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Effects of Brain Injury Severity and Effort on Neuropsychological Tests of Attention

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Abstract

Attention impairment is one of the most common complaints following Traumatic Brain Injury (TBI). Multiple studies have shown that performance on neuropsychological tests of attention is affected by many factors, including injury severity and effort. The aim of this study was to determine the effect of injury severity on neuropsychological tests across different domains of attention while controlling for effort. The domains of focused attention, selective attention, divided attention, sustained attention, and working memory were assessed by performance on the Digit Span Forward subtest, the Stroop Color Word Test, the Trail Making Test, the Conners' Continuous Performance Test - II, and Digit Span Backwards subtest, respectively. Effort was determined according to performance on the Portland Digit Recognition Test and the Test of Memory Malingering. Effort was found to have a greater effect on test performance (.79) than injury severity (.47). Clinical implications of the findings are discussed.

Effort, Neuropsychological Assessment, Traumatic Brain Injury, Attention

Introduction

Traumatic Brain Injury (TBI) is a significant health problem in the United States and around the world. It is estimated that over ten million people worldwide experience a TBI serious enough to require hospitalization or cause death each year (Langlois, Rutland-Brown, & Wald, 2006). In the United States, estimates of yearly TBIs range from 1.4 million to 3 million depending on the classification scheme used (McCrea, 2008), resulting in approximately 290,000 hospitalizations and 51,000 deaths (Rutland-Brown et al., 2003). Of those injured, 80,000-90,000 will have long-term disability (Coronado, Johnson, Faul, & Kegler, 2006). In 1999, there were an estimated 5.6 million people in the United States that were suffering from long-term disability due to TBI (Thurman, Alverson, Dunn, & Sniezek, 1999). The burden extends beyond the individuals who experienced a TBI; the annual costs of TBI in the United States is approximately $60 billion when calculating direct costs, such as medical expenses, and indirect costs, such as decreased work productivity (Langlois, Rutland-Brown, & Wald, 2006). Because of the substantial personal and financial impact of TBI, it is important to understand the pathophysiology, natural history, and functional outcome related to TBI.

Traumatic Brain Injury

Pathophysiology.

TBI is injury to the head that is sufficient to cause alteration in brain function “resulting in alterations of consciousness, neurological impairments, or cognitive deficits” (Lucas & Addeo, 2006, p.351). TBI can be classified as either penetrating head injury or closed head injury. Penetrating head injury involves trauma in which the skull and dura are crushed or penetrated by an object, whereas in closed head injury, the skull remains intact and the brain is not exposed (Hannay, Howieson, Loring, Fischer, & Lezak, 2004). The pathophysiology that occurs in head injury is due to two processes: primary injury and secondary injury (Lucas & Addeo, 2006).

Primary injury is damage that results directly from the penetrating or impact forces at the moment of injury (Kochanek, Clark, & Jenkins, 2007). Common primary injuries usually include contusions and lacerations typically seen at the site of impact and the area opposite the impact, referred to as coup and contrecoup, respectively (Lucas & Addeo, 2006); diffuse axonal injury (DAI) that results from movement of the brain within the skull, resulting in shearing of axons and white matter tracks (Gennarelli, Thibault, & Graham, 1998); and disruption of vasculature, including hematomas and hemorrhaging, due to blood vessels tearing on impact (Hannay, Howieson, Loring, Fischer, & Lezak, 2004; Lucas & Addeo, 2006). Primary injuries are usually focal and limited in duration (Lucas & Addeo, 2006).

Secondary injury is delayed brain damage due to the physiological processes that can occur after primary injury (Nolan, 2005). Secondary injuries occur more frequently, can be of longer duration, and can cause more damage than primary injuries (Gennarelli & Graham, 2005; Lucas & Addeo, 2006). Common secondary injuries are edema, ischemia, increased intracranial pressure, and changes in neurochemical concentrations (Lucas & Addeo, 2006).

Primary and secondary injury can further be classified as focal or diffuse based on clinical and neuroradiological findings after brain injury (Gennarelli & Graham, 2005). Focal brain damage is limited to the areas of the brain where the pathology occurs, and may include: contusions, lacerations, hematomas, and hemorrhages (Nolan, 2005).

Diffuse damage affects widespread areas across the brain, and may include: DAI, ischemia, and changes in neurochemical concentrations (Gennarelli & Graham, 2005).

Measurement of Injury Severity.

The degree to which different focal and diffuse injuries develop is related to trauma forces (Gaetz, 2004). Mild traumas usually produce axonal damage in the parenchyma that result in short-term symptoms and no permanent damage, while moderate-severe traumas can produce vasculature damages that result in widespread cell death and persistent symptoms (Gaetz, 2004; Iverson, 2005). Because of the clinical and pathobiological implications of traumatic brain injury, it is necessary to accurately assess the severity of the brain injury.

Injury severity is defined by the acute injury characteristics: alteration of consciousness, duration of coma, post-traumatic amnesia, focal neurologic signs, and abnormalities revealed during neuroimaging; not by the severity of the symptoms after trauma (Alexander, 1995; Binder, 1997; Lucas & Addeo, 2006). These acute injury characteristics can be used to classify TBI as mild, mild-complicated, moderate, or severe (Binder, 1997). The injury classification based on these characteristics provides insight into the extent of pathophysiological changes and functional outcome.

The Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) is a widely-accepted instrument used to evaluate TBI severity based on the presence and degree of coma (Dijkers & Greenwald, 2007; Hannay, Howieson, Loring, Fischer, & Lezak, 2004) . The scale is based on three response dimensions that evaluate level of consciousness: eye opening, verbal response, and best motor response. Eye opening is scored from 1 to 4, verbal response is scored 1 to 5, and best motor response is scored 1 to 6. Higher scores in each category reflect higher levels of functioning. The scores from each dimension are added to produce an overall score, ranging from 3 to 15, to evaluate injury severity. Scores ranging from 3 to 8 are considered severe, 9 to 12 are moderate, and 13 to 15 are mild (Clifton, Hayes, Levin, Michel, & Choi, 1992). GCS score has been shown to be significantly related to depth of lesions (Levin, Williams, & Crofford, 1988) and is a good predictor of outcome (Levin, Grossman, Rose, & Teasdale, 1979; Rovlias & Kotsou, 2004), though the predictive ability is not as strong for mild head injury (McCullagh, Oucterlony, Protzner, Blair, & Feinstein, 2001).

Duration of coma is also a good predictor of functional and neuropsychological outcome in moderate-severe injuries (Dikmen, Machamer, Winn, & Temkin, 1995; Katz & Alexander, 1994), but this relationship is not found in mild TBI. In a summary of research on mild TBI outcome, Iverson, Lange, Gaetz, & Zasler (2007) reported no associaton between brief duration of coma and neuropsychological outcome. Duration of coma less than 30 minutes is classified as mild injury and greater than 30 minutes as moderate-severe injury (Carroll, et al., 2004; Kay, et al., 1993).

Posttraumatic amnesia (PTA) is a "syndrome of disorientation to time, place, and person, confusion, diminished memory and reduced capabilities for attending and responding to environmental cues" that occurs after TBI (Mysiw, Fugate, & Clinchot, 2007, p.288). Duration of PTA is related to lesion depth on MRI scans (Wilson, Teasdale, Hadley, Wiedmann, & Lang, 1993) and highly correlates with GCS score (Levin, Benton, & Grossman, 1982). Length of PTA is one of the best predictors of outcome after TBI, with longer durations of PTA related to worse outcome (Ellenberg, Levin, & Saydjari, 1996; Greenwood, 1997). In severe TBI, PTA was found to be a better predictor of cognitive impairment than depth and duration of coma (Bishara, Partridge, Godfrey, & Knight, 1992). One potential issue with using PTA as an outcome measure in mild TBI is that it is difficult to assess because it is a short period of time and is usually assessed retrospectively (Iverson, Lange, Gaetz, & Zasler, 2007). PTA of less than 24 hours is classified as mild injury and greater than 24 hours as moderate-severe injury (Carroll, et al., 2004; Kay, et al., 1993).

Focal neurologic signs are deficits that provide information about focal brain dysfunction, including sensory and motor deficits, such as hemiplegia, anosmia, or aphasia (Lucas & Addeo, 2006). Findings of focal neurologic signs are indicative of moderate-severe injury (Alexander, 1995).

Neuroimaging techniques are commonly used to determine neurologic changes after TBI. Magnetic Resonance Imaging (MRI) is capable of revealing lesions, particularly those in the brainstem, which have been found to be strongly related with poor neuropsychological outcome (Firsching, Woischneck, & Klein, 2001; Wedekind, Fischbach, Pakos, & Terhaag, 1999). The ability to visualize lesions makes MRI capable of studying the centripetal model of brain injury severity which claims that the stronger the force applied to the brain, the deeper the lesions and the more severe the injury (Levin, Williams, & Crofford, 1988). MRI is also sensitive to damage caused by less severe injury, including non-hemorrhagic DAI and small extra-axial hematomas (Hannay, Howieson, Loring, Fischer, & Lezak, 2004). Computed Axial Tomography/Computed Tomography (CT) scans can detect bleeding and most significant contusions. Postive findings of contusions (Wallesch, Curio, Kutz, Jost, Bartels, & Synowitz, 2001) and hemorrhaging (Schaan, Jaksche, & Boszczyk, 2002;

Rovlias & Kotsou, 2004) have been associated with greater injury severity and poorer outcome.

Mild TBI with objective findings on neuroimaging has significant diagnostic implications; the severity classification changes from mild to mild-complicated TBI. Mild TBI severe enough to cause structural damage that can be visualized on neuroimaging is more likely to have cognitive symptoms and recovery consistent with moderate TBI (Iverson, 2005; Kashluba, Hanks, Casey, & Millis, 2008; Williams, Levin, & Eisenberg, 1990).

Natural History.

The pathophysiology resulting from TBI is presumed to underlie the neuropsychological deficits seen in trauma patients (Iverson, 2005), with more severe injuries producing greater dysfunction for longer duration (Rohling, Meyers, & Millis, 2003). In 2003, Schretlen and Shapiro conducted a meta-analysis of 39 articles from 1983 to 2003 comparing the neuropsychological outcomes of 742 mild TBI patients, 974 moderate-severe TBI patients, and 1164 control subjects. Results showed that injury had a moderate effect (d = -0.41) in mild TBI on test performance during the first six days post-injury, but had a negligible effect (d = -0.08) between 30 and 89 days post-injury, and actually outperformed controls (d = 0.04) at times greater than 89 days post-injury. In moderate-severe TBI, injury had a very large effect (d = -0.97) at less than 6 months post-injury and a moderate effect (d = -0.60) at 6-24 months post-injury. These findings provide important insights about the natural history of TBI: a) there is a dose-response relationship between injury severity and neuropsychological impairment, with moderate-severe TBI producing greater impairment for longer duration than mild TBI; b) time since injury moderates the effect on neuropsychological performance, with impairment being greatest in the acute injury phase and recovery occuring rapidly in the post-acute phase, then progressing at a slower rate; and c) neuropsychological impairment in mild TBI should be resolved by three months post-injury.

Some studies have found that cognitive impairment is still evident in mild TBI after three months post-injury. Binder et al (1997) conducted a meta-analysis of eight studies that included only patients that were tested at least three months post-injury and were diagnosed as mild TBI based on acute injury characteristics. Persisting cognitive impairment was discovered, but the weighted overall effect size was negligible (g = .07). With a small effect size, the effect sizes of other factors, such as age or pre-injury characteristics, could mimic an effect of mild TBI, making it difficult to assert that persisting impairment is due to the head injury (Dikmen, Machamer, & Temkin, 2001).

In another meta-analysis, Zakzanis et al. (1999) reported individual effect sizes for specific cognitive domains across 12 studies. The analysis found moderate (d = .44) to large effects (d = .72) for all domains. A major flaw with the study, however, is that the significance of the effect cannot be inferred because the study selection criteria and time since injury were not indicated, resulting in the possible inclusion of clinic-based and more acutely-injured participants (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005). In studies where possible confounding methodological issues, such as time since injury and litigation (Dikmen & Levin, 1993; Dikmen, Machamer, & Temkin, 2001), were properly controlled, neuropsychological impairment in mild TBI was resolved by three months (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005; Carroll, et al., 2004; Frencham, Fox, & Mayberry, 2005).

Persisting Symptoms.

Despite these findings, an estimated 10% of the mild TBI population reports experiencing persistent cognitive symptoms (Iverson, Lange, Gaetz, & Zasler, 2007), with some complaints continuing for years after the initial injury (McCrea, 2008). Poor outcome may be attributed to a multitude of factors such as: pre-morbid neurologic or psychiatric problems and life stressors (Ponsford et al., 2000), and co-morbid conditions, such as depression, anxiety, (McCauley, Boake, Levin, Contant, & Song, 2001) and financial incentive (Binder & Rohling, 1996). Although many factors have been linked to persisting symptoms, a World Health Organization Collaborating Centre Task Force on Mild TBI (2004) critical review of 120 articles related specifically to prognosis after mild TBI found that financial incentive was the only consistent predictor of persisting cognitive symptoms.

Effort.

Iverson (2005) found that financial incentive had a moderate effect ($d = 0.5$) on persisting symptoms in mild TBI, and effort was found to produce a very large effect ($d = 1.1$). When financial incentive is a factor, a patient may be motivated to appear impaired by performing poorly on neuropsychological tests. A study by Bianchini, Curtis, & Greve (2006) found that as financial incentive increased, effort on neuropsychological tests decreased. Thus, it is important to determine if effort during testing has an important effect on impairment in mild TBI cases.

Assessing Effort.

Neuropsychologists are often called upon to evaluate the severity of cognitive impairment and disability in patients who are seen in a compensation-seeking context

(Martelli, Nicholson, Zasler, & Bender, 2007). An objective measure of effort commonly used in neuropsychological assessment is the symptom validity test (SVT; Pankratz, 1979), which relies on statistical probability to assess effort (Strauss, Sherman, & Spreen, 2006). The SVT is a forced-choice measure that requires the patient to chose between a target item that was previously shown and a foil. Because only two alternatives are available, approximately 50% of the choices would be correct by chance alone (guessing) (Bianchini, Mathias, & Greve, 2001). When a patient shows below chance performance, it provides evidence that the patient knows the correct answer, but is purposely choosing the foil (i.e., negative response bias; Pankratz, 1983). Most patients who exaggerate do not perform worse than chance (Greve, Binder, & Bianchini, 2009). In these patients, poor effort is revealed by scores that fall below empirically-derived cutoffs for people with unequivocal cerebral dysfunction (Binder, 1993a; Binder & Kelly, 1996; Tombaugh, 1997).

Effect of Effort.

Green, Rohling, Lees-Haley, and Allen (2001) examined the effect of effort in a group of compensation-seeking patients seen in the context of a neuropsychological assessment. Objective measures were used to classify head injury severity (GCS, neuroimaging abnormalities, PTA, and coma duration) and effort (performance on two SVTs and an internal validity indicator). The test scores were converted to *Z*-scores and averaged, creating an Overall Test Battery Mean. The groups were then compared on their performance on popular neuropsychological measures across different cognitive domains (Executive Functioning, Attention and Working Memory, Verbal Comprehension). Attention and Working Memory was the cognitive domain most affected by brain damage. When the poor effort group was removed, the moderate-severe injury group performed significantly lower than the mild injury group. When looking at effort, the poor effort mild head injury group performed significantly worse than the good effort moderate-severe injury group.

A study by Binder, Kelly, Villanueva, and Winslow (2003) looked at the effect of motivation on neuropsychological test performance in mild TBI patients using a known-groups design. Subjects were divided into three groups: 1) mild head injury, good motivation; 2) mild head injury, poor motivation; and 3) moderate/severe head injury, good motivation based on performance on the Portland Digit Recognition Test (Binder, 1993), an SVT. The groups were then compared on performance on a neuropsychological test battery that covered a broad range of cognitive functions (Intelligence, Executive Functioning, Attention, Tactile Sensory Function). Results found that the mild head injury, poor motivation group performed significantly worse than both the mild and moderate/severe good motivation groups.

Attention

One task of the brain is to receive information from the environment, allowing people to interact effectively with their surroundings. Because the brain can only process a limited amount of information at one time, the large amount of information with which the senses are continuously confronted requires a system to select specific information for additional processing (Leclerq, 2002; Schneider & Shiffrin, 1977). Attention is a system of interacting components that enables an individual to filter pertinent information from the enviroment, hold and manipulate mental responses, and monitor/alter responses to stimuli (Strauss, Sherman, & Spreen, 2006; Zimmermann &

Leclerq, 2002). These components are subserved by discrete areas of the brain that are connected by functional systems (Kinsella, 1998). Neuroimaging and lesion studies have implicated all four lobes of the cortex, as well as thalamic, tegmental, and basal ganglia structures as parts of interconnected networks that comprise the attention system (Cohen, 1993; Kinsella, 1998; Posner & Petersen, 1990). These networks of brain structures work in various combinations to produce the components of the attention system (Kinsella, 1998) .

Accurately defining the components that comprise attention has been complicated by multiple factors. Due to the interrelated nature of the attention system, the assessment of a component process in isolation is unfeasible, making it difficult to differentiate components (Leclercq, 2002). Further, different areas of research use diverse methodologies and operational definitions, resulting in different terms that refer to overlapping or synonymous processes (Strauss, Sherman, & Spreen, 2006). Another issue is the lack of integration between disciplines; experimental research uses instruments that are more appropriate for cognitive models of attention, but do not take into account the clinical aspects of attention, such as tests commonly used in clinical practice to assess impairment and recovery (Cantagallo, 2002).

Despite the conflicting research methods and terminology, most models divide attention into component processes such as selective attention, divided attention, and sustained attention (Chan, 2002). One model by Sohlberg & Mateer (1989) is well-suited for studying TBI because it combines theory from experimental literature with empirically-developed clinical theory from patient observation and subjective complaints in a TBI population. The model divides attention into focused, selective, alternating, divided, and sustained attention component processes. For the purposes of this study, the constructs of processing speed and working memory will also be examined because they complement these processes and are commonly used in clinical practice.

Focused attention is the "ability to respond discretely to specific visual, auditory, or tactile stimuli" (Sohlberg & Mateer, 1989, p.120). Because only a limited number of stimuli can be attended to at one time, focused attention is the amount of information attended to at given time based on the temporal-spatial constraints of the environment (Cohen, 1993). This is the basic filtering of information from the environment, which is most commonly thought of when discussing the general concept of attention.

Selective attention is the "ability to focus on relevant stimuli in the presence of distracting stimuli and to select information for conscious processing" (Sohlberg & Mateer, 1989, p.121). Selective attention is different from focused attention due to the strength of the association of the distracting stimuli and responses (Sohlberg & Mateer, 1989). Selective attention requires conscious, effortful concentration on one aspect of the environment while ignoring competing stimuli, which can be automatic processes, (e.g. saying the color a word is printed in instead of reading the word) (MacLeod, 1991; Schneider & Shiffrin, 1977).

Alternating attention is the ability to shift attentional focus between tasks that have different cognitive requirements (Sohlberg & Mateer, 1989). Alternating attention is related to the operation of Disengagement (Cohen, Malloy, Jenkins, & Paul, 2006). Attention remains focused on one stimulus until another stimulus is presented; this shift in attention is dependent upon the ability to disengage from the original stimulus before attention can be allocated to new stimulus (Cohen, Malloy, Jenkins, & Paul, 2006).

Divided attention is the "ability to respond simultaneously to multiple tasks or multiple task demands"(Sohlberg & Mateer, 1989, p.121). In divided attention, resources are shared by two or more types of stimuli or mental operations (Van Zomeren, 1994). Divided attention will not be analyzed in this study because most tests of divided attention are experimental tasks that are not commonly used in clinical assessment (Cantagallo, 2002).

Sustained attention is the "ability to maintain consistent behavioral responses during continuous and repetitive activity "(Sohlberg & Mateer, 1989, p.121). Sustained attention occurs when the flow of information is fast and requires continuous active processing (Leclerq, 2004).

Processing Speed is not a component process of attention, but mental slowness is closely related to attention impairments (Leclerq & Azouvi, 2002). Slowed processing speed results in poor cognitive functioning because elementary processing operations cannot be executed due to time constraints and because products of early processing may not be available when later processing is completed (Salthouse, 1996). In studies where processing speed was controlled, impaired performance on attention tasks by patients with severe TBI did not significantly differ from controls (Felmingham, Baguley, & Green, 2004; Ponsford & Kinsella,1992; Rios, Perianez, & Munoz-Cespedes, 2004).

Working memory is a temporary storage of limited amounts of information where the information can be manipulated (Lucas & Addeo, 2006; Knudsen, 2007). Attention deficits can occur when the capacity of resources needed to temporarily store new information is reduced due to simultaneously performing mental operations on incoming or recently-accessed information, (Van der Linden & Collette, 2002). Working memory is necessary for goal maintenance, which is the ability to remember to inhibit certain stimuli while attending to others. Goal maintenance is critical for selective and divided attention (Kane & Engle, 2003).

Attention and TBI.

Attention deficits are the most common cognitive complaints in mild TBI (Hannay, Howieson, Loring, Fischer, & Lezak, 2004) and second to memory complaints in moderate and severe TBI (Leclerq, Deloche, & Rousseaux, 2002), though the latter finding may be deceptive because many complaints of memory problems may actually be due to attention deficits (Hannay, Howieson, Loring, Fischer, & Lezak, 2004). Problems associated with attention deficits can impede social and occupational recovery, especially in more severe injuries (van Zomeren & van den Burg, 1985). The effect of attention impairments on recovery is dramatic because the attention system subserves other cognitive constructs, such as memory, perception, language comprehension/production, and planning (Stierwalt & Murray, 2002; Zimmermann & Leclerq, 2002).

Attention impairments are frequently reported in TBI patients due to the nature of the injury. Areas of the brain that are typically damaged by trauma, the frontal and anterior temporal lobes, are some of the same areas that subserve attention (Cohen, Malloy, Jenkins, & Paul, 2006; Stierwalt & Murray, 2002). Because of the interconnected nature of the attention system, damage to one area of the brain can cause impairment in one, multiple, or all attention components to varying degrees (Niemann, Ruff, & Kramer, 1996). Selective attention impairment can be caused directly by parietal lesions, or indirectly by injury to the brainstem which can result in arousal deficits, producing higher component process dysfunction (Niemann, Ruff, & Kramer, 1996). Damage to subcortical white matter tracts can also contribute to attention impairment (Rios, Perianez, & Munoz-Cespedes, 2004). Diffuse injury to subcortical white matter tracts that connect anterior regions of the cortex with the posterior parietal region produce sustained attention impairments despite no findings of pathophysiology in either region (Chan, 2002). Diffuse white matter damage is also implicated in slowed information processing (Mathias, et al., 2004).

Recovery of attention function following TBI is similar to other cognitive processes. Attention impairment is most severe in the acute injury period (Stierwalt & Murray, 2002). Recovery occurs quickly in the early post-acute injury phase, beginning with basic attention functions and followed by higher-level attention components, such as working memory and divided attention (Alexander, 1995). Attention deficits resulting from moderate-severe TBI show most recovery during the first year post-injury and plateau during the second year, though more severe injuries continue to show marked recovery of complex attention components, such as alternating attention (Dikmen, Machamer, & Temkin, 1990). Some patients have continued recovery and impairment of processing speed and alternating attention five years post-injury (Millis, et al., 2001). In Mild TBI cases showing attention deficits, the worst impairments are in the first week, with most complex attention component processes resolved by one month (Alexander, 1995; Dikmen, Machamer, & Temkin, 2001) and complete resolution by three months (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005).

Neuropsychological Tests of Attention

The Trail Making Test (TMT; Reitan & Wolfson, 1993) is one of the top five tests used by neuropsychologists and is the top instrument used to measure attention (Rabin, Barr, & Burton, 2005). Part A is a test of processing speed (Lucas & Addeo, 2006). Part B of the TMT is commonly considered a test of divided attention because it assesses the ability to attend to multiple stimuli simultaneously, yet only one task is being performed at a time (Cantagallo, 2002). To clarify discrepancies in terminology, Part B is used as a measure of alternating attention because the subject is required to switch attention resources between competing stimuli in order to successfully complete the test. The TMT is sensitive to closed-head injury (Dikmen, Machamer, Winn, & Temkin, 1995; Iverson, Lange, Green, & Franzen, 2002) with moderate-severe TBI showing impairment years after injury (Millis, et al., 2001).

Digit Span is a subtest from the Wechsler Adult Intelligence Scale - III (WAIS-III; Wechsler, 1997) that is composed of two separate tasks, Digits Forward and Digits Backward. Using standard scoring procedures, the scores on both tasks are summed to create an overall subtest score, but examining the scores separately produces more significant neuropsychological findings because the tasks involve different attention processes that are affected differently by TBI (Banken, 1985). Digits Forward is a test of focused attention which is resistant to the effects of TBI and other brain disorders (Hannay, Howieson, Loring, Fischer, & Lezak, 2004). Severely amnestic patients can perform this task, providing evidence that it is a measure of short-term attention span, not memory (Cohen, 1993). Digits Backward is a test of working memory that requires the subject to retain information while performing a mental function (Hannay, Howieson, Loring, Fischer, & Lezak, 2004). Digits backward has been shown to be sensitive to brain damage (Black, 1986).

The Stroop Color and Word Test (Golden, 1978; Golden & Freshwater, 2002), a measure of selective attention and cognitive flexibility, is one of the oldest and most widely used techniques to examine attention (MacLeod, 1991). The test measures the cognitive control ability of the individual to maintain a goal while suppressing a habitual response for one that is less familiar (Strauss, Sherman, & Spreen, 2006). The Word Reading and Color Naming trials are used as measures of processing speed (Lucas & Addeo, 2006). The scores on the three trials (Word, Color, and Color Word Reading) are used to create an “interference” score. This interference score is a measure of selective attention. The Stroop test is sensitive to closed head injury, with patients typically responding slower on each subtask, though this finding is not consistently demonstrated on the interference condition (Batchelor, Harvey, & Bryant, 1995; Felmingham, Baguley, & Green, 2004; Ponsford & Kinsella, 1992).

The Connor’s Continuous Performance Test-II (CPT-II), a computerized test of sustained attention, is one of the top five attention tests used by neuropsychologists (Rabin, Barr, & Burton, 2005) . The test places limited cognitive demand on the subject, but requires attention over a repetitive and lengthy period of time (Cohen, 1993). The CPT-II has been found to be sensitive to head injury (Cicerone & Azulay, 2002).

Effort and Attention tests.

Poor effort is frequently observed on attention tests when external incentives to perform poorly are present. (Strauss, Spellacy, Hunter, & Berry, 1994). Multiple studies have looked at the ability of common tests of attention ability to detect poor effort. The Trail Making Test (Binder, Kelly, Villanueva, & Winslow, 2003; Green, Rohling, Lees-Haley, & Allen, 2001), Digit Span subtest (Axelrod, Fichtenberg, Millis, & Wertheimer, 2006; Babikian, Boone, Lu, & Arnold, 2006; Heinly, Greve, Bianchini, & Love, 2005), and Stroop (Lu, Boone, Jimenez, & Razani, 2004; Vickery, et al., 2004) have all be shown to differentiate TBI patients giving poor effort from those giving good effort, providing evidence that effort affects performance on attention tests. Thus, when examining attention in patients with external incentives, it is important to account for the effects of effort on test performance.

Purpose

The purpose of the current study is to examine the relationship between head injury severity and performance on neuropsychological tests across different aspects of attention: Focused attention, selective attention, alternating attention, sustained attention, working memory, and processing speed, while controlling for effort. Controlling for effort will provide a more accurate assessment of how head injury severity affects cognition, helping to clarify discrepancies in the literature. Examining the effect of effort will also elucidate the impact that poor effort has on neuropsychological tests. More accurate neuropsychological findings will help improve the care of those who suffer TBI.

Hypotheses

Hypothesis 1: The Effect of Traumatic Brain Injury Severity.

When effort is controlled, TBI severity is expected to show a dose-response relationship with performance on attention tests. The Mild TBI/Good Effort group will show no residual impairment and will not significantly differ on attention test performance when compared to a Control group consisting of non-head injured community participants. When impairment persists in the Mild TBI/Good Effort group, other factors, such as psychological issues, will be involved. Moderate-severe TBI/Good Effort patients will show impairment on the attention tests and will perform significantly worse than both the Mild TBI/Good Effort group and the Control group.

Hypothesis 2: The Effect of Effort.

The impact of effort will be greater than that of head injury severity. The Mild TBI/ Poor Effort group will perform significantly worse on attention tests across all domains than both Mild TBI/Good Effort and Control groups. The Mild TBI/Poor Effort will also score similar to or significantly worse than the Moderate-severe/Good Effort group on attention tests across all domains.

Methods

Participants

Archival data was collected from approximately 195 TBI patients seen in the context of a neuropsychological evaluation at a private psychological practice in southern Louisiana. To be included in the study, the participants must have completed the Trail Making Test, Stroop Color and Word Test, Continuous Performance Test-II, WAIS Digit Span subtest, Portland Digit Recognition Test, and Test of Memory Malingering. Patients were excluded if they were younger than 18 or older than 55 years of age, had less than 8 or more than 16 years of education, or were evaluated less than 6 months after injury. Altogether, 122 patients met these criteria. Of the 122 patients, 111 (91%) had financial incentive. The majority of these patients were seen for either Worker's Compensation (30%) or personal injury (56%) claims.

Forty participants approximating the demographic characteristics of the TBI sample were recruited from the community to serve as a control group. Each was administered the Trail Making Test, Stroop Color Word Test, Continuous Performance Test-II, WAIS-III Digit Span subtest, and Portland Digit Recognition Test based on standard administration procedures and given financial compensation for their participation.

Group Classification

TBI Severity Classification.

TBI patients were divided into two injury severity groups: mild and moderate-severe. Patients were placed in the mild TBI group if they meet the Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine (Kay, et al., 1993) criteria including: 1) loss of consciousness less than 30 minutes; 2) a Glasgow Coma Scale of 13-15 after 30 minutes; 3) post traumatic amnesia less than 24 hours; and Alexander (1995) criteria of 4) no focal signs and 5) no abnormalities on neuroimaging attributed to the accident. Patients that exceeded any of the criteria were placed into the moderate-severe TBI group. Therefore, the moderate-severe group included a broad range of injury severity from mild-complicated to severe TBI.

Effort Classification.

All TBI patients were classified as giving good or poor effort during the evaluation based on performance on the Portland Digit Recognition Test (PDRT; Binder,1993b) and the Test of Memory Malingering (TOMM; Tombaugh, 1996)(see below). Control participants were administered the PDRT to ensure good effort was given on the measures. Patients were placed in the poor effort group if they achieve scores below the published cut-offs scores: 25 on the “easy” trial, 19 on the “hard” trial, or 46 when the trials are combined for the PDRT (Greve & Bianchini, 2006), or 39 on Trial 1, 47 on Trial 2, or 47 on the Retention Trial of the TOMM (Greve, Bianchini, & Doane, 2006).

Using these cut-off scores, the PDRT and TOMM have been shown to detect over 50% of people giving poor effort using scores that occur in 5% of TBI patients giving good effort (Greve & Bianchini, 2006; Greve, Bianchini, & Doane, 2006; Tombaugh, 1997). Subjects that meet criteria for the abbreviated administration of the PDRT were considered to be giving good effort (Binder, 1993b; Doane, Greve, & Bianchini, 2005).

Classification Results.

The following groups were created based on the classification scheme described above:

1) *Mild TBI/Good Effort* (n = 40). Patients in this group met criteria for Mild TBI and scored above all of the cut-off scores on the PDRT and TOMM.

2) *Mild TBI/Poor Effort* (n = 42). Patients in this group met criteria for Mild TBI and scored below at least one of the cut-off scores on the PDRT or TOMM.

3) *Moderate-severe TBI/Good Effort* (n = 40). Patients in this group exceeded at least one Mild TBI criteria and scored above all of the cut-off scores on the PDRT and TOMM.

4) *Moderate-severe TBI/Poor Effort* (n = 14). Patients in the group exceeded at least one Mild TBI criteria and scored below at least one of the cut-off scores on the PDRT or TOMM. Because the sample size is likely was small and the group greatly varies in injury severity, the data from this group was not analyzed.

5) *Control* (n = 40). Participants in this group consist of non-head injured subjects recruited from the community to match the demographic characteristics of the TBI sample.

Measures

Attention Measures.

Digit Span. Digit Span is a subtest of the Wechsler Adult Intelligence Scale, 3rd Edition (WAIS-III; Wechsler, 1997). The test is composed of two separate tasks, Digits Forward and Digits Backward. Both tasks consist of seven pairs of random number sequences that begin with two numbers per pair and increase to nine numbers per pair. In the first task, the examiner reads the numbers aloud and asks the subject to repeat the numbers. In the second task, the examiner reads the numbers aloud, but requires that the subject repeat the numbers in the reverse order of how they were read. Each task is discontinued when the subject incorrectly repeats both number sequences from the same pair. The variable being studied is the length of the longest number sequence repeated correctly for each task. Age-corrected t-scores (Wechsler, 1997) are used for the analyses.

Trail Making Test. The Trail Making Test (TMT; Reitan & Wolfson, 1993) is composed of two parts, TMT-A and TMT-B. In part A, the subject uses a pen to connect, in order, 25 numbered circles randomly arranged on a page as quickly as they can. In part B, the subject must connect, in order, 25 circles alternating between numbers and letters. If the subject makes an error, the examiner informs the subject, repeats the instructions, and moves the subject to the last correctly marked circle. Each part is discontinued when the subject cannot complete the task within five minutes. The variable being studied is the amount of time needed to complete each part. Corrected t-scores for age, gender, ethnicity, and education (Heaton et al., 2004) are used.

Stroop. The Stroop Color and Word Test (Golden, 1978; Golden & Freshwater, 2002) consists of three parts: A page consisting of 100 color words (red, blue, green) typed in black ink; a page of 100 Xs in red, blue, or green ink; and a page of 100 color words (red, blue, green) printed in different ink colors (red, blue, green). The color of the ink might not match the color word in the third condition. The subject is required to read down the columns as quickly as possible within a 45 second time limit. The subject reads the word in the first condition, and the color of the ink in the second and third conditions. If the subject makes an error, the examiner informs the subject and requests that the subject attempt the word again. The variable being studied is the interference score derived from performances on the three trials. Age-corrected t-scores from the manual (Golden & Freshwater, 2002) are used for analyses

Continuous Performance Test-II. The Continuous Performance Test-II (CPT-II; Conners & MHS Staff, 2000) is a computer-based test that consists of random letters flashing onto the computer screen. The subject must press the space bar as soon as a letter flashes on the screen, except for the letter "X". If an "X" appears on the screen, the subject is to wait for another letter to appear on the screen before pushing the space bar. The variable being studied is the number of omissions for letters other than "X". Age- and education-corrected t-scores from the manual (Conners & Staff, 2000) are used for analyses.

Effort Measures.

Portland Digit Recognition Test. The Portland Digit Recognition Test (PDRT; Binder, 1993b) is a forced-choice symptom validity test. The subject is required to remember a five-digit number that is read by the examiner. After the examiner reads the number, the subject has to count backwards for a specified amount of time as a distraction delay. After the delay, the examiner shows the subject a card with two five-digit numbers on it; one number is the number the examiner read. The subject then picks the number they remember the examiner reading. The subject is given feedback after each item. The test is composed of an "easy" section and a "hard" section. The easy section is composed of 36 items. For the first 18 items, the subject counts backwards from 20 for five seconds. For the next 18 items, the subject counts backwards from 50 for 15 seconds. The hard section is composed of 36 items. The subject counts backwards from 100 for 30 seconds for all 36 items. Summation of both sections produces a total score. Based on administration protocol, if a subject scores at least 19 of 36 on the “easy” section and either 7 of the first 9 items or 12 of the first 18 items on the “hard” section, administration of the remaining items is optional (Binder, 1993). The variables being studied are the number of correct items for each section and the combined total score.

Test of Memory Malingering. The Test of Memory Malingering (TOMM: Tombaugh, 1996) is a forced-choice symptom validity test. The test consists of three trials. In the first two trials, the subject is instructed to look at 50 line drawings of common objects one at a time for three seconds. After the 50 drawings have been shown, the subject is shown two drawings, one that was among the 50 shown and a foil. The subject is instructed to point to the drawing they remember seeing for each of the 50 drawings; feedback is given after each item. The second trial is immediately given after the first is completed and contains the same items as the first trial. There is a 15 minute time delay between the second and third trial. The third trial only contains the recognition portion. The variables being studied are the number of correct items on each trial, respectively.

Results

Group Characteristics

Demographics and Injury Characteristics.

Descriptive statistics were evaluated for age, education, ethnicity, and gender to determine if the groups significantly differed on demographic characteristics. Analysis of variance (ANOVA) indicated no significant group differences for age (F[3, 159] = 1.539; p = .207; η^2 = .028), nor education (F[3, 159] = 2.362; p = .073; η^2 = .043). Pearson's Chi-square analyses revealed a significant group difference for ethnicity (X^2[12] = 28.229; p = .005; Cramer's V = .241), but not for gender (X^2[3] = 5.090; p = .165; Cramer's V = .177). Results are presented in Table 1.

Descriptive statistics were also examined for injury characteristics. The three TBI groups did not significantly differ on time between injury and evaluation (F[2, 120] = .974; p = .281; η^2 = .016), but showed significant differences for GCS score (F[2, 87] = 55.113; p = .000; η^2 = .562). As expected, the score for the moderate-severe TBI group was significantly lower than both mild TBI groups. The scores for the mild TBI groups did not significantly differ.

Because of the range of severity in the Moderate-severe TBI group, it is important to further examine the injury characteristics of this group. Based on the injury classification scheme discussed above, 9 patients met criteria for mild-complicated, 11 for moderate, and 18 for severe TBI. There was insufficient information to accurately label two patients, but available information placed the patients in the mild-complicated to moderate range. Thus, almost half (45%) of the patients in the moderate-severe group experienced a severe TBI.

Based on the results, ethnicity and injury severity are the only characteristics that are significantly different between the groups. Ethnicity is not expected to affect test performance because: ethnicity-corrected scores are used for two variables (Trail Making Test A & B); ethnicity does not affect test performance on the CPT nor the Stroop Interference score (Strauss, Sherman, & Spreen, 2006); and ethnicity itself is not an explanatory variable because it is confounded with education and other factors (Lezak, Howieson, & Loring, 2004). Thus, greater injury severity in the moderate-severe TBI group is the only factor that is likely to affect test performance. See Table 1 for specific breakdown of demographic and injury characteristics.

Table 1
Demographic and injury characteristics by group.

	Mild TBI Good Effort M (sd)	Mild TBI Poor Effort M (sd)	Moderate-severe TBI M (sd)	Control M (sd)
Age	38.1 (9.7)	39.2 (9.6)	34.4 (10.5)	38.0 (12.8)
Education	12.9 (2.0)	12.0 (1.8)	12.8 (2.1)	12.9 (1.6)
Gender (% Male)	65	71	80	58
Race				
(% Caucasian)	75	57	80	68
(% African Am.)	25	38	15	10
(% Hispanic)	0	5	0	15
(% Asian)	0	0	3	5
(% Other)	0	0	3	3
Time Since Injury (Months)	34.8 (36.5)	26.1 (17.9)	33.3 (33.4)	--
GCS	14.8 (0.50)	14.9 (0.40)	9.12 (4.28)	--

Note. M = mean; sd = standard deviation; TBI = traumatic brain injury; GCS = Glasgow coma scale.

Dependent Variables

Prior to analysis, the six dependent variables were screened for normality of distribution and outliers. Results indicated that the distribution of the CPT Omission scores was skewed. The skewed score should not affect results because the large sample size ensures robustness to violations of normality (Tabachnick & Fidell, 2007), and analysis of transformed scores was almost identical to the original scores. Thus, CPT scores were not adjusted in order to maintain clinically-useful comparisons. The Mahalanobis distance test, using a *p* value of .001 ($X^2[6] = 22.46$; Tabachnik & Fidell, 2007), was conducted to test for multivariate outliers. No multivariate outliers were identified.

A one-way multivariate analysis of variance (MANOVA) was conducted to determine if the four groups (Mild TBI/Good Effort, Mild TBI/Poor Effort, Moderate-severe TBI/Good Effort and Control) differed on performance on the six dependent variables: Trail Making Test A, Trail Making Test B, Stroop Interference, Digits Forward, Digits Backward, and CPT Omissions. Box's *M* test was significant, $p < .001$. The results of Box's *M* test are ignored, however, because the sample sizes are equal, which assumes robustness of significance tests (Tabachnick & Fidell, 2007). Using Pillai's Trace as a conservative analysis, performance on the combined dependent variables was significantly different across the groups, $F(18, 465) = 3.98$, $p < .001$, accounting for 13% of the variance (η^2).

As seen in Table 2, follow-up ANOVAs found significant group differences for five of the variables: Trail Making Test A, Trail Making Test B, Digits Forward, Digits Backward, and CPT Omissions. Stroop Interference was not significantly different between the groups. Post-hoc analyses were conducted for the five significant variables. Dunnett's C test was used for CPT Omissions because Levene's Test was significant, $p < .001$. All other variables used Tukey's b. The Mild TBI/Poor Effort group performed significantly worse than the Mild TBI/Good Effort group on three of the five variables, with CPT Omissions and Trail Making Test B as the exceptions. The moderate-severe TBI group performed significantly better than the Mild TBI/Poor Effort group on CPT Omissions and Digits Forward. The moderate-severe TBI group performed significantly worse than the Mild TBI/Good Effort group on one test, Trail Making Test A. The Control group scored significantly better than the Mild TBI/Poor Effort group on all variables except Digits Backward, and both the Moderate-severe and Mild TBI/Good Effort groups on two variables. Group scores relative to the Control group across the variables are presented in Figure 1.

Table 2
Mean scores by group, and results of follow-up ANOVAs and post-hoc analyses.

	Mild TBI Good Effort M (sd)	Mild TBI Poor Effort M (sd)	Moderate-severe TBI M (sd)	Control M (sd)	*F*	η^2
TMT A	44.48[a] (11.78)	35.14[b] (12.11)	37.28[b] (13.55)	51.28[c] (10.53)	15.07***	.22
TMT B	42.13[ab] (12.16)	36.62[a] (12.56)	39.45[ab] (10.48)	45.70[b] (12.09)	4.35**	.08
Digit F	41.65[a] (7.58)	36.47[b] (9.75)	41.30[a] (6.83)	47.13[c] (9.05)	11.01***	.17
Digit B	43.37[a] (8.02)	38.12[b] (7.20)	40.79[ab] (7.20)	42.03[ab] (6.81)	3.85*	.07
Stroop Int	49.63[a] (6.67)	51.71[a] (7.62)	51.5[a] (8.16)	51.23[a] (9.28)	.58	.01
CPT Omit	81.65[ab] (59.61)	110.04[a] (82.28)	74.45[b] (58.87)	52.55[b] (15.12)	6.52***	.11

Note. M = mean; sd = standard deviation; TBI = traumatic brain injury; TMT A = Trail Making Test A; TMT B =Trail Making Test B; Digit F = Digits Forward; Digit B = Digits Backward; Stroop Int = Stroop Interference; CPT Omit = CPT Omissions.
[ab] Row means with same letter are not significantly different using Tukey's b corrections (alpha = .05). Note. CPT Omit used Dunnett's C test due to significant Levene's Test.
*p < .05, **p < .01, ***p < .001.

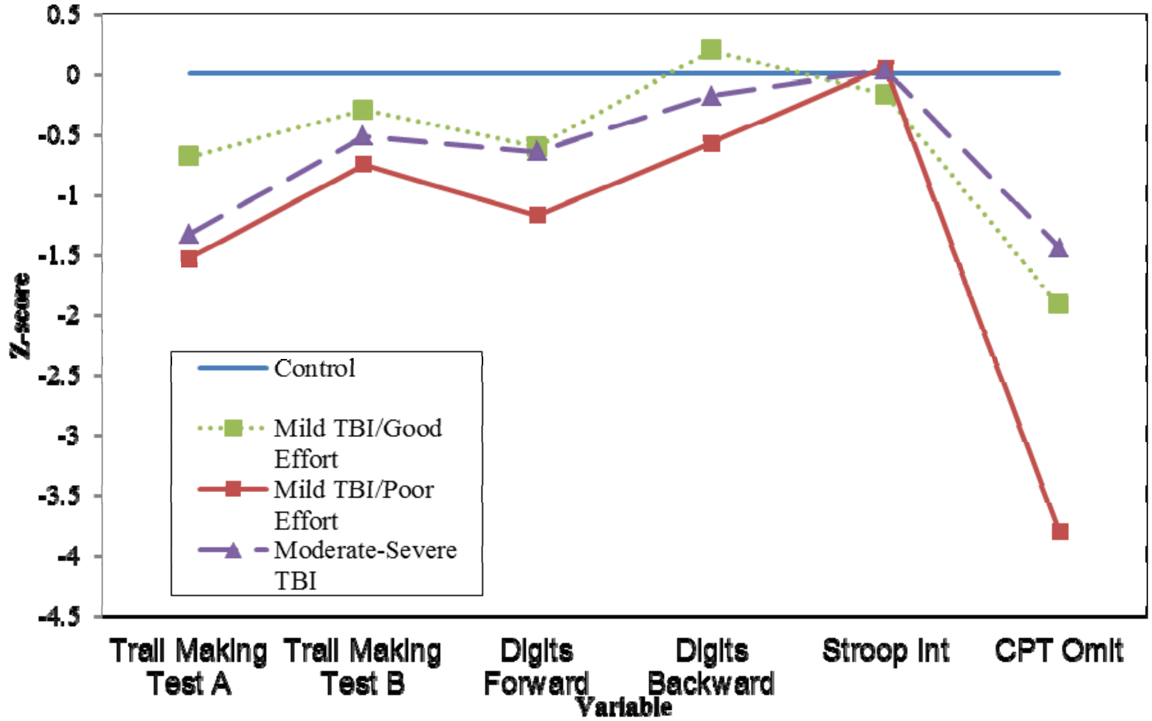

Figure 1. Group scores on Attention variables relative to control group. Z-scores were created from control group distribution. TBI = traumatic brain injury. Stroop Int = Stroop Interference. CPT Omit = CPT Omissions. Note. CPT Omission z-scores were made negative to denote poorer test performance.

Effect Size.

Effect sizes (Cohen's d) were calculated for the six dependent variables to determine the relative effects of injury severity and effort. Effect sizes for injury severity were calculated comparing the Mild TBI/Good Effort and Moderate-severe TBI groups to the Control Group. Effect sizes for effort compared the Mild TBI/Poor Effort and Control groups. Effect sizes for individual tests ranged from -.18 to .67 for mild TBI, from -.26 to 1.15 for moderate-severe TBI, and -.06 to 1.42 for effort. When averaged across the six tests, the effect was small for mild TBI (.37), medium for moderate-severe TBI (.48), and large for effort (.79). The effect size by test is presented in Figure 2.

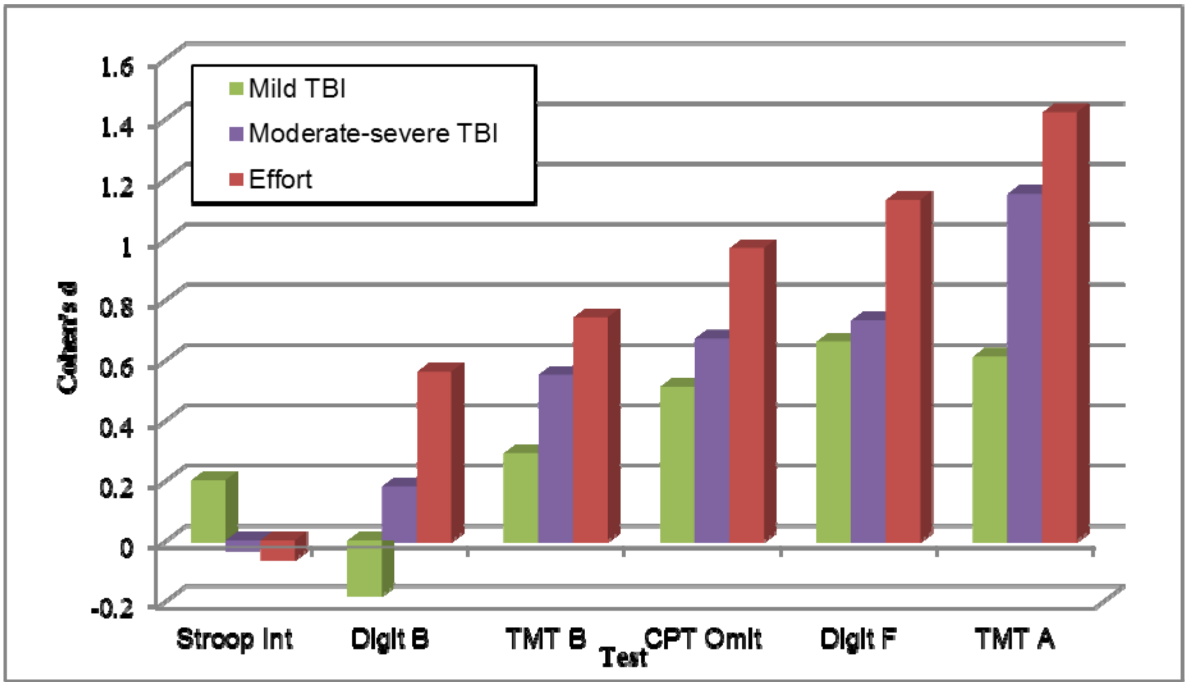

Figure 2. Effect Size for Individual Tests by Group. TBI = Traumatic Brain Injury; Stroop Int = Stroop Interference; Digit B = Digit Span Backward; TMT B = Trail Making Test B; CPT Omit = CPT Omissions; Digit F = Digit Span Forward; TMT A = Trail Making Test A.

Impairment.

Impairment on individual tests, as well as overall Attention impairment, was examined to further describe group performance. Impairment scores were based on t-scores derived from the normative sample for each measure. A t-score of 35 or below (65 or higher for CPT Omission) was considered impaired for this study. When examining individual measures, the Mild TBI/Poor Effort group produced the greatest number of impaired scores on all variables except on the Stroop. Results are reported in Table 3.

Table 3
Frequency of Impaired Test Scores by Group

	Mild TBI Good Effort	Mild TBI Poor Effort	Moderate-severe TBI	Control
TMT A	9 (23%)	26 (62%)	14 (35%)	2 (5%)
TMT B	13 (33%)	25 (60%)	13 (33%)	8 (20%)
Digit F	4 (10%)	15 (36%)	6 (15%)	2 (5%)
Digit B	3 (8%)	10 (24%)	4 (10%)	3 (8%)
Stroop Int	0	1 (2%)	3 (8%)	2 (5%)
CPT Omit	17 (43%)	21 (50%)	15 (38%)	4 (10%)

Note. TBI = traumatic brain injury; TMT A = Trail Making Test A; TMT B =Trail Making Test B; Digit F = Digits Forward; Digit B = Digits Backward; Stroop Int = Stroop Interference; CPT Omit = CPT Omissions.

For Overall attention impairment, a t-score of 35 or below (65 or higher for CPT Omission) on at least three measures was considered an overall impaired score. This cutoff score limits false positive errors, $p<.05$, by controlling normal variability across multiple measures (Ingraham & Aiken, 1996). Pearson's Chi-square analysis found significant group differences on overall impairment (X^2 [15] = 53.657, $p<.001$) with almost half (43%) of the Mild TBI/Poor Effort showing impairment, as opposed to 13% of the Good Effort and 20% of the Moderate-severe TBI groups. Frequency of overall impairment by group is presented in Table 4.

Table 4
Frequency and Cumulative Percentage of Impaired Scores

	Mild TBI Good Effort		Mild TBI Poor Effort		Moderate-severe TBI		Control	
	F	Cum%	F	Cum%	F	Cum%	F	Cum%
5	0	0	5	12	0	0		
4	0	0	7	29	2	5		
3	5	13	6	43	6	20	0	0
2	7	30	8	62	10	45	5	13
1	17	73	11	88	9	68	11	40
0	11	100	5	100	13	100	24	100

Note. F = frequency; Cum% = cumulative percentage; TBI = traumatic brain injury.

Case Analysis

The patient files of Mild and Moderate-severe TBI/Good Effort cases classified as displaying attention impairment were examined to elucidate factors that may have affected test performance.

Mild TBI.

Patient KG is a 44 year-old white male with 12 years of education who suffered a blow to the left temple. He was dazed for approximately 20 minutes. CT scan showed bruising on his left temple but no brain insult. A few days later he began to have nausea and tinnitus. He reported these symptoms plus headaches, fatigue, insomnia, and attention problems during evaluation ten months after the accident.

The patient had passing scores on the PDRT (26/36 and 13/18) and the TOMM (40/50, 50/50, and 48/50), but demonstrated poor effort on two other effort tests, the Computerized Assessment of Response Bias (CARB; Allen, Conder, Green, & et al., 1997) and Word Memory Test (WMT; Green, 2003), producing scores of 30/37, 31/37, and 34/37 for the CARB and Immediate Recognition (IR) = 75.0, Delayed Recognition (DR) = 85.0, Consistency 1 (CN1) = 80.0, and Consistency 2 (CN 2)=60.0 for the WMT.

He also produced scores consistent with those intentionally exaggerating cognitive deficits on a standard neurocognitive measure, the Finger Tapping Test (Total = 41; Arnold, et al., 2005).

Evaluation of Minnesota Multiphasic Personality Inventory 2nd edition (MMPI-2; (Butcher, Dahlstrom, Graham, Tellegen, & Kaemmer, 1989) scores found conscious exaggeration of physical complaints (FBS=30 raw; Hs = 94; Hy = 99). The patient also earned a score of 4 on the Meyer's validity scale composite index (MI; Meyers, Millis, & Volkert, 2002), which is designed to assess exaggeration of self-reported symptoms. This score is in the range of people known to be intentionally exaggerating cognitive deficit in mild TBI (Greve, Bianchini, Love, Brennan, & Heinly, 2006). Based on these findings, the patient was diagnosed with malingering, which is intentional poor effort in order to obtain some external incentive (American Psychiatric Association, 2000).

Patient DH is a 32 year-old black female with 16 years of education who was struck in the head by an object. There was no loss of consciousness. Patient reported an aphasic episode that occurred the day after the accident in which she could not walk or talk for 15 minutes. CT scans the day after the accident and five months later were both normal. She had a second aphasic episode a couple of months after the accident. Patient reported memory loss, concentration, dizziness, auditory hallucinations, eye pain, mood swings, over-emotionality, headaches, and irritability during evaluation seven years after the accident.

The patient had passing scores on both the PDRT (26/36, 23/36, and 49/72) and TOMM (46/50, 50/50, and 49/50), but displayed poor effort on the WMT (IR – 62.5, DR – 60.0, CN1 – 47.5) and CARB (36/37, 31/37, 30/37). Evaluation of MMPI-2 scores found exaggeration of symptoms (MI = 4), which is in the range of patients known to be intentionally exaggerating (Greve, Bianchini, Love, Brennan, & Heinly, 2006). The patient was diagnosed as malingering.

KL is a 50 year-old white male with 11 years of education who was injured in a car accident. There was no LOC and GCS score was 15. CT scans taken that day were negative for brain trauma, but were positive for compression fractures at T2 and T3. Evaluation of medical files since the accident found that the patient's self-report of the event became more dramatic over time, and that the patient met criteria for malingering in a previous psychological examination. He reported poor attention, comprehension problems, memory problems, depressed mood, insomnia, tinnitus, and light sensitivity during interview over 2 years after the accident.

During testing, the patient had passing scores on the PDRT (28/36 and 7/9) and TOMM (49/50, 50/50, and 50/50), but displayed poor effort on the WMT (IR = 80.0, DR = 77.5, CN1 = 62.5). He also provided poor effort on three standard cognitive measures: CVLT-II Recognition Hits = 9 and Linear Shrinkage Model = 4.52 (Greve, Curtis, Bianchini, & Ord, 2009); and Finger Tapping Test total score = 86 (Arnold, et al., 2005).

MMPI-2 scores found elevations on scales L (78) and K (68), which is associated with minimizing psychological problems and presenting oneself in an overly favorable manner. The scores also indicated exaggeration of physical complaints (FBS = 28 raw, Hs = 92, Hy =104). The patient was diagnosed with Pain Disorder with both Psychological Factors and General Medical Condition (GMC), and Depressive Disorder NOS.

AV is a 55 year-old patient white female with 13 years education who hit her head after a fall of approximately five feet. She had broken bones in both arms. She was positive for brief LOC and had a GCS score of 15. CT and MRI scans of head were negative. She was diagnosed with scalp contusion, left radial head and right wrist fractures, and orbital fracture. She complained of concentration and memory problems, dizziness, numbness, aching, and unsteadiness in both legs during an evaluation 32 months after injury.

The patient had a history of cardiac-like symptoms that was ultimately treated with psychotropic medication. She also had multiple accidents with injury for which compensation was sought. Her husband reported that patient was disabled for over 20 years from injuries and a nervous condition.

During evaluation, she had passing scores on the PDRT (27/36, 22/36, and 49/72) and TOMM (43/50, 50/50, and 50/50). Examination of MMPI scores found exaggeration of physical complaints (FBS = 25 raw; Hs = 80; Hy =87). The patient was diagnosed with Pain Disorder with Psychological Factors, Anxiety Disorder NOS, and Undifferentiated Somatoform Disorder.

TB is a 39 year-old white male with 13 years of education who was injured after a fall. There was no LOC and GCS score was 15. CT scan was normal. He reported headaches, short-term memory loss, light sensitivity, and problems with attention and comprehension during evaluation 9 months post-injury.

During testing, the patient had passing scores on the PDRT (28/36, 25/36, and 53/72), TOMM (50/50, 50/50, and 50/50), and CARB (72/74), but displayed poor effort on the WMT (IR = 72.5, DR = 65.0, and CN1 = 67.5). Examination of MMPI-2 scores found exaggeration of psychological (F = 70) and physical complaints (FBS = 29 raw; Hs = 97; Hy = 96). The patient was diagnosed with Pain Disorder with both Psychological Factors and GMC, and Adjustment Disorder with Mixed Anxiety and Depression.

Based on the case analysis, all of the patients were correctly classified as mild TBI based on injury characteristics. Each patient had evidence of poor effort on cognitive tests, and psychological overlay. Thus, impairment may be better attributed to the influence of secondary factors as opposed to the effects of mild TBI.

Moderate-severe TBI.

Eight moderate-severe TBI patients met the criteria for overall attention impairment. Examination of the patient files found that seven of the patients suffered a severe TBI based on injury characteristics. All seven passed all performance validity measures (PDRT, TOMM, and WMT). Analysis of MMPI-2 scores found no indications of intentional exaggeration of physical or psychological symptoms.

One patient was classified as a moderate injury based on injury characteristics. Patient CP is a 19 year-old white male with 11 years of education involved in a motorcycle accident 46 months earlier. He did not have external incentive. He had passing scores on the PDRT (28/36 and 12/18) and TOMM (47/50, 50/50, and 50/50), but displayed poor effort on the WMT (IR = 60.0, DR = 75.0, CN1 = 62.5). MMPI findings could not be interpreted due to inconsistent or random responding (VRIN = 84). Patient history revealed premorbid psychosocial factors (family issues) that were exacerbated by the accident. He was 15 years old at the time of the accident. Thus, the interaction of brain injury and developmental factors was likely affecting test performance. The patient was diagnosed with Depressive D/O NOS.

Based on individual case analysis, seven of the eight patients were classified as severe TBI. Each gave good effort during test performance and did not have findings of psychological overlay. The impairment on the attention measures likely reflects cognitive deficits resulting from the severe TBI. The impaired scores from the moderate TBI patient likely reflect the influences of brain injury, psychological overlay, and developmental factors.

Discussion

Attention impairment is one of the most common complaints following TBI. Multiple studies have shown that performance on neuropsychological tests of attention is affected by many factors, including injury severity and effort. The current study examined the relationship between injury severity and performance on neuropsychological tests across different domains of attention while controlling for effort. The domains of attention (Sohlberg & Mateer, 1989) studied were focused attention, selective attention, divided attention, and sustained attention, which were assessed by performance on the WAIS-III Digit Span Forward subtest, the Stroop Color Word Test, Trail Making Test B, and the Conners' Continuous Performance Test – II, respectively. Processing speed and working memory, measured by performance on Trail Making Test A and WAIS-III Digit Span Backward subtest, were also examined due to their common clinical use. Effort determination was based on two symptom validity measures, the Portland Digit Recognition Test and the Test of Memory Malingering.

Hypothesis 1: The Effect of Traumatic Brain Injury Severity

Mild TBI.

The Mild TBI/Good Effort group's test performance, while slightly lower, did not significantly differ from the Control group on most variables. Significant differences were found on Trail Making Test A and Digits Forward. When evaluating the effects of mild TBI, effect sizes ranged from small to moderate, with CPT Omissions showing the largest effect (.67). The greatest frequency of impairment in mild TBI for an individual test was also the CPT, with 43% of the group scoring in the impaired range. Significant differences in frequency of impairment were found for overall impairment, TMTA, and the CPT. Five mild TBI patients were classified as overall impaired on the attention measures. The results from the effect sizes and impairment in the mild group was not expected, as mild TBI does not show residual impairment after three months post-injury (Schretlen & Shapiro, 2003).

As hypothesized, other factors likely affected test performance in those patients with residual impairment. All five patients had some indication of suspect effort based on other symptom validity measures, with two patients meeting criteria for malingering, which is intentional poor effort for secondary gain (American Psychiatric Association, 2000). The three other patients were diagnosed with psychological disorders: Depression, Anxiety and Somatoform Disorder, and Adjustment Disorder with mixed Depression and Anxiety, respectively. Thus, these examples demonstrate that performance in the mild TBI/Good Effort group may be influenced by psychological and contextual factors despite measures to control for effort.

With the removal of those five patients, the Mild TBI group still produced more impaired scores than the control group when looking at individual tests. This group consists of patients seen for neuropsychological evaluation an average of three years (m = 34.8 months; sd = 36.5) after injury with complaints long after deficits in mild TBI are expected to be resolved. Evaluation of the group's mean MMPI-2 scores found slight exaggeration of psychological symptoms (F [M= 65, sd = 19.1]; Fb [M = 65, sd = 21.5]), endorsement of physical complaints (Hs [M = 78; sd = 13.0]; Hy [M= 79, sd = 16.0]), and a tendency to minimize pre-existing adjustment problems and emphasize injury-related complaints (FBS = 23 raw, sd = 5.2). This somatization profile is the most frequently observed pattern in persisting mild TBI and likely reflects premorbid personality trends (Greiffenstein & Baker, 2001).

The involvement of psychological factors in persisting deficits in mild TBI is consistent with previous research (McCauley, Boake, Levin, Contant, & Song, 2001; Ponsford, et al., 2000), and has been found to affect test performance on different cognitive domains (Iverson, 2005), including attention (Batchelor, Harvey, & Bryant, 1995; Moritz, et al., 2002). Thus, the findings of this group, though measured as giving good effort, may reflect psychological overlay and not residual dysfunction due to the brain injury.

The presence of financial incentive is another factor that is likely affecting test performance. Ninety three percent of the mild TBI group was seen in a compensation-seeking context. Financial incentive has an effect on test performance (Binder & Rohling, 1996), and is the only consistent predictor of persisting symptoms in mild TBI (Carroll, et al., 2004).

These findings suggest that secondary factors, including psychological overlay, financial incentive, and effort are influencing test performance. This underscores two important points: 1) that it is important to look at factors other than an apparent TBI when determining reasons for persisting deficits and 2) the assessment of effort requires continuous evaluation that measures different aspects of cognition because false negatives are an inherent part of symptom validity tests and effort level can fluctuate during evaluation (Boone, 2009).

Moderate-severe TBI.

As hypothesized, the moderate-severe TBI patients did score significantly below the Mild TBI/Good Effort and Control groups on some measures based on the MANOVA findings. Findings were not uniform as they did perform better or similar to the mild TBI and control groups on certain measures. When evaluating effect sizes, moderate-severe TBI produced large deficits on some tests, with Trail Making Test A being the largest (1.2). The overall effect of moderate-severe TBI (.47) was greater than that of mild TBI (.37). When evaluating impairment, the moderate-severe TBI group performed worse than the control group on overall impairment, TMT A, and the CPT. Impairment was similar for all individual tests and overall impairment when comparing the mild and moderate-severe TBI groups.

There are two possible explanations for the comparable performances of the moderate-severe and mild TBI groups. First, secondary factors may have had a larger influence on test performance in the mild group compared to the moderate-severe group. Deficits are apparent when comparing the moderate-severe TBI to the control group. Second, more than half of the moderate-severe group experienced a mild-complicated to moderate head injury. Moderate TBI shows less impairment than severe TBI during the acute phase and displays more rapid recovery at six and twelve months post-injury, which ultimately results in test performance that is poorer, but not significantly worse, than that of trauma control patients two years post-injury (Dikmen, Machamer, & Temkin, 1990; Lannoo, Colardyn, Jannes, & De Soete, 2001). Recovery from mild-complicated TBI is slightly better than moderate TBI at one and twelve months post-injury, though this difference is not significant (Kashluba, Hanks, Casey, &

Millis, 2008). This is in contrast to severe TBI patients who still show cognitive impairment up to 20 years after injury (Hoofien, Gilboa, Vakil, & Donovick, 2001). These findings are exemplified in the overall attention impairment score. Seven of the eight (88%) moderate-severe patients that produced overall impairment were classified as severe TBI based on injury characteristics.

These findings support evidence of a dose-response relationship between injury severity and test performance. Overall, the moderate-severe TBI group produced worse scores, greater effect size, and more impairment when compared to the mild TBI group, though many of those differences were not significant. There is also the implication that the dose-response relationship is found within the moderate-severe TBI group as well, with most of the impaired scores coming from severe TBI patients. Thirty nine percent of the severe TBI patients produced overall impairment, opposed to only 5% of the mild-complicated/moderate patients. This relationship is tenable, however, because a separate moderate injury group was not assessed.

Hypothesis 2: The Effect of Effort

The Mild TBI/Poor Effort group overall performed worse than the other groups, though significance varied depending on the variable. Based on MANOVA results, performance was worse than the Control group on four measures, the Mild TBI/Good Effort group on three measures, and the moderate-severe group on two measures. Effort had a large effect (.79) on test performance, which was greater than both mild and (.37) moderate-severe (.47) TBI.

Z-scores comparing the poor effort group to controls found scores that were much lower than either the mild and moderate-severe TBI/good effort groups (see Figure 1). The effect of effort is best seen when examining impairment. When examining individual tests, 50% or more of the poor effort group produced impaired scores on three measures (both sections of the Trail Making Test and the CPT). The closest either good effort group came to producing similar results was on one measure, the CPT, producing impairment in 38% and 43% of the mild and moderate-severe groups, respectively. When examining overall impairment, almost half (18) of the poor effort group produced impaired scores, which is more than three times the number of the Mild (5) and two times the number of the Moderate-severe (8) TBI/Good Effort patients. These findings support the hypothesis that the effect of effort is greater than the effect of brain injury severity.

Stroop Color and Word Test

The Stroop Interference score was the one variable that was not significantly different between the groups, and was also the only variable where the poor effort group had the best performance. The interference score is derived from an equation based on the Word and Color Reading trials of the test, which is then compared to the Color Word Reading trial. Thus, poor performance on these two trials would mask an impairment of selective attention because poor response inhibition would not be differentiated from slow reading. Examination of the other three Stroop scores in the TBI groups found significant differences on Word Reading ($F[2, 115] = 7.392$, $p = .001$, $\eta^2 = .114$) and Color Reading ($F[2, 115] = 7.226$, $p = .001$, $\eta^2 = .112$), with the poor effort group performing worse than both mild and moderate/good effort groups. The poor effort group scored lower than the other two groups on Color Word Reading, but was not significant ($F[2, 115] = 2.439$, $p = .092$, $\eta^2 = .041$). The poorer performance on the

Word and Color Reading trials in relation to the Color-word condition explains the poor effort group's higher interference score.

The Stroop Interference score's sensitivity to TBI is also questioned. Only three moderate-severe TBI patients produced an impaired score on this measure, only one of which was considered to have overall attention impairment. The Word and Color Reading trials are reported to be measures of processing speed (Lucas & Addeo, 2006). Slowed processing speed is one of the most common cognitive symptoms after TBI and deficits can last for years after injury (Hoofien, Gilboa, Vakil, & Donovick, 2001; Millis, et al., 2001). Three studies (Batchelor, Harvey, & Bryant, 1995; Felmingham, Baguley, & Green, 2004; Ponsford and Kinsella, 1992) found significantly better performance on the Word and Color Reading trials but not the Color Word Reading trial, resulting in better selective attention performance in the severe TBI patients. Thus, the interference score is likely insensitive to both effort and brain injury severity.

Limitations

Five limitations of the study are important to discuss. First, the TBI sample contains patients seen for evaluation at least six months post-injury in a compensation-seeking context. These patients represent a small sub-population of TBI patients who are more likely to have persisting symptoms. The findings of the study are representative of this sub-population of TBI patients, not the TBI population at large, and likely over-represent patients who are still experiencing symptoms and impairments.

Second, the use of healthy volunteers as the control group may have contributed to findings of residual impairment in mild TBI patients. Attention test performance can be affected by multiple factors (Lezak, Howieson, & Loring, 2004). The finding of residual impairment in mild TBI patients may be influenced by other factors, such as orthopedic pain or psychological overlay in experiencing persisting symptoms. The inclusion of a group of orthopedic injury patients would help differentiate the effects of other factors (e.g., pain, persisting symptoms) from the effects of mild TBI.

Third, effort classification was based only PDRT and TOMM performance. Though these tests are sensitive to poor effort, they do not detect all instances of poor effort. Thus, some patients giving poor effort were incorrectly included in the good effort group. Using a more sophisticated classification system based on a variety of validity measures (both SVTs and embedded indicators) is more likely to result in more refined effort classification. The poor effort on the WMT in the five Mild TBI/Good Effort group exemplifies the need for more comprehensive effort assessment.

Fourth, test selection to measure the different aspects of attention was limited due to the use of archival data. The interference score of the Stroop Color Word Test was insensitive to both injury severity and effort, preventing the evaluation of how these factors affect selective attention. The use of a selective attention measure that better controls the influence of other attention aspects would better describe the effect of injury severity and secondary factors in the component process.

Fifth, psychosocial issues have been found to be one of the major contributors to persisting deficits in mild TBI, and these effects were evident in the mild TBI/Good Effort group. These issues were not addressed when defining the TBI groups. The inclusion of indicators of psychological overlay would help determine the effects and interactions of head injury severity and psychosocial issues.

Summary

This study found a relationship between injury severity and attention test performance when accounting for effort. Moderate-severe TBI produced overall worse performance than mild TBI patients and control subjects. Mild TBI showed some effect on test performance, but deficits were likely due to secondary factors including financial incentive, psychological overlay, and poor effort. When examining secondary factors, effort was found to produce the greatest effect on test performance. These findings underscore the importance of taking secondary factors into account when interpreting attention impairments in TBI cases.

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Vita

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