theory at first glance. However, perceptual load theory predicts differential responses to distractors across varying levels of perceptual load, as described above. Therefore, the lack of any main effect of Distractor Type or interaction between Task Load and Distractor Type in the low load task weakens the conclusion that the increase in perceptual load in the high load task has eliminated the distractor interference effect. This is because there was no statistically significant evidence in the current experiments for perceptual load having an effect on participants' responses to the different types of distractors in any condition. In particular, perceptual load theory predicts increased distractor interference from incompatible distractors compared to neutral distractors in the low load condition. Despite visual inspection of the data showing differences in the predicted direction in the low load conditions of both computer tasks, these differences were not significant. Whilst the trend of RTs was in the predicted direction in both conditions of low and high load, the size of the sample may have been too small to have detected statistically significant differences. Future research would benefit by increasing the number of participants, although recruiting participants can be difficult with clinical populations such as the one used here.

Attention deficits following even mild TBI have been reported in previous research (Belanger et al., 2005; McCrae, 2008; Ziino & Ponsford, 2006). In the current study it was hypothesised that TBI participants would be more affected on the experimental computer tasks and tests of attention than controls because of their attention deficits. As discussed above, the current study, as predicted, found consistently poorer performances on average for the TBI group on standardised neuropsychological tests of selective attention compared with control participants. However, the results relating to the experimental computer tasks were variable. For mean reaction times, there were no differences found between groups for either computer task and therefore this hypothesis was not supported. With regard to error rates, there were significant differences (with small to medium effect sizes) between groups for computer task A and B respectively. For both computer tasks, TBI participants were found to have made significantly more errors than control participants, thus providing partial support for this hypothesis.

Although not universal across all baseline tests of selective attention, there were several significant correlations found for TBI participants between TEA measures and computer task error rates. For computer task A, poor performance on the TEA Map Search test was related to higher error rates, with one minute measures correlating significantly with low perceptual load, and the two minute measures correlating with high perceptual load. In addition to this, poor performance on TEA Telephone Search (version B) was associated with higher error rates under conditions of high perceptual load for both computer tasks. Although the computer tasks did not elicit the interaction effects predicted by perceptual load theory, they have revealved significant differences between TBI participants and controls with regard to error rates, and were shown to be significantly associated with selective attention deficits as measured by standard neuropsychological tests of attention. In this study then, error rates were shown to be a more sensitive measure of selective attention deficits than reaction times.

The non-significant differences across distractors found in the current study may be due to the experimental computer tasks used, rather than a true lack of effect of perceptual load on distractor processing. For example, differences in the timing of exposure associated with display presentation may have lead to potential differences when compared to Lavie's Experiment 2a (1995). In Lavie's study, the experimental stimuli were presented for a period of 100 ms with neurologically intact participants. In the current study, stimuli were presented for 200 ms for both groups as it was thought the TBI participants would need more time to process information and would therefore find the tasks too difficult if stimuli were presented for the shorter time period.

However, the time course for the presentation of stimuli can affect performance on selective attention tasks. For example, a phenomenon known as the attentional blink (AB) refers to the inhibitory effects of selective attention mechanisms that are dependent upon the time course that target and distractor stimuli are presented (Shapiro & Terry, 1998). There is lively theoretical debate about the mechanisms involved in AB that relate to resource capacity limitations and/or selective attention processes as the cause of AB. For example, studies have found that the time course for AB can vary between 200ms and 500ms for presentation of stimuli and that results are dependent upon whether targets are presented repeatedly or interspersed with distractors (Olivers, Hulleman, Spalek, Kawahara & Di Lollo, 2010).

Interpreting the effect that the longer presentation time had on performance in the current study is difficult as the time that stimuli were presented was constant across all trials. It may be that the longer presentation time engages different processes such as inhibitory control mechanisms similar to those mechanisms involved in AB. The extra exposure time may have attenuated the interference effects of the different distractor types in the low load conditions. Potentially, the longer exposure time to the display may account for a reduced effect of interference from incompatible distractors when compared to neutral distractors, thus reducing the magnitude of the differences in mean RTs between the two distractor types, although retaining the direction of these differences. Changing the time course that stimuli were presented may have contributed to the inability of the current study to replicate Lavie's (1995) findings.

Further differences between previous research and the current study are found from studies with neuropsychological patients that utilised varying set sizes to manipulate load (Kumanda & Humphreys, 2002; Lavie & Robertson, 2001). These studies found that even a small increase in the set size by the addition of just one extra flanker was enough to induce a high load condition for these patients, resulting in the virtual elimination of differential distractor interference effects. This would suggest that for the current study, there should have been differential distractor responses for the TBI group who were demonstrated to have selective attention deficits, even if this effect was not observed for the neurologically intact control group. However, despite the observation that perceptual load had been effectively manipulated in the current computer tasks, there were no significant differences seen for the distractors in the low load condition. In addition to this, there were no significant differences found when TBI participants were divided into mild versus moderate TBI groups (although this analysis was limited by small sample sizes). Using set size to manipulate load rather than using a verbal instruction may be a more effective way of testing perceptual load with this sample, as set size manipulations allow a more gradual increase in perceptual load. This is likely to be more sensitive in detecting the point at which load is high enough to eliminate the effects of distractors in mild TBI patients.

Although there has been support for perceptual load theory from previous research using similar instructions as used in the current study with neurologically intact populations (Lavie, 1995; Lavie & Tsal, 1994), research with neuropsychological populations has used varying set size as the main mechanism for manipulating perceptual load (Lavie, 2001; Lavie & Cox, 1997; Lavie & Fox, 2000; Rees et al., 2000). Using identical displays and manipulating perceptual load via instruction alone has not previously been attempted with neuropsychological populations. However, it is possible that the verbal instructions used in the current study made the task more difficult than locating a target amongst varying display set sizes. The level of task difficulty of the instructions may therefore have confounded the results. Qualitative observation of participants' practice trials and anecdotal participant reports of difficulty in remembering the specific instructions suggest that the computer tasks used in the current study are potentially more difficult than previous studies. It may be that these instructions were sufficiently difficult to retain in memory (essentially creating a working memory demand) leaving responses open to extraneous effects due to the tasks' level of cognitive difficulty. However, this explanation cannot account for the results of the control participants, as verbal instructions have been shown to manipulate load in the desired way with neurologically intact populations (Lavie, 1995; Lavie & Tsal, 1994).

Lavie, et al. (2004) proposed that for accurate selective attention, a form of attentional control is necessary for rejecting irrelevant distractors when they have been perceived (such as in the low perceptual load condition). Lavie and colleagues conducted a series of experiments that showed that the cognitive load involved in a task modulates distractor interference independently of perceptual load. They concluded that increasing perceptual load reduces distractor interference, but increasing cognitive load has the opposite effect and increases distractor interference (Lavie, et al., 2004).

In the current study, the instructions to search based on a single feature (low load) or a conjunction of features (high load) appears to have manipulated perceptual load. However, if the cognitive load of remembering the instructions was sufficiently high its effects would be to make participants' responses even more susceptible to distractor interference (Lavie, 2010). Increased cognitive load leads to increased interference of perceived distractors to the point that varying types of distractors no longer differentially affect selective attentional processes. Whereas Lavie and colleagues (2004) were able to demonstrate separate perceptual load and cognitive load effects in their experiments, the instructions provided in the current study were based on previous research that had provided support for perceptual load theory without controlling for cognitive load, therefore cognitive load was not controlled for in the current study. Using set size to manipulate perceptual load with this population would minimise any interference from cognitive load in future research.

4.3. Implications for rehabilitation

An original impetus for this research and indeed a suggestion by Lavie (2010) was to investigate the utility of perceptual load theory to inform potential rehabilitation strategies for selective attention deficits in clinical populations. However, a concern regarding the efficacy of manipulating perceptual load by instruction alone with mild to moderate TBI patients relates to the potential confounding effects of cognitive load (Lavie et al., 2004). Even if the current study had found support for Lavie's (1995) perceptual load theory, the potential of cognitive load impacting on performance in addition to perceptual load places serious limitations on the usefulness of perceptual load theory as a basis for developing rehabilitation techniques for selective attention difficulties.

One appeal of perceptual load theory was that it could be manipulated via instruction alone with no need to alter the display. If the instructions provided have the potential to increase the cognitive load sufficiently to impact on distractor interference they may lead to nothing other than an increase in the difficulty of a task (as seen here by significant Task Load effects), with no effect on improving performance (no significant differences seen for Distractor Type). Future research with mild/moderate TBI patients may benefit from varying display set size to manipulate load instead of verbal instruction as was used in the current study.

4.4. Strengths and limitations of the study

Incorporating standardised neuropsychological tests of attention into the research design was a strength of the current study. As seen in previous research, the presence of attention difficulties is commonly reported in mild to moderate TBI (Belanger et al., 2005; Belmont, Agar, & Azouvi, 2009; Chan, 2000; McCrae, 2008). Including the tests allowed the study to demonstrate that TBI participants as a group had selective attention deficits compared with the control group and they were therefore a representative sample of the targeted population. Also, the demonstration of selective attention deficits using neuropsychological tests suggests that the experimental computer tasks were unable to detect these selective attention difficulties, at least with regard to reaction times. TBI participants made on average more errors than control participants in both computer tasks A and B and this was consistent with the selective attention deficits seen on neuropsychological testing.

The difficulty involved in accessing suitable participants lead to recruiting a relatively small sample size and subsequently limited the statistical robustness of the current study. TBI participants were recruited from an Acquired Brain Injury service at a regional health service. While medical and allied health staff of the service agreed to participate with the recruitment procedure, there were several changes in staff during the recruitment period. Recruitment and retention of staff to regional areas has been a major concern for both federal and state governments in Australia and specialised programs targeting the recruitment of medical and allied health staff for regional areas have yet to fill the demand. This left the service understaffed with vacancies for periods of several months at a time. The rehabilitation physician was the clinical leader of the service and this role was vacated on three separate occasions. In addition to this, there was high turnover of case managers with similar difficulties in recruiting staff to replace them. These periods of absence of staff meant that there were multiple periods of several months duration where recruitment of TBI participants was not possible.

In addition to this, the pressures on resources of the specialist ABI service and the necessity for them to allocate resources to the highest clinical priorities meant that many of their clients were unsuitable for this study because of higher levels of injury severity. Although a mild TBI pathway is part of the services provided, this consists of a follow-up call to monitor subjectively reported symptoms. Many of these potential clients followed the natural course of good recovery within one to three months and were never actually seen by the rehabilitation physician. As it was a requirement of the current study for the rehabilitation physician to classify the severity rating of the TBI participant's injuries, many of these ABI service clients could not be included in the study.

Another limitation of the current study related to differences between the groups on education level and predicted IQ. These differences may be due to some bias in the sampling procedure. The control participants were recruited using a convenience sampling strategy. Difficulty in recruiting participants including the inability to co-ordinate the availability of potential participants and access to research facilities led to control participants being drawn from friends, colleagues and acquaintances of the researcher, many of whom were university-trained professionals, thus leading to higher levels of education. Also, the WTAR estimated IQ scores use education levels as part of the calculation of premorbid IQ with higher levels of education generally leading to higher predicted IQ scores. In contrast to this, TBI participants were recruited directly from patients attending a specialist acquired brain injury service where there was no bias towards higher education or higher IQ as the ABI services target population was any member of the general public with a TBI, regardless of qualifications. The bias in control sampling as well as the known overrepresentation of people with lower levels of education in TBI populations (Ponsford, 1995) are both likely to have contributed to the significant difference in predicted IQ.

The decision not to control for cognitive load reflects a limitation of the current study. Lavie et al. (2004) highlighted the effects of high cognitive load on distractor interference under conditions of low perceptual load. Although the decision not to control for cognitive load was based on previous research into perceptual load theory not requiring to control this variable (e.g. Lavie, 1995), the potential of using instruction alone to manipulate the perceptual load of a target may have unknowingly introduced an element of cognitive load that impacted on participants responses.

4.5. Conclusions and future directions

This study used Lavie's (1995, 2010) perceptual load theory to investigate selective attention deficits after mild to moderate TBI. Overall, the results for both computer task A and B were similar and provided only partial support for Lavie's (1995) perceptual load theory in this sample.

Although perceptual load was demonstrated to have been effectively manipulated by the computer tasks and differences in RTs showed a pattern consistent with the predicted direction, the current study did not show any significant differences in mean reaction times or percentage errors between distractors (incompatible, neutral or compatible) under either condition of Task Load. Perceptual load theory predicts differential responses to distractors across varying levels of perceptual load. Therefore, the lack of any main effect of Distractor Type or interaction between Task Load and Distractor Type is not consistent with perceptual load theory. Possible reasons for the inability of the current study to replicate Lavie's (1995) results include the longer time of exposure to stimuli that may have changed the selective attention perceptual processes and inhibitory mechanisms (e.g. attentional blink), and the inadvertent introduction of increased cognitive processing demands and subsequent interference with active inhibitory processes associated with increased cognitive load.

The current study, as predicted, found consistently poorer performances on average for the TBI group on standardised neuropsychological tests of selective attention compared with control participants. Consistent with this, TBI participants were found to have made significantly more errors than control participants on both computer tasks A and B. In contrast to these findings however, there were no differences found between groups for either computer task on mean reaction times.

To use perceptual load as a basis for selective attention rehabilitation techniques, the theory would need to be supported in a range of ecologically valid environments and everyday tasks. Although there is an impressive body of research using tightly controlled experimental conditions supporting perceptual load theory, applications for perceptual load theory beyond the experimental laboratory are yet to be validated and provide direction for future research. Future research with mild/moderate TBI patients may benefit from varying display set size to manipulate load instead of verbal instruction as was used in the current study.

Recruitment of participants for this study was limited by the regional nature of the service from which participants were sourced. Recruiting of mild to moderate TBI participants for future research into perceptual load theory may be more effective if done from metropolitan hospital emergency departments where larger numbers of patients are cared for and researchers can follow-up and screen potential participants more directly.

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APPENDICES

Appendix A: ICD – 10 Criteria for Postconcussional Syndrome

ICD – 10 Diagnostic Criteria for Postconcussional Syndrome

A. History of head trauma with loss of consciousness precedes symptoms onset by maximum of four weeks.

B. Symptoms in three or more of the following symptom categories:

- Headache, dizziness, malaise, fatigue, noise tolerance
- Irritability, depression, anxiety, emotional lability
- Subjective concentration, memory, or intellectual difficulties without neuropsychological evidence of marked impairment
- Insomnia
- Reduced alcohol tolerance
- Preoccupation with above symptoms and fear of brain damage with hypochondriacal concern and adoption of sick role

From: *International Statistical Classification of Diseases and Related Health Problems, 10th ed.*

Appendix B: Semi – structured interview and data sheet

Structured Interview and data form

		ID:	Date:
Group TBI / Control	DOB:	Age:	Gender:
Years Education:	Handedness:	Date Injury:	Time since injury:

TBI Markers			
GCS:			
PTA:			
Imaging?			
Drs rating (circle)	Mild	Mild to Moderate	Moderate

Vision Screen: Yes / No

WTAR	Raw:	Predicted FSIQ:	Range:

RAVLT __, __, __, __, __, Total(__), List B(__), ___; Delay ___, Recognition ___.
Mean __, __, __, __, __, Total(__), List B(__), ___; Delay ___, Recognition ___.
StDev __, __, __, __, __, Total(__), List B(__), ___; Delay ___, Recognition ___.

TMT A: _______seconds **TMT B:**______seconds

HADS: Anxiety: ____________. Range ____________.
Depression: ____________. Range ____________.

TEA – Map Search

Version A			**Version B**	Date	
1 min	Raw	SS	1 min	Raw	SS
2 min	Raw	SS	2 min	Raw	SS

TEA – Telephone Search

Version A				**Version B**			
Time	Total Correct	Raw	SS	Time	Total Correct	Raw	SS

Appendix C: Informed Consent and Information to Participant forms

Ballarat Health Services
Putting your health first

VICTORIA UNIVERSITY

Consent Form for Subjects Involved in Research

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study into impulsivity and distractibility following mild to moderate Traumatic Brain Injury (TBI)

CERTIFICATION BY SUBJECT
I,
of

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study entitled: Developing the basis of rehabilitation techniques for impulsivity and distractibility after frontal lobe damage in mild to moderate Traumatic Brain Injury (TBI).

being conducted at Victoria University by:

Dr Alexia Pavlis (Principal Investigator)
Chris Waters (Student Investigator)

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Chris Waters

and that I freely consent to participation involving the use on me of these procedures.

Procedures:
Interview, 6 common paper & pencil tests of attention and memory, 2 computer tasks as described in the "Information to Participants" document provided to me.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: .... }

Witness other than the researcher: } **Date: ....**

....}

Any queries about your participation in this project may be directed to the researcher (Name: Alexia Pavlis ph. (03) 9### ####). If you have any queries or complaints about the way you have been treated, you may contact the Secretary, University Human Research Ethics Committee, Victoria University of Technology, PO Box 14428 MCMC, Melbourne, 8001 (telephone no: 03-9### ####).

Ballarat Health Services
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VICTORIA UNIVERSITY

INFORMATION TO PARTICIPANTS

Title of study: Developing the basis of rehabilitation techniques for impulsivity and distractibility after frontal lobe damage in mild to moderate Traumatic Brain Injury (TBI).

Principal Investigator: Dr Alexia Pavlis
Student Investigator: Chris Waters

This document informs the participant on the purpose, aim and procedure of the study. Please feel free to ask any questions if this document is not clear or if you do not fully understand anything in this document. Please take your time in reading this document carefully. A copy of this document will be provided for you to take home. If you are an undergraduate or postgraduate student please note that participation in this study will not provide a credit in your course.

Purpose of study:

We are trying to develop a rehabilitation strategy to reduce impulsivity and distractibility after mild to moderate Traumatic Brain Injury (TBI). This means that people with mild to moderate TBI often have difficulty making appropriate responses such as choosing the right object from many possibilities in the environment. They may also become distracted by objects in their environment which are irrelevant. These difficulties present a significant obstacle to a return to independent living, and are the focus of the rehabilitative strategy to be developed in this project.

Participants will be asked to attend 2 sessions. In the first session they will undertake a short interview and will be asked to complete six commonly used tests of attention and memory. Following this they will be asked to complete a computer based task that will run for approximately 35 minutes. The task will require the participant to identify either letters or line drawings such as cups or glasses, and then to press the corresponding button on the keyboard. There will be short breaks provided during the task. The first session will take approximately 90 minutes to complete.

One week later, participants are to attend a second session in which they will be asked to complete a second computer task (similar to the first task) and two commonly used tests of attention. The second session will take approximately 45 minutes to complete.

In these tasks there are no invasive procedures. Some personal information will be asked of the participants regarding their history of head injury and other possible risk factors. If participants are patients under the care of Ballarat Health Services – Acquired Brain Injury Service, permission is also sought to document their involvement in the research in their ABI service file. Information will be available only to the researchers and placed on the patient's file. All data are confidential and only the Principal Investigator (Alexia Pavlis) and Student Investigator (Chris Waters) will have access to the data. Names of participants will be coded, and participants' names will remain confidential. The data will be kept under lock and key for five years as per university requirements.

Participation in the study is completed voluntarily and participants are free to withdraw at any time of the study. Withdrawal from the study will not have any negative repercussions. If you have any concerns at this stage of the study you can contact Alexia Pavlis on (03) 9### ####

If you decide to continue your participation in this study you will be asked to sign a Consent Form. Signing the consent form will indicate that you have fully understood the requirements of the study and you consent to participate in the research. Please note that you are still able to withdraw from the study even though the consent form has been signed. A copy of the consent form will also be provided for you to take home.

We appreciate that you have taken the time to participate in this study and thank-you for your participation.

Chris Waters and Dr Alexia Pavlis

Ballarat Health Services
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VICTORIA UNIVERSITY

Consent Form for Subjects Involved in Research

INFORMATION TO PARTICIPANTS (Healthy Participants):

We would like to invite you to be a part of a study into impulsivity and distractibility following mild to moderate Traumatic Brain Injury (TBI)

CERTIFICATION BY SUBJECT

I,
of

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study entitled: Developing the basis of rehabilitation techniques for impulsivity and distractibility after frontal lobe damage in mild to moderate Traumatic Brain Injury (TBI).

being conducted at Victoria University by:

Dr Alexia Pavlis (Principal Investigator)
Chris Waters (Student Investigator)

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by: **Chris Waters**

and that I freely consent to participation involving the use on me of these procedures.

Procedures:
Interview, 6 common paper & pencil tests of attention and memory, 2 computer tasks as described in the "Information to Participants" document provided to me.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: .... }

Witness other than the researcher: } **Date: ....**

..}

Any queries about your participation in this project may be directed to the researcher (Name: Alexia Pavlis ph. (03) 9### ####. If you have any queries or complaints about the way you have been treated, you may contact the Secretary, University Human Research Ethics Committee, Victoria University of Technology, PO Box 14428 MCMC, Melbourne, 8001 (telephone no: 03 9### ####

Ballarat Health Services
Putting your health first

VICTORIA UNIVERSITY

INFORMATION TO PARTICIPANTS
(Healthy Participants)

Title of study: Developing the basis of rehabilitation techniques for impulsivity and distractibility after frontal lobe damage in mild to moderate Traumatic Brain Injury (TBI).

Principal Investigator: Dr Alexia Pavlis
Student Investigator: Chris Waters

This document informs the participant on the purpose, aim and procedure of the study. Please feel free to ask any questions if this document is not clear or if you do not fully understand anything in this document. Please take your time in reading this document carefully. A copy of this document will be provided for you to take home. If you are an undergraduate or postgraduate student please note that participation in this study will not provide a credit in your course.

Purpose of study:

We are trying to develop a rehabilitation strategy to reduce impulsivity and distractibility after mild to moderate Traumatic Brain Injury (TBI). This means that people with mild to moderate TBI often have difficulty making appropriate responses such as choosing the right object from many possibilities in the environment. They may also become distracted by objects in their environment which are irrelevant. These difficulties present a significant obstacle to a return to independent living, and are the focus of the rehabilitative strategy to be developed in this project.

Participants will be asked to attend 2 sessions. In the first session they will undertake a short interview and will be asked to complete six commonly used tests of attention and memory. Following this they will be asked to complete a computer based task that will run for approximately 35 minutes. The task will require the participant to identify either letters or line drawings such as cups or glasses, and then to press the corresponding button on the keyboard. There will be short breaks provided during the task. The first session will take approximately 90 minutes to complete.

One week later, participants are to attend a second session in which they will be asked to complete a second computer task (similar to the first task) and two commonly used tests of attention. The second session will take approximately 45 minutes to complete.

In these tasks there are no invasive procedures. Some personal information will be asked of the participants regarding their history of head injury and other possible risk factors. All data are confidential and information will be available only to the researchers. That is, only the Principal Investigator (Alexia Pavlis) and Student Investigator (Chris Waters) will have access to the data. Names of participants will be coded, and participants' names will remain confidential. The data will be kept under lock and key for five years as per university requirements.

Participation in the study is completed voluntarily and participants are free to withdraw at any time of the study. Withdrawal from the study will not have any negative repercussions. If you have any concerns at this stage of the study you can contact Alexia Pavlis on (03) 9### ####.

If you decide to continue your participation in this study you will be asked to sign a Consent Form. Signing the consent form will indicate that you have fully understood the requirements of the study and you consent to participate in the research. Please note that you are still able to withdraw from the study even though the consent form has been signed. A copy of the consent form will also be provided for you to take home.

We appreciate that you have taken the time to participate in this study and thank-you for your participation.

Chris Waters
Dr Alexia Pavlis

Appendix D: Tests of normality

		Shapiro-Wilk		
		Statistic	df	Sig.
Participant age	Control	.925	12	.326
	TBI	.945	12	.566
Years of education	Control	.938	12	.477
	TBI	.884	12	.099
Predicted Full Scale IQ from WTAR	Control	.894	12	.133
	TBI	.969	12	.903
RAVLT trial 1 score	Control	.645	12	.000
	TBI	.887	12	.107
RAVLT trial 5 score	Control	.841	12	.028
	TBI	.887	12	.107
RAVLT lng curve trial 5-1	Control	.831	12	.021
	TBI	.945	12	.570
RAVLT Total score	Control	.926	12	.342
	TBI	.962	12	.808
RAVLT delayed recall	Control	.856	12	.044
	TBI	.962	12	.811
RAVLT recognition score	Control	.623	12	.000
	TBI	.807	12	.011
Trail Making Test part A score in seconds	Control	.969	12	.900
	TBI	.951	12	.655
Trail Making Test part B score in seconds	Control	.964	12	.840
	TBI	.935	12	.436
Hospital Anxiety and Depression Scale - Anxiety score	Control	.924	12	.318
	TBI	.924	12	.317
Hospital Anxiety and Depression Scale - Depression score	Control	.734	12	.002
	TBI	.967	12	.883
Test of Everyday Attention - Map Search Version A 1min- Scale Score	Control	.911	12	.222
	TBI	.959	12	.772
Test of Everyday Attention - Map Search Version A 2min - Scale Score	Control	.958	12	.760
	TBI	.932	12	.405
Test of Everyday Attention - Map Search Version B 1min - Scale Score	Control	.863	12	.053
	TBI	.929	12	.372

Test of Everyday Attention - Map Search Version B 2min - Scale Score	Control	.912	12	.228
	TBI	.923	12	.314
Test of Everyday Attention - Telephone Search Version A - Scale Score	Control	.945	12	.563
	TBI	.905	12	.185
Test of Everyday Attention - Telephone Search Version B - Scale Score	Control	.909	12	.209
	TBI	.888	12	.112

Appendix E: Additional exploratory analysis

GLM Repeated Measures for TBI Participants on Computer Task A

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
load	Sphericity Assumed	2090951.611	1	2090951.611	43.797	.000
Error(load)	Sphericity Assumed	525155.929	11	47741.448		
distractors	Sphericity Assumed	360.082	2	180.041	.130	.879
Error(distractors)	Sphericity Assumed	30574.499	22	1389.750		
load * distractors	Sphericity Assumed	1537.717	2	768.858	.374	.692
Error(load*distractors)	Sphericity Assumed	45233.324	22	2056.060		

GLM Repeated Measures for TBI Participants on Computer Task B

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
load	Sphericity Assumed	2611597.942	1	2611597.942	70.760	.000
Error(load)	Sphericity Assumed	405986.779	11	36907.889		
distractors	Sphericity Assumed	255.698	2	127.849	.083	.921
Error(distractors)	Sphericity Assumed	33843.830	22	1538.356		
load * distractors	Sphericity Assumed	4903.823	2	2451.911	.970	.395
Error(load*distractors)	Sphericity Assumed	55612.408	22	2527.837		

GLM Repeated Measures for Control Participants on Computer Task A

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Load	Sphericity Assumed	3545547.485	1	3545547.485	83.293	.000
Error(Load)	Sphericity Assumed	468236.607	11	42566.964		
Distractor	Sphericity Assumed	1072.316	2	536.158	.320	.730
Error(Distractor)	Sphericity Assumed	36909.320	22	1677.696		
Load * Distractor	Sphericity Assumed	4101.231	2	2050.616	1.818	.186
Error(Load*Distractor)	Sphericity Assumed	24812.805	22	1127.855		

GLM Repeated Measures for Control Participants on Computer Task B

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Load	Sphericity Assumed	4230499.188	1	4230499.188	104.540	.000
Error(Load)	Sphericity Assumed	445144.563	11	40467.688		
Distractor	Sphericity Assumed	1279.161	2	639.580	.465	.634
Error(Distractor)	Sphericity Assumed	30273.917	22	1376.087		
Load * Distractor	Sphericity Assumed	4950.632	2	2475.316	1.039	.370
Error(Load*Distractor)	Sphericity Assumed	52393.520	22	2381.524		

Kolmogorov-Smirnov Z tests (D) comparing Mild TBI (n=7) and Moderate TBI (n=5) Participants

	D	Sig.
RAVLT Total score	0.732	0.658
RAVLT delayed recall	0.244	1.000
RAVLT recognition score	0.537	0.936
Trail making test part A score in seconds	0.878	0.423
Trail making test part B score in seconds	0.732	0.658
Test of Everyday Attention - Map Search Version A 1min - raw score	1.122	0.161
Test of Everyday Attention - Map Search Version A 1min- Scale Score	0.878	0.423
Test of Everyday Attention - Map Search Version A 2min - raw score	0.732	0.658
Test of Everyday Attention - Map Search Version A 2min - Scale Score	0.488	0.971
Test of Everyday Attention - Map Search Version B 1min - raw score	0.976	0.297
Test of Everyday Attention - Map Search Version B 1min - Scale Score	0.878	0.423
Test of Everyday Attention - Map Search Version B 2min - raw score	0.781	0.576
Test of Everyday Attention - Map Search Version B 2min - Scale Score	0.634	0.816
Test of Everyday Attention - Telephone Search Version A - raw score	0.683	0.739
Test of Everyday Attention - Telephone Search Version A - Scale Score	0.683	0.739
Test of Everyday Attention - Telephone Search Version B - raw score	0.488	0.971
Test of Everyday Attention - Telephone Search Version B - Scale Score	0.293	1.000
Grand Mean A Low: Go - Blue - distractor = Compatible: RT mean	0.878	0.423
Grand Mean A Low: Go - Blue - distractor = Neutral:RT mean	1.025	0.244
Grand Mean A Low: Go - Blue - distractor = Incompatible: RT mean	0.878	0.423
Grand Mean A High: Go - distractor = Compatible: RT mean	0.390	0.998
Grand Mean A High: Go - distractor = Neutral: RT mean	0.390	0.998
Grand Mean A High: Go - distractor = Incompatible: RT mean	0.634	0.816
Grand Mean B Low: Go - Blue - distractor = Compatible: RT mean	0.683	0.739
Grand Mean B Low: Go - Blue - distractor = Neutral:RT mean	0.634	0.816
Grand Mean B Low: Go - Blue - distractor = Incompatible: RT mean	0.439	0.990
Grand Mean B High: Go - distractor = Compatible: RT mean	0.634	0.816
Grand Mean B High: Go - distractor = Neutral: RT mean	0.390	0.998
Grand Mean B High: Go - distractor = Incompatible: RT mean	0.488	0.971
Percentage Errors A Low: distractor = Incompatible	1.025	0.244
Percentage Errors A Low: distractor = Neutral	0.781	0.576
Percentage Errors A Low: distractor = Compatible	0.390	0.998
Percentage Errors A High: distractor = Incompatible	0.537	0.936
Percentage Errors A High: distractor = Neutral	0.488	0.971
Percentage Errors A High: distractor = Compatible	0.781	0.576
Percentage Errors B Low: distractor = Incompatible	0.634	0.816
Percentage Errors B Low: distractor = Neutral	1.025	0.244
Percentage Errors B Low: distractor = Compatible	0.195	1.000
Percentage Errors B High: distractor = Incompatible	0.390	0.998
Percentage Errors B High: distractor = Neutral	0.683	0.739
Percentage Errors B High: distractor = Compatible	0.634	0.816

Kolmogorov-Smirnov Z tests (D) comparing TBI Participants Showing the Predicted Trend (n=8) and Non-predicted Trend (n=4) on Computer Task A

	D	Sig.
Trail making test part A score in seconds	.408	.996
Trail making test part B score in seconds	.816	.518
Test of Everyday Attention - Map Search Version A 1min- Scale Score	.408	.996
Test of Everyday Attention - Map Search Version A 2min - Scale Score	.408	.996
Test of Everyday Attention - Map Search Version B 1min - Scale Score	.612	.847
Test of Everyday Attention - Map Search Version B 2min - Scale Score	.612	.847
Test of Everyday Attention - Telephone Search Version A - Scale Score	.408	.996
Test of Everyday Attention - Telephone Search Version B - Scale Score	.408	.996

Kolmogorov-Smirnov Z tests (D) comparing TBI Participants Showing the Predicted Trend (n=8) and Non-predicted Trend (n=4) on Computer Task B

	D	Sig.
Trail making test part A score in seconds	1.275	.100
Trail making test part B score in seconds	.408	.996
Test of Everyday Attention - Map Search Version A 1min- Scale Score	.408	.996
Test of Everyday Attention - Map Search Version A 2min - Scale Score	.612	.847
Test of Everyday Attention - Map Search Version B 1min - Scale Score	.408	.996
Test of Everyday Attention - Map Search Version B 2min - Scale Score	1.021	.249
Test of Everyday Attention - Telephone Search Version A - Scale Score	.408	.996
Test of Everyday Attention - Telephone Search Version B - Scale Score	.612	.847

Wilcoxon Signed Ranks Test (Z) for Test of Everyday Attention
Time 1 versus Time 2

TBI participants N=12

	Z	**Sig.**
Test of Everyday Attention - Map Search Version B 1min - raw score – Test of Everyday Attention - Map Search Version A 1min - raw score	-0.990	0.322
Test of Everyday Attention - Map Search Version B 1min - Scale Score – Test of Everyday Attention - Map Search Version A 1min- Scale Score	-0.586	0.558
Test of Everyday Attention - Map Search Version B 2min - raw score – Test of Everyday Attention - Map Search Version A 2min - raw score	-0.936	0.349
Test of Everyday Attention - Map Search Version B 2min - Scale Score – Test of Everyday Attention - Map Search Version A 2min - Scale Score	-0.103	0.918
Test of Everyday Attention - Telephone Search Version B - raw score – Test of Everyday Attention - Telephone Search Version A - raw score	-1.098	0.272
Test of Everyday Attention - Telephone Search Version B - Scale Score – Test of Everyday Attention - Telephone Search Version A - Scale Score	-1.736	0.083

Control participants N=12

	Z	Sig.
Test of Everyday Attention - Map Search Version B 1min - raw score – Test of Everyday Attention - Map Search Version A 1min - raw score	-0.579	0.563
Test of Everyday Attention - Map Search Version B 1min - Scale Score – Test of Everyday Attention - Map Search Version A 1min- Scale Score	-0.630	0.529
Test of Everyday Attention - Map Search Version B 2min - raw score – Test of Everyday Attention - Map Search Version A 2min - raw score	-0.119	0.906
Test of Everyday Attention - Map Search Version B 2min - Scale Score – Test of Everyday Attention - Map Search Version A 2min - Scale Score	0.000	1.000
Test of Everyday Attention - Telephone Search Version B - raw score – Test of Everyday Attention - Telephone Search Version A - raw score	-1.138	0.255
Test of Everyday Attention - Telephone Search Version B - Scale Score – Test of Everyday Attention - Telephone Search Version A - Scale Score	-0.159	0.874

Non-parametric (Kendall's tau) correlations for baseline tests of attention and mood across computer tasks A & B (RTs) for TBI participants (N=12)

		Incompatible distractors			
		A Low	A High	B Low	B High
Trail Making Test	A	-.27	-.11	-.43	-.43
	B	.18	.21	.00	.00
Test of Everyday Attention	Map Search A 1 minute	.10	.19	.13	.35
	Map Search A 2 minute	.05	-.05	.36	.33
	Map Search B 1 minute	.11	.25	.02	.21
	Map Search B 2 minute	.36	.11	.30	.30
	Telephone Search A	-.10	-.20	..07	.03
	Telephone Search B	.02	-.22	.05	-.08
HADS	Anxiety	-.08	.08	.14	.14
	Depression	-.14	-.11	-.14	.14

* Correlation is significant at the 0.05 level

Non-parametric (Kendall's tau) correlations for baseline tests of attention and mood for TBI participants (N=12)

		HADS	
		Anxiety	Depression
Trail Making Test	A	.11	.16
	B	-.48	-.41
Test of Everyday Attention	Map Search A 1 minute	.08	-.14
	Map Search A 2 minute	.07	-.13
	Map Search B 1 minute	.08	-.16
	Map Search B 2 minute	-.27	- .30
	Telephone Search A	-.12	-.02
	Telephone Search B	-.29	-.28

* Correlation is significant at the 0.05 level

Non-parametric (Kendall's tau) correlations for baseline tests of attention across computer tasks A & B (Errors) for TBI participants (N=12)

		Incompatible distractors			
		A Low	A High	B Low	B High
Trail Making Test	A	.24	.38	.07	.17
	B	.35	.13	.07	.00
Test of Everyday Attention	Map Search A 1 minute	-.53*	-.17	-.16	-.25
	Map Search A 2 minute	-.25	-.50*	-.28	-.35
	Map Search B 1 minute	-.49*	-.15	.04	-.17
	Map Search B 2 minute	-.11	-.53*	.14	-.29
	Telephone Search A	.21	-.10	-.09	-.26
	Telephone Search B	.08	-.66*	-.15	-.64*

* Correlation is significant at the 0.05 level