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Executive Dysfunction following Traumatic Brain Injury and Factors Related to Impairment

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Abstract

Deficits in executive function are commonly reported following Traumatic Brain Injury (TBI) and are important for establishing functional impairments. Understanding the nature of executive dysfunction following TBI is often complicated by secondary factors that can impact measured ability. This study sought to clarify the persistent effects of TBI on executive function, as measured by the Wisconsin Card Sorting Test (WCST), while accounting for effort given during testing, as measured by the Portland Digit Recognition Test. Results suggested a dose-response relationship between TBI severity and subsequent WCST deficits. Mild TBI patients who provided good effort during testing showed no observable differences from locally matched controls on WCST performance. Effort during testing was found to have a larger overall effect on WCST performance than moderate-to-severe TBI or dementia. The present study highlights the need to account for secondary factors, such as effort during testing, to accurately measure cognitive dysfunction following compensable injuries.

Keywords: Traumatic Brain Injury, Wisconsin Card Sorting Test, Executive Function, Effort, Malingering, Neuropsychological Assessment

Introduction

Traumatic brain injury (TBI) has increasingly become a focus of research since being declared a major public health problem by the National Institutes of Health in 1999. According to a report prepared by the Centers for Disease Control and Prevention, each year at least 1.4 million Americans sustain a TBI; resulting in 1.1 million emergency room visits, 235,000 hospitalizations, and 50,000 deaths (Langlois, Rutland-Brown, & Thomas, 2006). Further, an estimated 80,000 to 90,000 (16%) of these TBI patients will experience long-term or permanent disabilities. With approximately 5.3 million Americans (2% of the population) currently living with TBI-related disability (Thurman, Alverson, Dunn, Guerrero, & Sniezek, 1999), the total yearly cost of direct medical expenses and lost productivity is thought to be over $60 billion (Finkelstein, Corso, & Miller, 2006). Given the large personal and societal costs of TBI, it is crucial to understand factors related to long-term outcome and disability following injury.

Traumatic Brain Injuries

Characteristics

TBI refers to head injuries that cause a disruption in brain function as a result of physical trauma, as opposed to organic pathologies such as stroke or dementia. Traumatic injuries can be caused by blunt impact, penetrating objects, or by inertial forces such as rapid rotation or acceleration / deceleration (Alexander, 1995; Elson & Ward, 1994; Sweeney, 1992). Injuries are referred to as *penetrating* if the skull and dura are pierced or *closed* if the dura remains intact. Damage to brain tissue can be caused directly by the forces of impact or by secondary processes set in motion by the injury. The extent and pattern of damage depends heavily on the nature and severity of the injury (Gaetz, 2004).

Injury Severity Classification

TBI severity is typically classified according to initial injury characteristics such as alterations of consciousness, length of coma, post traumatic amnesia, focal neurologic signs, and abnormalities revealed during neuroimaging. While there are some differences among grading systems, these criteria are typically used to classify injuries as mild, mild-complicated, moderate, or severe. Extensive research has shown that these factors provide an accurate measure of the extent of neuropathology, expected severity of subsequent cognitive impairments, and overall injury-related disabilities (Alexander, 1995; Binder, 1997; Bush et al., 2003; Iverson, 2005; Rohling, Meyers, & Millis, 2003).

Alterations of consciousness. Changes in conscious functioning are often measured by emergency medical facilities and first responders using the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974). The GCS system combines grades of occular, verbal, and motor responses, producing a score ranging from 3 (completely unresponsive) to 15 (alert and oriented). GCS has proven valuable for establishing TBI severity and predicting subsequent disability; with scores over 12 associated with mild injuries, scores between 9 and 12 associated with moderate injuries, and scores below 9 associated with severe injuries (Jennett, Snoek, Bond, & Brooks, 1981; Jennett & Teasdale, 1981; Whyte, Cifu, Dikmen, & Temkin, 2001).

Length of coma. The duration of unconsciousness following a head injury is also a good predictor of resulting neuropathology and outcome (Dacey et al., 1991; Dikmen, Machamer, Temkin, & McLean, 1990; Levin et al., 1990). Injuries with loss of consciousness lasting less than 30 minutes are typically considered mild while injuries resulting in loss of consciousness lasting longer than 30 minutes are typically considered moderate or severe.

Post traumatic amnesia. Post traumatic amnesia (PTA) refers to the period after a head injury where episodic memory functions are disrupted or not continuous. PTA has also proven useful for establishing TBI severity and is a good predictor of neuropathology and cognitive outcome (Brooks, Aughton, & Bond, 1980). PTA lasting less than 24 hours is typically considered mild while PTA lasting over 24 hours is considered moderate-to-severe. However, difficulty in objectively assessing the length of PTA, especially though retrospective self-report, has limited some of the usefulness of this measure (Macartney-Filgate, 1990).

Focal neurologic signs. Focal signs are findings or observations made during neurological examination that suggest damage to a specific area of the brain. This may take the form of loss of sensory functions; a specific behavioral deficit, such as aphasia; or unnatural physical reactions, such as unresponsive pupils (Levin et al., 1990). Verifiable signs of focal impairments are a good indication of underlying neuropathology and signify a moderate-to-severe head injury.

Abnormalities on neuroimaging. Findings from neuroimaging can provide an objective basis for establishing the presence of neuropathology. Classically, only mass intracranial lesions detected by magnetic resonance imaging or computerized tomography were considered strong evidence of pathological processes (Binder, 1997). A number of recent studies have suggested that modern functional imaging techniques may be able to identify more subtle physiological changes associated with diffuse injuries; however, the formal diagnostic utility of these techniques is not yet clear (Belanger, Vanderploeg, Curtiss, & Warden, 2007; Binder, Rohling, & Larrabee, 1997; Levine et al., 2006; Fontaine, Azouvi, Remy, Bussel, & Samson, 1999).

Patterns of Neuropathology

Diffuse pathology. TBI can result in a combination of diffuse and focal neuropathologies depending on the nature and severity of the injury (Gaetz, 2004). Diffuse brain injury, also known as diffuse axonal injury (DAI), refers to damage that is spread over a relatively wide area of the brain. DAI is caused by pathophysiologic processes set in motion by the physical stress of rotational twisting or waves of contraction and expansion in the brain (Gennarelli et al., 1982; Povlishock, 1993). Damage is typically worst for superficial white matter layers and extends inward as trauma forces increase (Gaetz, 2004). Following severe head trauma, DAI may result in marked cell death observed as white matter atrophy or small lesions and lacerations over a wide area of the brain (Gale, Johnson, Bigler & Blatter, 1995). However, in mild head trauma, processes associated with DAI are not expected to result in substantial cell death (Alexander, 1995; Iverson, 2005). While temporary disruptions in neural functioning may be observed, full recovery is expected to occur relatively quickly (Iverson, 2005).

Focal pathology. Primary and secondary pathophysiologic processes can also result in damage to a specific focal area. Blunt forces can cause contusions both at the point of impact (coup) and on the opposite side of the head (contrecoup; Gennarelli, 1986). Injuries that penetrate the dura can also directly damage neural tissue or vascular structures (Gaetz, 2004). Hemorrhaging and hematoma in the brain (intra-axial) or between the brain and the skull (extra-axial) can result in focal cell death (Genarelli, 1993). A number of secondary processes, such as ischemia or edema, can also cause focal neural damage (Gaetz, 2004; Gennarelli, 1993).

Neuropsychological Outcome

Neuropsychological deficits following TBI are presumed to arise from corresponding changes in neural function due to pathogenic processes (Iverson, 2005). It has been well established that TBI severity, based on initial injury characteristics, provides the most reliable measure of neuropathological processes. In fact, studies that have properly controlled for contributing factors have reported a near linear dose-response relationship between TBI severity and subsequent neurocognitive deficits (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005; Ponsford et al., 2000; Rohling, Meyers, & Millis, 2003; Schretlen & Shapiro, 2003; Sherer, Madison, & Hannay, 2000). These deficits are worst in the acute post-injury stages and significant recovery is usually seen in the first few months (Alexander, 1995; Lehtonen et al., 2005). A recent review by Iverson (2005) reported that mild TBI had some acute effects on neuropsychological function (Cohen's $d = 0.4$), but essentially no observable persistent effects (Cohen's $d = 0.1$). The reported effects of moderate-to-severe TBI were larger in the acute stages (Cohen's d = 1.0) and showed more persistence over time (Cohen's d = 0.8).

While some studies have reported cases of persistent cognitive dysfunction in mild TBI (e.g. Rimel, Goirdani, Barth, Boll, & Jane, 1981; Leininger, Gramling, Farrell, Kreutzer, & Peck, 1990), the effects have generally been small. More importantly, failure to properly control for contextual factors, such as incentives to perform poorly, has hindered the applicability of these studies (Dikmen & Levin, 1993; Mittenberg & Strauman, 2000). Studies that have adequately accounted for these factors have consistently found that mild TBI is not expected to result in observable neuropsychological deficits lasting longer than three months (Belanger el al., 2005; Binder, Rohling, & Larrabee, 1997; Belanger & Vanderploeg, 2005; Carroll et al., 2004; Ponsford et al., 2000; Vanderploeg, Curtiss, & Belanger, 2005).

Effects of Incentive

When long term cognitive symptoms do persist following a mild TBI, factors other than neurological pathology are often suspected (Bazarian et al., 1999). The World Health Organization's Collaborating Center performed an extensive review of the literature on mild TBI and found that the most consistent prognostic indicator of persistent cognitive symptoms was financial incentive to perform poorly (Carroll et al., 2004). A meta-analysis reported that incentive alone has a moderately negative effect (0.47) on TBI outcome (Binder & Rohling, 1996). As neuropsychological measures are reliant on patient cooperation and motivation, poor effort during testing has long been thought to mediate the effect of financial incentive on measured outcome (Trueblood & Schmidt, 1993). A recent study by Bianchini, Curtis, and Greve (2006) lends support to this idea, finding a dose-response relationship between financial incentive and intentional poor performance during neuropsychological testing.

Poor effort can take the form of intentional negative response bias, known as malingering, or motivation that is poor enough to have a meaningful impact on test performance (Millis, Putnam, Adams, & Ricker, 1995; Pankratz & Binder, 1997; Sweet et al., 2000). Poor effort may be caused by conscious or unconscious factors and thus the term is generally considered broader than the term malingering. For the purposes of this study, related terms such as incomplete, insufficient, inadequate, or suboptimal effort or motivation will be considered interchangeable. The potential differences these terms may have in a legal context are not being considered.

Detecting Poor Effort

Objective assessment of motivation and effort during testing began with the development of measures known as Symptom Validity Tests (SVT; for a review see Bianchini, Mathias, & Greve, 2001). The prototypical SVT is a forced-choice recognition memory test in which subjects are asked to discriminate a previously presented stimulus from a foil. Using this procedure, even completely random guessing should produce correct answers approximately half of the time. Thus, when a subject scores worse than would be expected by chance alone it can be inferred that the subject does recognize the correct stimulus but is intentionally choosing the incorrect response (i.e. negative response bias; Pankratz, 1983). The sensitivity of SVTs to poor effort has been further increased by psychometric advances, such as increasing apparent difficulty, and by establishing empirical “floors” of poor performance in patient populations providing good effort. Increasingly, similar methodological designs are being employed to establish performance patterns on standard neuropsychological measures that can also be used as indicators of poor or suspect effort (Larrabee, 2003a).

The Effects of Effort During Testing

Poor effort has been reported to negatively impact test performance across a number of domains, including cognitive (e.g. Bernard, Houston, & Natoli 1993; Iverson & Binder, 2000), motor (e.g. Greiffenstein, Baker, & Gola, 1996), and sensory functioning (e.g. Green & Iverson, 2001). Binder, Kelly, Villanueva, and Winslow (2003) examined the performance of TBI patients on nineteen measures across these domains and found that the mild TBI poor motivation group performed significantly worse than the mild TBI good motivation group on nearly every measure. On most learning, memory, and sensory measures, the mild TBI poor motivation group actually performed worse than the moderate-to-severe TBI patients. A meta-analysis of TBI outcome studies by Iverson (2005) reported that exaggeration / malingering had a larger overall effect on neuropsychological performance (Cohen's d = 1.1) than mild TBI (Cohen's d = 0.1) or moderate to severe TBI (Cohen's d = 0.8).

Green, Rohling, Lees-Haley, and Allen (2001) performed a systemized examination of the effect that effort has on neuropsychological testing in TBI patients with incentive to perform poorly. In this study, GCS, LOC, PTA, and neuroradiological findings (CT and MRI scans) were used to establish injury severity. The Computerized Assessment of Response Bias (CARB; Allen, Conder, Green, & Cox, 1997), Word Memory Test (WMT; Green, Allen, & Astner, 1996), and an internal validity indicator from the California Verbal Learning Test (CVLT; Millis et al., 1995) were used to identify patients giving poor effort. Results from a full battery of neuropsychological measures were converted to a single z-score for each participant referred to as the Overall Test Battery Mean (OTBM; developed by Miller & Rohling, 2001). This study reported a number of interesting findings. Patients with mild head injuries had the highest rate of SVT failures (34%) and the largest effort effect during testing (1.4 standard deviations). When the effects of effort were not considered, the mild injury group scored essentially identically to the moderate-to-severe injury group. When scores between good effort and poor effort groups were compared, all of the poor effort groups showed significantly lower performance. Overall, effort was found to account for 53% of the variance on neuropsychological measures. These results suggest that when incentive is present, effort during testing has a much larger effect on measured neuropsychological functioning than actual brain pathology.

Executive Function

Impairments in executive function are commonly claimed following even mild TBI and can have a large impact on expected disabilities (McDonald, Flashman, & Saykin, 2002). In the US, a large portion of compensatory awards following TBI are often based on expected loss of future wages resulting from functional impairments or disability. Thus, even small impairments in executive function may significantly increase the amount of expected financial compensation. Considering the effects of financial incentive on effort during testing, it would stand to reason that measures of executive function may be particularly prone to poor motivation and intentionally poor performance. Therefore, it is especially important to consider these motivational factors when examining executive functions in patient populations with incentive to perform poorly.

Characteristics

Executive functions are higher order processes that serve to integrate and optimize the operation of a number of cognitive systems (Baddeley, 1996). These processes work to preserve our awareness of self in relation to environment and are integral for initiating behavior, planning and strategizing, decision making, incorporating feedback, and making appropriate behavioral adjustments to adapt to changing environmental demands (Damasio & Anderson, 2003; Shallice & Burgess, 1991; Stuss, 1991). Essentially, these functions enable the ability to engage in independent, purposeful, goal-directed behavior. Deficits or impairments in executive function can result in a dramatic loss of overall functionality, such as the ability to work (Sherer et al., 1998) or form social relationships (Mazaux et al., 1997), regardless of other cognitive abilities (Cicerone et al., 2000).

Neuropathology

Anatomically, executive functions are primarily served by the frontal lobe and its complex connections with other brain regions (Goldberg & Builder, 1987; McDonald et al., 2002; Stuss & Levine, 2002). Due to the shape of the skull, these areas may be particularly susceptible to contusions and diffuse injuries following traumatic head injuries (Gennarelli & Graham, 1998; Gentry, Godersky, & Thompson, 1988). Even in the absence of focal damage to the frontal lobes, severe injuries may significantly reduce neural metabolism and function in these areas (Fontaine et al., 1999). This effect may be compounded by the increased load put on frontal systems during complex tasks following diffuse brain injury (Scheibel et al., 2003).

Deficits related to executive dysfunction are among the most prominent and persistent impairments associated with TBI (Cicerone et al., 2000; McDonald et al., 2002). Focal and diffuse damage, particularly in the frontal and frontal-temporal lobes, has been associated with impairments across a number of neurocognitive domains such as attention, concentration, processing speed, and short term memory, along with behavioral symptoms such as fatigue and irritability (Fork et al., 2005; Lehtonen et al., 2005; Scheid, Walther, Guthke, Preul, & von Cramon, 2006; Wallesch, Curio, Galazky, Jost, & Synowitz, 2001). Differences in the nature of executive dysfunction often depend on the location and magnitude of neural damage (Stuss et al., 2002).

As with other TBI-related impairments, these deficits in executive function are expected to correlate to injury severity and decrease over time (McDonald et al., 2002). While some impairments have been observed in the acute stages following even mild head injuries (Brooks, Fos, Greve, & Hammond, 1999; Gentilini et al., 1985), significant deficits are not expected to persist in the absence of observable organic pathology (Iverson, 2005). Despite expectations, many studies have reported persistent mild TBI-related deficits in executive function domains such as attention, working memory, mental flexibility, planning, and problem solving (McDonald et al., 2002; Nolin, 2006; Raskin, Mateer, & Tweeten, 1998; Raskin & Rearick, 1996; Vanderploeg et al., 2005). Currently, it is not clear whether these findings are due to a unique vulnerability for executive dysfunction following even mild head injuries; or methodological factors pertaining to outcome research, such as how injury severity is defined, whether incentive and motivation are considered, or how executive function is measured.

The Wisconsin Card Sorting Test

Objective assessment of executive function is particularly challenging given the nature and complexity of the associated processes. The primary difficultly lies in structuring a situation that can objectively measure how well the participant can create a working system for themselves. A variety of measures have been developed for this purpose, though most are only designed to assess specific parts of the entire process (for a review see Goldberg & Bougakov, 2005). A survey of practicing neuropsychologists by Rabin, Barr, and Burton (2005) reported that the most widely used clinical measure of executive function is the Wisconsin Card Sorting Test (WCST; Grant & Berg 1948; Heaton, 1981; Heaton, Ghelune, Talley, Kay, & Curtiss, 1993). The WCST assesses mental flexibility, response to feedback, and goal directed behavior by creating an environment in which participants must develop a response strategy, maintain that strategy, and then adjust that strategy when contingences change (Goldberg & Bougakov, 2005).

Validity

The construct validity of the WCST as a measure of executive function has been demonstrated in a number of patient populations (Heaton et al., 1993). Though results have varied somewhat, factor analyses have shown that there are three primary components to WCST performance in both normal and clinical samples: I) cognitive flexibility and accuracy; II) problem solving and learning; III) response maintenance and distractibility (Greve, Bianchini, Hartley, & Adams, 1999; Greve, Brooks, Crouch, Williams, & Rice., 1997; Greve, Ingram, Bianchini, 1998; Greve et al., 2002; Greve, Stickle, Love, Bianchini, & Stanford, 2005; Wiegner & Donders, 1999).

Further validation of the WCST as a measure of executive function is provided by the numerous studies linking frontal lobe damage to impairments in WCST performance (Demakis, 2003; Heaton et al., 1993). Categories completed and perseverative responses are reported to be particularly sensitive to frontal lobe damage, especially in the dorsolateral and superior medial cortical areas (Stuss et al., 2000). Some studies have suggested that nonperseverative errors show frontal sensitivity as well, though meta-analysis indicated that the differences between frontal and non-frontal injuries on this measure are not significant (Demakis, 2003). Overall, the WCST should not be considered perfectly specific, or sensitive, to frontal lobe lesions (Mountain & Snow, 1993). Some patients with obvious frontal damage show normal performance on the WCST (Heck & Bryer, 1986), while some patients without discrete frontal damage show poor performance (Anderson, Damasio, Jones, & Tranel, 1991).

Effects of Traumatic Brain Injury

The effects of mild TBI on WCST performance are difficult to interpret due to variations in study designs, administration, and scoring. Iverson, Slick, & Franzen (2000) examined the acute effects (< 10 days) of mild TBI and presented normative tables for total errors, preservative errors and responses, and nonperseverative errors. A comparison of Iverson's tables to normal distributions presented by Heaton & PAR Staff (2000) suggested a slightly negative shift in score distributions at the higher end of performance. However, even acutely, mild TBI did not result in an observable increase in the percentages of severely impaired performances. Raskin et al. (1998) examined acute and post-acute mild TBI patients and found that 15% completed 4 or fewer categories, a level considered impaired by the authors. However, the Heaton et al (1993) U.S. matched normative table reports that at least 16% of “normal” adults completed fewer than 3 categories, indicating that the Raskin et al. results do not suggest increased impairment in mild TBI.

Following moderate-to-severe TBI, persistent WCST deficits have been observed in both focal and diffuse injuries (Fork et al., 2005; Himanen et al., 2005). These impairments were found to lessen over time and significant improvements in performance were observed regardless of the nature of the injury (Demakis, 2003; Millis et al., 2001; Lehtonen et al., 2005). Interesting, Lehtonen et al. reported that there were no longer significant differences in WCST performance between frontal and non-frontal lesions one year post injury. This improved performance over time is thought to reflect meaningful improvements in executive function and not just learning related to repeated test administrations (Greve, Love, Sherwin, Mathias, & Houston et al., 2002).

A study by Greve, Love, Sherwin, Mathias, and Ramzinski et al. (2002) provided a detailed examination of the factor structure of WCST scores along with performance subgroups in TBI. Analysis suggested a three factor solution with Factor I (cognitive flexibility) accounting for 60% of score variance, Factor II (problem solving) accounting for 22% of score variance, and Factor III (response maintenance) accounting for 14% of score variance. Variable loading indicated that Factor I was primarily associated with perseverative responses/errors, Factor II with nonperseverative errors, and Factor III with failures-to-maintain set. A cluster analysis of performance subgroups suggested that four distinct patterns of functioning were present: a normal functioning group; a perseverative group; a poor problem solving group; and a poor response maintenance group. As these factors are considered hierarchically dependent processes, the observed performance patterns were thought to reflect degrees of overall impairment rather than qualitatively different functioning. Essentially, problem solving can not be demonstrated if set shifting is impaired, and responses maintenance can not be demonstrated unless the "problem" is solved. This structural dependence likely contributes to the observations that Factor I scores, particularly perseverative responses/errors, are the most sensitive to TBI (King, Sweet, Sherer, Curtiss, & Vanderploeg, 2002; Love, Greve, Sherwin, & Mathias, 2003; Millis et al., 2001; Sherer, Nick, Millis, & Novack, 2003).

Effects of Poor Effort and Malingering

The effects of malingering and poor effort on WCST performance have proven difficult to isolate and examine. Early studies of malingering on the WCST concentrated on identifying patterns of performance that could discriminate feigned impairment. Bernard, McGrath, and Houston (1996) and by Suhr and Boyer (1999) each developed a discriminate function that initially showed promise for accurately identifying feigned impairment (Donders, 1999; King et al., 2002). Further analyses of these formulas, however, have reported excessive false positives in clinical samples at the recommended cut-offs (Greve & Bianchini, 2002) and relatively poor overall classification accuracy (Greve, Bianchini, Mathias, Houston, & Crouch, 2002).

Another method to detect malingering using the WCST, first suggested by Knight, Webster, Goetsch, Malloy, and Greve (1986), examines *unique responses* (also called *other responses*), which fail to match on any stimulus category, and *perfect matches missed* (PMM), which fail to match a key card that is exactly the same as the response card. These types of responses, especially PMM, were hypothesized to reflect either intentionally poor performance or a failure to understand the demands of the task. Greve, Bianchini, and Mathias et al. (2002) examined the classification accuracy of these measures and compared them to the original Bernard and Suhr formulas. Few subjects missed any perfect matches resulting in poor overall classification accuracy for this measure. Examining the remaining measures at a similar specificity (94%) suggested better sensitivities for unique responses (35%) and the Suhr formula (34%) compared to the Bernard formula (10%). Importantly, an analysis of joint classification accuracy indicated that each measure was identifying unique malingerers, suggesting that at least three relatively different strategies were being employed by malingerers to appear impaired.

Overall, the WCST has not shown a strong ability to differentiate malingered performances from true brain injury. One cause of this relatively insensitivity to malingering may be related to the unstructured nature of the test. Essentially, the WCST creates a situation in which malingerers first must develop and apply a strategy to "solve the test"; then develop a response strategy to show impaired performance. Thus, the malingering strategy chosen is likely to vary depending on actual executive abilities. In effect, their executive functions are being tested as they try to feign impairment. Additionally, malingerers may choose a variety of overall strategies for feigning dysfunction during assessment (Beetar & Williams, 1995). Taken together, WCST malingerers are likely employing a number of distinct strategies, at various levels of competency, to show different kinds of impairment. Contrast this with a prototypical forced-choice recognition task in which only one malingering strategy is possible, right or wrong, and it becomes clear why tests of problem solving and executive function have generally shown relatively poor ability to classify malingered performances.

While the WCST may not be particularly effective for discriminating malingered performance, these findings do suggest that effort has an observable effect on WCST performance. Thus, studies that fail to account for effort during testing when examining WCST performance in TBI patients may be overestimating impairments, especially in samples with clear incentives to perform poorly. Given the importance of executive function for determining expected outcome and planning rehabilitation, it is vital to have an understanding of factors that account for executive dysfunction following TBI.

Purpose

This study examined WCST performance in post-acute TBI patients while accounting for the effects of effort given during testing. A focus was placed on differentiating the effects of brain pathology from secondary factors contributing to poor performance during testing. Examining WCST performance in patients providing good effort should provide a more accurate assessment of the relationship between TBI severity and subsequent executive dysfunction. Additional steps were taken to isolate and examine the impact that poor effort has on WCST performance. Examining the interaction of TBI severity and effort effects will provide a better understanding of factors that may contribute to measured executive dysfunction following a TBI.

Hypotheses

Hypothesis 1: The Effect of Traumatic Brain Injury

TBI severity is expected to show a dose-response relationship to impairment on the WCST. Mild TBI patients providing good effort are predicted to show no significant deficits in WCST performance compared to healthy controls. In mild TBI cases where impairment is observed, contributing factors such as psychological complications or low premorbid functioning are expected to be found. Moderate-to-severe TBI patients are expected to show some impairment across WCST scores, particularly perseverative responses due to it's reported sensitivity to brain injury (Heaton et al., 1993). These impairments are expected to be worst for patients at the severe end of the TBI severity spectrum. Dementia patients are expected to show the highest levels of impairment on WCST measures.

Hypothesis 2: The Effect of Effort

The effect of effort during assessment, examined in mild TBI patients, is expected to account for significant impairments in performance across standard WCST variables. The largest deficits are expected to be observed on perseverative responses, trials to first category, and failures-to-maintain set. Overall, effort is expected to have a larger impact on WCST performance than actual brain pathology.

Methods

Participants

Data were initially obtained on approximately 500 TBI and 120 dementia cases seen for neuropsychological evaluation at a clinical practice in southern Louisiana between 1989 and 2003. To facilitate comparisons to normative samples, TBI patients were excluded from the study if they were younger than 18, older than 55, or had less than 8 years of education. Patients who were seen less than one year post-injury were excluded to isolate the long-term effects of TBI. Finally, any patient evaluation that did not include the WCST, PDRT, WAIS (Revised or 3rd Edition), and MMPI-2 was excluded to insure that sufficient information was available for post-hoc examination of neuropsychological profiles. Dementia patients were excluded if they were more than 80 years old or had less than 8 years of education to insure valid comparisons using normative corrections. Twenty healthy subjects matching the approximate demographic distribution of the TBI samples were recruited from the community to serve as a local control group. Each was administered the WCST and the PDRT in standard fashion and reimbursed for their time.

Group Classification

TBI Severity

TBI cases were classified according to injury severity as mild or moderate-to-severe. Injuries were considered mild if there was: a) loss of consciousness less than 30 minutes; b) GCS of 13-15; c) post traumatic amnesia less than 24 hours; d) no focal neurologic signs; e) no abnormalities on neuroimaging attributable to the head injury.

Any injury that met one or more of these criteria was classified as moderate-to-severe. These criteria accord with most diagnostic standards and a majority of current research in this field (Alexander, 1995; Peloso et al., 2004).

Effort During Testing

All TBI cases were classified as giving good effort or poor effort during testing based on PDRT performance using methods discussed below. Effort was not examined in dementia cases as these evaluations are rarely performed in the context of incentive to perform poorly and thus SVTs are typically not administered. All control subjects were confirmed to have provided good effort according to performance on the PDRT using the same methods employed for TBI cases. Similar methodology for classifying effort has been previously used for examination of neuropsychological outcome (e.g. Binder et al., 2003).

Summary

These classifications resulted in the following groups: 1) *Mild TBI Good Effort* (mTBI good effort) patients (n = 54) who meet all criteria for mild TBI and scored above the specified cut-offs on all PDRT scores; 2) *Mild TBI Poor Effort* (mTBI poor effort) patients (n = 35) who meet criteria for mild TBI and scored below the specified cut-offs on any of the PDRT scores; 3) *Moderate-to-Severe TBI Good Effort* (m-sTBI) patients (n = 39) who exceeded one or more of the criteria for mild TBI and scored above the specified cutoffs on all PDRT scores; 4) *Dementia* patients (n = 68) with no secondary neurological diagnoses and 5) *Control* subjects (n = 20) recruited from the community to match the general demographic characteristics of the TBI groups. Moderate-to-severe

TBI patients who showed poor effort on the PDRT (n = 10) were not examined in this study due to the small group size and difficultly of clarifying effort effects in these cases.

Measures

The Wisconsin Card Sorting Test

Executive function was evaluated with the WCST using administration and scoring procedures detailed by Heaton et al. (1993). The WCST consists of four key cards and 128 ordered response cards, each depicting figures of varying color, form, and number. The key cards are placed in front of participants and instructions are given that each response card must be matched to one of the four key cards. Participants are not told how to match the cards, simply that the will receive feedback as to whether they are right or wrong. Response cards matching one or more of the key cards on figure parameters (color, form, and number) are handed to the subject one at a time and feedback is given after each sort. Responses are scored according to the figure parameters matched to and the correct matching principle is rotated without warning each time ten consecutive correct responses are made. This process is repeated until six categories are successfully completed or all 128 cards have been sorted.

The Heaton et al. (1993) manual provides scoring details for a number of WCST variables, some of which are not useful for the purposes of this study. To improve the clarity of analyses, seven of these standard variables were selected to represent the pertinent factors of WCST performance. Factor I abilities such as cognitive flexibility and accuracy are represented by Total errors (TE), perseverative responses (PR), and percent conceptual level responses (PCLR). Factor II abilities such as problem solving strategy and efficiency are represented primarily by nonperseverative errors (NPE) and to a lesser extent trials to complete first category (T1C). Factor III abilities such as attention and inhibition are represented by failures-to-maintain set (FMS). Categories completed (CAT) was included as an overall measure of strategy development and execution.

The Portland Digit Recognition Test

Effort during testing will be measured using the Portland Digit Recognition Test (PDRT; Binder, 1991b), a forced-choice recognition memory test. Participants are asked to memorize a five-digit number string and then count backward for a short period of time as a distraction delay. Two choices are then presented and participants are asked to discriminate the original stimulus from a foil. Items are simply scored as correct or incorrect and this feedback is given after each trial. The "easy" portion of the test involves 18 trials with 5 second delays and 18 trials with 15 second delays. The "hard" portion has 36 trials with 30 second delays. Summing the overall correct responses produces the total score. Binder's administration procedures suggest that participants who score at least 19/36 on the easy portion and then correctly answer 7 of the first 9 or 12 of the first 18 hard trials qualify for the abbreviated format, making administration of the remaining trials optional.

A PDRT score below 22 on the easy section, 20 on the hard section, or 44 overall was considered evidence of poor effort. Binder and Kelly's (1996) study reported excellent specificity in TBI at these cut-offs, falsely identifying less than 2% of no-incentive patients with severe head injuries. A number of additional studies have confirmed PDRT classification accuracy at these cut-offs in TBI samples (Bianchini, Mathias, Greve, Houston, & Crouch, 2001; Binder, 1993a; Binder & Kelly, 1996; Greve & Bianchini, 2006). Subjects qualifying for the abbreviated administration were classified as showing good effort based on procedures from Binder and validation from Doane, Greve, and Bianchini (2005).

Effort Validation

Reliable Digit Span. Reliable Digit Span (RDS; Greiffenstein, Baker, & Gola, 1994; Greiffenstein, Gola, & Baker, 1995) will be used as a validation of assessed effort on cognitively based measures. RDS is an internal validity indicator derived from the Digit Span subtest by summing the longest forward and backward digit spans on which both trials were repeated correctly. Digit Span scores were obtained from the Wechsler Adult Intelligence Scale – 3rd edition (WAIS-III; Wechsler, 1997a), Wechsler Memory Scales – 3rd edition (WMS-III; Wechsler, 1997b), or Wechsler Adult Intelligence Scale – Revised (WAIS-R; Wechsler, 1981). If multiple scores were available, preference was given to the score obtained from the WAIS. RDS has been validated as an accurate measure of poor effort / malingering in a number of studies (Etherton, Bianchini, Greve, & Heinly, 2005; Heinly, Greve, Love, Brennan, & Bianchini, 2005; Mathias, Greve, Bianchini, Houston, & Crouch, 2002; Meyers & Volbrecht, 1998; Strauss et al., 2002). For this study, scores below 7 were considered evidence of poor effort, a cut-off associated with less than a 5% false positive error rate in TBI (Heinly et al., 2005; Meyers & Volbrecht, 1998). RDS scores were not used to classify or exclude subjects, only to assess and validate the group effort classifications.

The Minnesota Multiphasic Personality Inventory - Revised. Two distinct measures of exaggeration were selected from the Minnesota Multiphasic Personality Inventory – Revised (MMPI-II; Butcher, Dahlstrom, Graham, Tellegen, & Kaemmer, 1989). Infrequency-back (Fb) is a measure of psychological symptoms rarely endorsed by subjects without severe psychopathology. The Fake Bad Scale (FBS; Lees-Haley, English, & Glenn, 1991), recently adopted as a standard validity scale by Pearson Assessment, is a measure of excessive focus on, or exaggeration of, physical symptom-related complications. Scores above 80 on Fb or 27 on FBS will be considered indications of symptom exaggeration (Greve, Bianchini, Love, Brennan, & Heinly, 2006).

Analyses

Age and education corrected t-scores will be used whenever possible to help control for the large WCST score variations seen in normal populations. For the parametric variables (TE, PR, NPE, and PCLR), these corrections were available for full distributions up to three standard deviations from the mean. For the nonparametric variables (CAT, T1C, FMS), these corrections were only available for categories of impaired scores up to the 16^{th} percentile. Special mention will be made whenever raw scores were used for analysis.

Mean group differences were examined using analysis of variance (ANOVA) with Tukeys-b corrections for pairwise group comparisons. A multivariate ANOVA was not performed because WCST variables are not independent measures. Effect sizes were compared using Cohen's d statistic which was calculated for each variable by dividing the mean difference between the groups by the pooled standard deviation. The

Pearson chi-square statistic was used to examine group differences on categorical demographic and outcome variables. Levels of impairment were created to accord with the Heaton et al. (1993) normative tables to facilitate comparisons.

Results

Group Characteristics

Demographics

Analysis of variance reveled no significant group differences in education ($F[4] = 1.866$; $p = .118$; $\eta^2 = .034$). A significant difference in age was observed ($F[4] = 164.138$; $p = .000$; $\eta^2 = .757$) and pairwise post-hoc analysis indicated that the dementia group was significantly older than the other groups, as expected. Pearson Chi-Square analysis indicated no significant ethnic differences across the groups ($\chi 2\ [12] = 11.866$; $p = .457$). A significant gender difference was observed ($\chi^2\ [4] = 13.714$; $p = .008$), though the association was relatively weak (Cramer's V = .252). Gender is reported to have no significant impact on WCST performance (Heaton et al., 1993); thus, this small difference is not expected to affect analysis. Table 1 presents a breakdown of age, education, and gender characteristics for each group.

Table 1

Group Demographic Characteristics

		Age		Education		Gender
Group	N	M	SD	M	SD	% (Male)
Controls	20	33.15	10.63	12.70	2.13	80.0
Mild TBI Good Effort	54	37.46	10.05	12.97	2.02	64.8
Mild TBI Poor Effort	35	37.03	7.76	12.11	2.36	74.3
M/S TBI Good Effort	39	32.10	10.52	12.56	2.52	79.5
Dementia	68	69.25	7.44	13.47	3.14	50.0

Note. M/S = Moderate-to-severe; TBI = Traumatic Brain Injury

TBI Injury Characteristics

Injury characteristics were examined in the TBI groups to ensure that the mild TBI groups did not differ on injury severity and that the m-sTBI group only differed on injury severity. In the mild groups, no significant differences where observed on mean time between injury and evaluation (mTBI good effort = 34.9 months; mTBI poor effort = 31.0 months; p = .817) or mean GCS (mTBI good effort = 14.9; mTBI poor effort = 14.7; p = .158). The m-sTBI group had a longer mean time between injury and evaluation (44.7 months); however, the difference across all three TBI groups was not significant (F [2] = 2.119, p = .126). These results suggest that injury characteristics should not significantly impact TBI group comparisons.

A breakdown of severity characteristics in moderate-to-severe TBI was performed to better characterize this group. The majority (n = 24; 61.5%) were identified as severe TBI cases using only clearly defined injury characteristics (GCS < 9 or LOC > 24 hours). Thirteen of the fifteen remaining cases (33.3%) were identified as having suffered at least a moderate TBI; defined as having a GCS less than 12, LOC greater than 30 minutes, positive focal signs, or injury related neurosurgery. The final two cases (5.1%) could not be unambiguous defined as moderate; however, factors such as reported PTA, skull fracture, and abnormalities on neuroimaging suggested at least mild-complicated injuries. These conservative classifications of severity suggest that the m-sTBI group is composed mostly of cases at the severe end of the spectrum. However, it should be noted that “severe” TBI is a very wide diagnostic category and patients in this group likely display large variations in neuropathology.

Effort Validation

Criteria used to establish effort during testing were validated using Reliable Digit Span (RDS), a cognitive based internal validity indicator, along with two indicators of exaggeration from the MMPI-II, infrequency-back (Fb) and the fake-bad scale (FBS). Mean scores across the measures suggested that the mTBI poor effort group showed significantly more cognitive, psychological, and physical symptom exaggeration than the mTBI good effort group. Compared to the mTBI good effort group, the mTBI poor effort group was 4.6 times more likely to show cognitive exaggeration on RDS, 2.8 times more likely to show psychological exaggeration on Fb, and 2.7 times more likely to show physical symptom exaggeration on FBS. The low rates of RDS failures in the good effort TBI groups (mTBI = 5.6%, m-sTBI = 7.7%) indicate that the PDRT served as an effective screen for cognitive malingering. However, failure rates for Fb (mTBI good effort = 20.4%, m-sTBI = 21.1%) and FBS (mTBI good effort = 24.1%, m-sTBI = 2.6%) suggested that some patients with psychological complications were classified as good effort by the PDRT. Post-hoc analyses were performed to examine these complications and a full discussion of the potential effects will follow.

The TBI groups were further validated by applying the Slick, Sherman, and Iverson (1999) criteria for malingered neurocognitive dysfunction (MND). Criteria were met if the patients had (a) a below-chance finding from the PDRT or TOMM (B1), (b) two indications of malingering from cognitive measures (B2), or (c) indication of malingering on both a cognitive measure (B2) and a self-report measure (C5). Appendix A provides a full list of indicators and cut-offs used to meet these criteria (note that all indicators were not necessarily available for each subject). The Slick et al.

system identified 88.6% of the mTBI poor effort group as malingerers, while only 5.6% of the mTBI good effort group and 5.1% of the m-sTBI group were found to be malingering. Thus, classification using the PDRT appears to have validly created groups that differed on effort given during testing. Full results of this group validation are presented in Table 2.

Table 2

Percent Showing Exaggeration on Validity Indicators by Group

Indicator		Mild TBI Poor Effort	Mild TBI Good Effort	M/S TBI Good Effort
Reliable Digit Span (RDS)	%	25.7	5.6	7.7
Infrequency-back (Fb)	%	57.1	20.4	21.1
Fake Bad Scale (FBS)	%	65.7	24.1	2.6
Slick Criteria (MND)	%	88.6	5.6	5.1

Note. M/S = Moderate-to-severe; MND = Malingered Neurocognitive Dysfunction; TBI = Traumatic Brain Injury

Analysis of WCST Data

The WCST variables were first examined to insure that no significant threats to statistical analysis were present. The variables were distributed normally, with the exception of T1C which showed slightly elevated skew (1.95) and kurtosis (2.21). Levene's test indicated that error variances were not equal across groups on NPE (F [4,211] = 6.032; $p < .000$), T1C (F [4,211] = 25.148; $p < .000$), and FMS (F [4,211] = 3.106; $p = .016$). It should be noted that some non-normality in distributions was expected for these factors given the methods used to score them. A linear group analysis of WCST scores will invariably have difficulties examining higher factor scores and the implications of this are addressed in the discussion. Additional considerations regarding the impact of variable interdependence were addressed separately for each statistical analysis and are discussed in each respective section.

WCST Performance

Mean Scores

Univariate ANOVAs reported significant group differences across TE ($p = 0.002$), PR ($p = 0.002$), PCLR ($p = 0.011$), CAT ($p < .000$), and T1C ($p < .000$). Significant differences were not observed in NPE ($p = 0.704$) or FMS ($p = 0.658$). This pattern was expected given the structure of NPE and FMS and serves to highlight the difficulty of observing differences among higher factors in a group study. Pairwise comparisons using Tukeys-b post-hoc corrections were performed to examine homogeneous subsets of groups at a .05 alpha value. Comparisons showed that the mTBI poor effort and dementia groups had significantly more TE than the mTBI good effort group. The mTBI poor effort group also showed significantly more PR than the mTBI good effort and control groups. Finally, dementia cases completed fewer categories than all other groups and took longer to complete their first category than all other groups except mTBI poor effort. No other comparisons were significant using these methods. Group performances relative to controls across Factor I scores with age and education corrections (TE, PR, and PCLR) are presented in Figure 1. Table 3 presents group means and standard deviations for each WCST variable along with ANOVA results and homologous subgroups from pairwise comparisons. Raw scores for the age and education corrected variables (TE, PR, NPE, and PCLR) are made available in Appendix B.

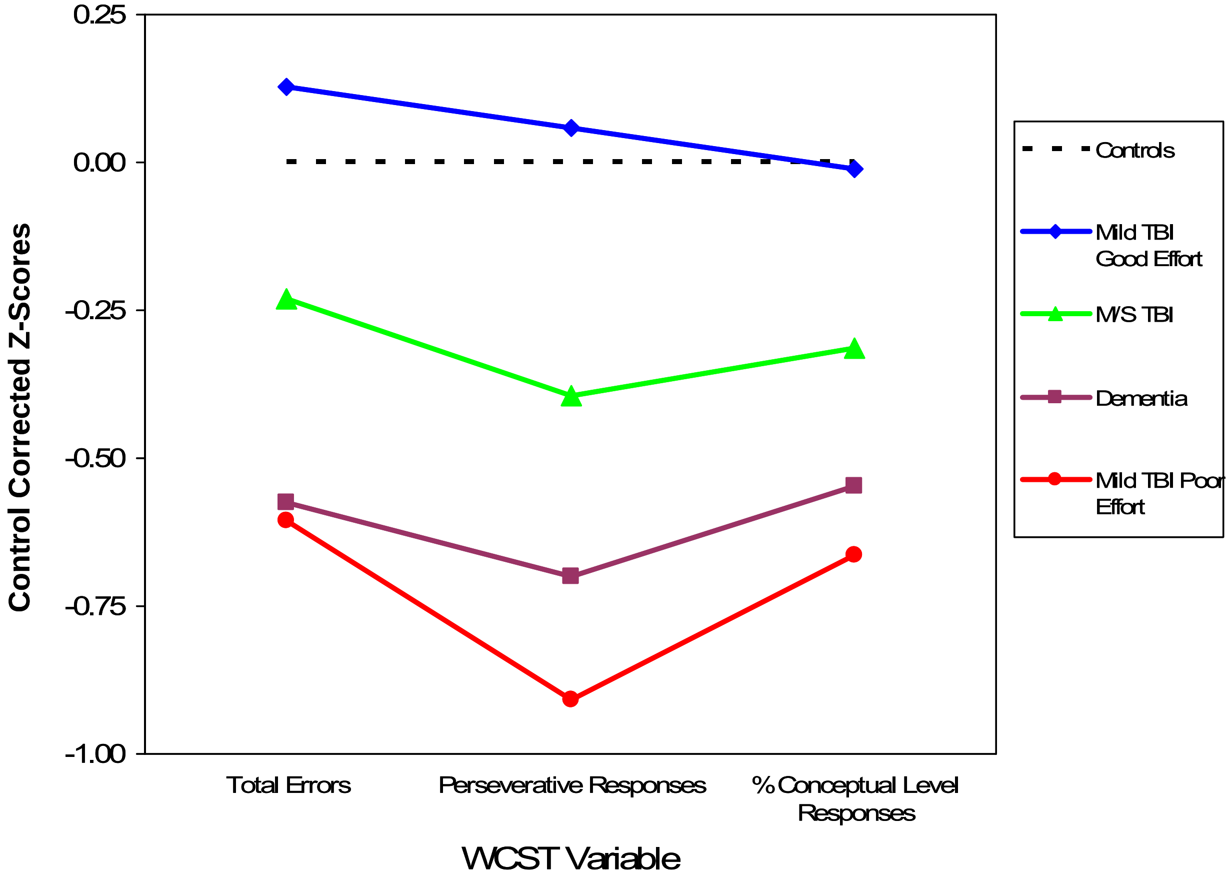

Figure 1. Group performances relative to the control group on selected WCST variables. Z-scores were created from the control group distribution after applying age and education corrections. For clarity of comparisons, only Factor I variables with age and education corrections available are displayed. M/S = moderate to severe; TBI = traumatic brain injury.

Table 3

Mean WCST Scores by Group and Analysis of Variance Results

WCST Variables			Mean Scores					ANOVA		
			Controls	Mild TBI Good Effort	Mild TBI Poor Effort	M/S TBI Good Effort	Dementia	F [4]	*p*	η^2
TE	(T-Score)	M	45.95 [ab]	47.24 [a]	39.89 [b]	43.64 [ab]	40.19 [b]	4.46	0.00	0.08
		SD	9.66	10.69	10.97	10.90	10.68			
PR	(T-Score)	M	49.15 [a]	49.72 [a]	40.06 [b]	45.21 [ab]	42.16 [ab]	4.31	0.00	0.08
		SD	12.42	12.75	14.18	13.61	12.63			
NPE	(T-Score)	M	44.70 [a]	46.46 [a]	42.66 [a]	44.56 [a]	44.97 [a]	0.54	0.70	0.01
		SD	9.92	9.50	8.54	9.10	16.46			
PCLR	(T-Score)	M	46.75 [a]	46.63 [a]	40.11 [a]	43.62 [a]	41.28 [a]	3.35	0.01	0.06
		SD	9.44	10.84	10.54	10.43	10.46			
CAT	(Raw)	M	4.85 [a]	4.98 [a]	4.14 [a]	4.56 [a]	2.44 [b]	15.76	0.00	0.23
		SD	1.66	1.86	2.06	1.93	2.10			
T1C	(Raw)	M	19.65 [a]	19.50 [a]	32.40 [ab]	20.90 [a]	49.47 [b]	7.11	0.00	0.12
		SD	21.24	24.00	33.13	25.31	50.87			
FMS	(Raw)	M	1.25 [a]	0.89 [a]	1.23 [a]	1.15 [a]	1.18 [a]	0.61	0.66	0.01
		SD	1.16	0.88	1.35	1.51	1.35			

Note. CAT = Categories Completed; FMS = Failures-to-Maintain Set; M/S = Moderate-to-severe; NPE = Nonperseverative Errors; PCLR = Percent Conceptual Level Responses; PR = Perseverative Responses; T1C = Trials to First Category; TBI = Traumatic Brain Injury; TE = Total Errors; WCST = Wisconsin Card Sorting Test.

[abc] Row means with same letter represent homologous subgroups using Tukey's-b corrections at p = .05

Effect Sizes

Effects sizes were examined for TE, PR, and PCLR using Cohen's d statistic. CAT, T1C, and FMS were not examined because full distributions of age and education corrected scores were not available and NPE was not examined because its hierarchical dependence on PR prevents accurate measurement in cases showing elevated perseveration. The effects of mild TBI, moderate-to-severe TBI, and dementia were examined by comparing each corresponding group to the control group. The effect of effort was examined by comparing the mTBI good effort and poor effort groups. Averaged across the three examined variables, mild TBI showed essentially no effect on WCST performance (Cohen's d = -0.053), moderate-to-severe TBI showed a medium effect (Cohen's d =.281), and dementia showed a large effect (Cohen's d =.558). The effect of effort (Cohen's d =.668) was higher than any of the observed effects for neuropathology. Table 4 presents effect sizes on each examined variable for TBI, dementia, and effort and Figure 2 presents these effect sizes averaged across the variables.

Table 4

Effect Sizes for TBI, Dementia, and Effort Presented Using Cohen's d Statistic

Selected WCST Variables	Mild TBI[a]	M/S TBI[a]	Dementia[a]	Effort[b]
Total Errors	-0.13	0.22	0.57	0.68
Perseverative Responses	-0.05	0.30	0.56	0.72
Percent Conecptual Level Responses	0.01	0.32	0.55	0.61

Note. M/S = Moderate-to-severe; TBI = Traumatic Brain Injury; WCST = Wisconsin Card Sorting Test.
[a] Measured by comparing each corresponding group to the control group.
[b] Measured by comparing the Mild TBI good effort and poor effort groups.

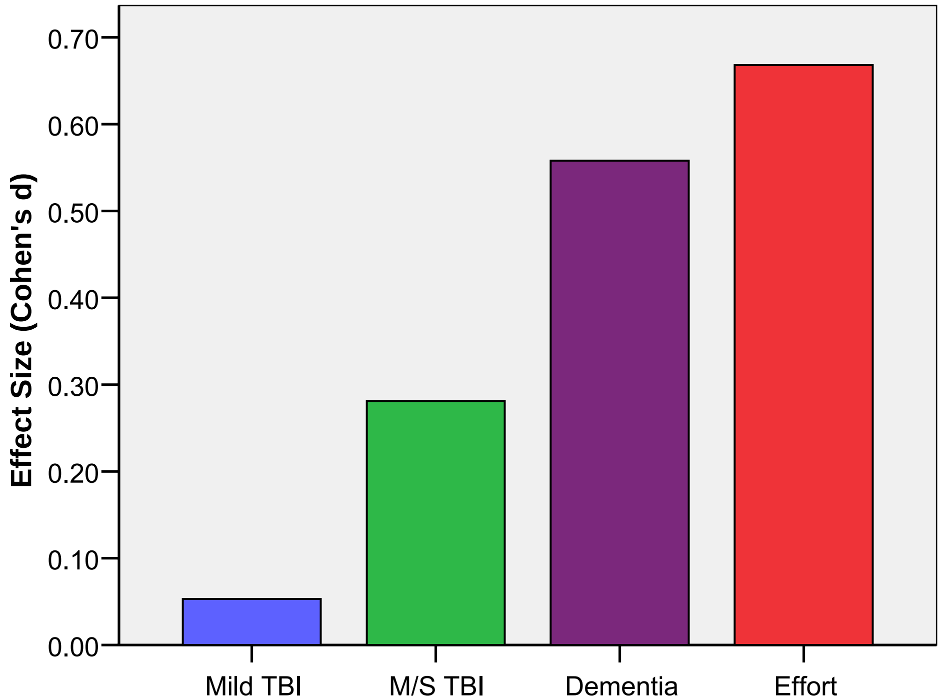

Figure 2. Mean effect sizes of TBI, dementia, and effort across examined variables. M/S = Moderate-to-Severe; TBI = Traumatic Brain Injury. Note that the mean effect size for mild TBI was actually negative but was inversed for clarity of presentation.

Impairment

Groups were also examined to compare differences in the percentage of subjects scoring in the impaired range on WCST variables. To facilitate comparisons with a large control group, levels of impairment were first examined corresponding to ranges presented by Heaton et al. (1993). For TE, PR, NPE, and PCLR, impairment was categorized as mild (t-scores of 35-39, 7 to 15th percentile), mild-to-moderate (t-scores of 30-34, 3rd to 6th percentile), moderate (t-scores of 25-29, 0.5 to 2nd percentile), and moderate-to-severe (t-scores < 24, bottom .5%). Due to the categorical nature of CAT, T1C, and FMS, the Heaton et al manual establishes impairment at slightly different ranges with age and education corrected percentile scores of <=1, 2-5, 6-10, and 11-16 making up the reported groups. Cumulative percentages calculated from the Heaton et al. normative charts for normal and clinical subjects (tables E1 & E2) are also presented for comparison. Pearson chi-square analyses reported significant differences across levels of impairment on PR (χ^2 [20] = 49.587; p < .000), PCLR (χ^2 [20] = 35.756; p = .016), CAT (χ^2 [16] = 49.016; p < .000), T1C (χ^2 [16] = 26.771; p = .044), and FMS (χ^2 [16] = 35.337; p = .004). Table 5 presents cumulative frequencies of impairment for each group across the examined WCST variables according to levels of impairment from Heaton et al.

Table 5

Cumulative Frequencies of Impairment Across Each WCST Measure

			Mild TBI				Heaton et al.	
		Controls	GE	PE	M/S TBI	Dementia	Normal	Clinical
T-Score	Percentile	%	%	%	%	%	%	%
Total Errors								
<25	0.5		3.7	2.9	2.6	2.9	1.1	14.3
25-29	2.0		5.6	20.0	10.3	11.8	2.7	25.4
30-34	6.0	10.0	14.8	37.1	23.1	32.4	6.9	40.6
35-39	14.6	35.0	22.2	51.4	41.0	51.5	14.2	57.8
Perseverative Responses								
<25	0.5		5.6	11.4	2.6	10.3	1.1	18.1
25-29	2.0		5.6	17.1	15.4	14.7	1.9	26.2
30-34	6.0		9.3	37.1	23.1	22.1	5.5	38.2
35-39	14.6	15.0	14.8	57.1	43.6	42.6	12.5	52.5
Nonperseverative Errors								
<25	0.5		1.9	2.9		5.9	1.5	4.6
25-29	2.0	5.0	3.7	5.7	2.6	16.2	2.0	11.0
30-34	6.0	25.0	13.0	14.3	17.9	29.4	6.4	20.3
35-39	14.6	30.0	24.1	40.0	30.8	41.2	15.8	38.1

(table 5 continued)

Percent Conceptual Level Responses								
<25	0.5		3.7	2.9	2.6	1.5	0.8	10.7
25-29	2.0		7.4	20.0	12.8	10.3	3.1	22.9
30-34	6.0	5.0	18.5	25.7	23.1	30.9	7.0	38.6
35-39	14.6	30.0	22.2	54.3	33.3	47.1	14.0	54.3
Categories Completed								
<28	<= 1	10.0	5.6	5.7	17.9	16.2	0.8	14.0
29-34	2-5	15.0	18.5	31.4	23.1	16.2	2.9	30.9
35-37	6-10	20.0	24.1	40.0	30.8	41.2	9.9	46.4
38-40	11-16	40.0	27.8	54.3	46.2	45.6	13.5	58.1
Trials to First Category								
<28	<= 1	10.0	3.7	14.3	12.8	8.8	0.5	11.1
29-34	2-5	20.0	16.7	45.7	20.5	19.1	3.9	28.0
35-37	6-10	25.0	27.8	60.0	43.6	38.2	8.3	35.9
38-40	11-16	40.0	33.3	62.9	43.6	44.1	11.7	40.9
Failures-to-maintain Set								
<28	<= 1	5.0	1.9	5.7	10.3	2.9	0.8	2.6
29-34	2-5	5.0	3.7	17.1	12.8	8.8	1.8	7.0
35-37	6-10	5.0	9.3	20.0	15.4	14.7	6.5	13.4
38-40	11-16	35.0	11.1	28.6	23.1	16.2	10.7	21.0

Note. GE = Good Effort; M/S = Moderate-to-severe; PE = Poor Effort; TBI = Traumatic Brain Injury; WCST = Wisconsin Card Sorting Test.

Frequency of impairment was also examined for each variable at equivalent levels (the 1st, 5th, 10th, and 16th percentiles) to facilitate comparisons. Impairment across the WCST variables was examined by (a) calculating the percentage of cases showing severe impairment across any WCST variable and (b) by averaging the frequency of impairment across all WCST variables. The ratio of severe impairment (1^{st} percentile) across any WCST variable in the mTBI good effort and control groups (odds ratio = 1.8; 95% CI = .35 to 9.16) suggested that mild TBI does not cause a significant increase of impairment. Averaged impairment (10^{th} percentile) across all of the variables indicated that relative to controls mTBI good effort cases were slightly less like to show impairment (.95), mTBI poor effort cases were 2.1 times more likely to show impairment, m-sTBI cases were 1.6 times more likely to show impairment, and dementia cases were 1.8 times more likely to show impairment. Table 6 presents a full breakdown of cumulative frequencies of impairment using these two methods to examine performance. Figure 3 presents the odds ratios of severe impairment (1st percentile) across any WCST variable for each group relative to controls.

Table 6

Cumulative Frequencies of Impairment Across Multiple WCST Variables

Method of Combining Variables		Controls %	Mild TBI Good Effort %	Mild TBI Poor Effort %	M/S TBI Good Effort %	Dementia %
Impaired on Any Variable						
T-Score	Percentile					
<28	<= 1	10.0	16.7	34.3	28.2	33.8
29-34	2-5	40.0	29.6	62.9	46.2	54.4
35-37	6-10	50.0	40.7	71.4	69.2	76.5
38-40	11-16	65.0	50.0	80.0	71.8	80.9
Average Impairment Across All Variables						
T-Score	Percentile					
<28	<= 1	3.6	4.8	12.2	10.3	10.7
29-34	2-5	11.4	13.5	29.8	20.5	22.7
35-37	6-10	20.0	19.0	41.6	31.5	35.7
38-40	11-16	34.3	24.9	51.0	38.5	42.4

Note. M/S = Moderate-to-severe; TBI = Traumatic Brain Injury; WCST = Wisconsin Card Sorting Test.

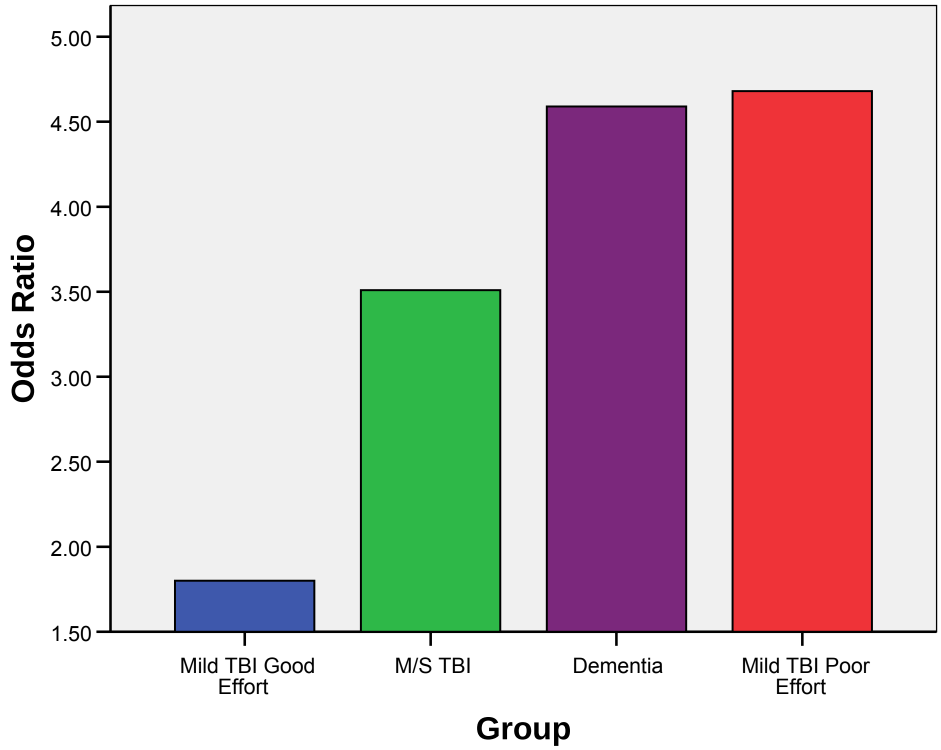

Figure 3. Odds ratio of severe WCST impairment relative to controls. M/S = Moderate-to-severe; TBI = Traumatic Brain Injury. Note that the odds of impairment at the 1st percentile across any WCST variable were used for calculations.

Hypothesis 1: The Effect of Traumatic Brain Injury

The effects of neuropathology on WCST performance were examined by comparing the control, mTBI good effort, m-sTBI, and dementia groups. As hypothesized, mild TBI had no measurable effect on WCST performance as the mTBI good effort group did not differ significantly from controls on any variable. Of examined effect sizes, only PCLR showed an effect towards worse performance, and this effect was very small (Cohen's d = .012). On average, mild TBI cases were only 1.2 times more likely than controls to show impairment at the 5^{th} percentile level, a difference that was not significant (χ^2 [1] = .062, p = .151). Moderate-to-severe TBI also showed no significant differences from controls, however a strong negative trend was indicated by the larger mean effect size (Cohen's d = .28). The effects of moderate-to-severe TBI were strongest for PCLR (Cohen's d = .315) and PR (Cohen's d = .303). On average, m-sTBI cases were 1.8 times more likely to score in the impaired range (5^{th} percentile) relative to controls. The dementia group showed lower overall performance, though significant differences were only observed on CAT and T1C. Note that mean differences on these variables could not be examined with age or education corrections, which likely contributed to the observed significance. The average effect of dementia on corrected Factor I scores (Cohen's d = .558) was almost twice as strong as that seen for moderate-to-severe TBI. On average, dementia cases were twice as likely to show impairment (5^{th} percentile) than controls. Overall, these findings support the hypothesis of a dose-response relationship between injury severity and impaired WCST scores.

Hypothesis 2: The Effect of Effort

The effect of effort on WCST performance was isolated by comparing the mTBI good effort group to the mTBI poor effort group. ANOVA results indicated significant differences between these groups on TE ($p = .002$), PR ($p = .001$), PCLR ($p = .006$), CAT ($p = .049$), and T1C ($p = .036$); along with moderately significant differences on NPE ($p = .058$). A conservative correction for multiple comparisons (.05 / 7 = .007 alpha) would suggest that only TE, PR and PCLR were confirmed to be significantly different across the groups. The hypothesized difference across T1C was observed as a large mean difference between the mild TBI groups (good effort = 19.5; poor effort = 32.4), however this difference was only marginally significant due to the large variation in scores (pooled standard deviation = 28.5). The hypothesized difference in FMS was not observed (p = .155), likely due to the difficulty of observing group differences across higher factor scores. Overall, poor effort mTBI cases were 2.2 times more likely than mTBI good effort cases to show impairment at the 5th percentile. Further, the average effect of effort across TE, PR, and PCLR (Cohen's d = .668) was larger than the effect of dementia, over twice as large as the effect of moderate-to-severe brain injuries, and more than 12 times as large as the effect of mild brain injuries. These findings support the hypothesis that effort has a larger effect on WCST performance than actual brain pathology.

Case Analysis

A closer examination of good effort cases showing impairment was carried out to identify factors that may have contributed to poor performance on the WCST. Impairment on PR was chosen as the criterion variable because (a) it is not hierarchically dependent on other WCST variables, (b) it has been reported to be the most sensitive to brain injury (Heaton et al., 1993), and (c) factor analyses generally show that perseverative measures account for the most variance in WCST performance. A level of impairment equal to the 1st percentile according to Heaton et al. was chosen because this was the only level of impairment at which mild TBI cases were more impaired than would be expected by normal distributions (χ^2 [1] = 11.320, p = .001). Impairment at this level was observed in three (5.6%) mTBI good effort cases, four (10.3%) m-sTBI cases, and no controls.

Mild TBI Cases

Case 5104. This patient's WCST scores were in the bottom 1% on TE, PR, PCLR; 5% on CAT and T1C; 15% on NPE. No failures-to-maintain set were observed.

The patient was a 41 year old male with 12 years of education involved in a motor vehicle accident. The patient reported no loss of consciousness and first responders reported a GCS of 15 at the scene, indicating that the head injury was mild at worst. The patient was seen for neuropsychological evaluation approximately fifteen months post-injury reporting problems with pain, attention, concentration, forgetfulness, irritability, and depression.

Results from the full neuropsychological evaluation indicated normal ranges of function on standard measures of intelligence (WAIS-III FSIQ = 107), new learning (CVLT Total trials 1-5 t-score = 46), and attention / concentration (Trails A t-score = 55, Trails B t-score = 40; Stroop interference t-score = 61). WRAT reading (50) and spelling (45) accorded with the patients education level, however his math score was low (t-score = 21). Related to executive functions, FAS (t-score = 45) and animal naming (t-score = 39) indicated no serious deficits in initiation. Scores on WAIS-III similarities (11), matrix reasoning (17), and the category test (t = 67) were above average and no signs of perseveration were apparent on a recursive figures task.

There was no suggestion of exaggeration on cognitive validity measures, with the patient scoring 66 out of 72 on the PDRT, 13 on RDS, and 47/50/50 on the TOMM. However, results from the MMPI-II suggested psychological factors may have been presented related to a focus on physical symptoms (FBS = 23) and tendencies towards somatization (Scale 1 = 73; Scale 3 = 81). Indications of depression were also present given the patients elevated score on scale 2 (72) and reported symptoms during interview. The examining neuropsychologist also noted that “very compulsive tendencies” were apparent (personal communication, July 23, 2007).

A detailed examination of this patient’s WCST responses was performed in an attempt to explain the large discrepancy observed between WCST performance and other measures of executive function. The patient first attempted to match to number, and despite feedback that 8 out of the first 10 sorts were wrong, a different matching principle was not attempted until the 11^{th} card. Form was then incorrectly matched four times, three of those being unambiguous. On card 24, the subject finally grasped the color matching principle and then completed the set; after which color was perseverated to for the next 30 responses. Number was then perseverated to over the next 47 cards on every trial except two unambiguous color matches and one *other response*. An unambiguous match to form was not attempted again until card 112 at which point the patient made a successful run to complete the category. Form responses were then perseverated until the end of the test.

At no point did the patient seem to intentionally respond incorrectly. When a matching rule was finally understood, the category would be completed. Instead, these results suggest a particularly strong mental inflexibility that prevented the patient from incorporating feedback to create a working strategy and test different matching principles. After the patient attempted four matches to form early in the test, it appears that he became locked to the idea that it was incorrect, and further attempts to match to form were not made until very late in the test. The WCST’s lack of structure may make it particularly sensitive to this type of mental inflexibility explaining why these results were markedly lower than results from other measures of executive function. The examining neuropsychologist concluded that this specific deficit was most likely explained by pre-existing factors, reporting that "He also shows... deficits in cognitive flexibility which cannot be attributed to the injury sustained in the accident". Thus, secondary factors such as pre-existing deficits and psychological complications, as opposed to injury-related neuropathology, were the most likely cause for this patient's poor performance on the WCST.

Case 3107. The patient's WCST performance was in the 2nd percentile for TE, 1st percentile for PR, 3rd percentile for PCLR, and 5th percentile for CAT and T1C. No failures-to-maintain set were observed. The patient was a 35 year old male with 9 years of education involved in a work-related head injury. The patient reported loss of consciousness lasting approximately 1.5 hours. However, a review of medical records clearly disputed this claim as patient was reported to be "alert and oriented times 3" (GCS of 15) when emergency medical services arrived and hospital records on the day of the incident reported no loss of consciousness. A CT scan showed no signs of abnormalities confirming that the patient suffered a mild TBI at worst. Since the injury, patient has undergone multiple back surgeries that have failed to relieve self-reported pain symptoms. Notes from a treating neurologist reported "sick room behavior and physiologic inconsistencies" including numerous Waddell signs documented on three consecutive visits. This neuropsychological evaluation was performed approximately 6 years post-injury in the context of an ongoing workers compensation claim.

The patient scored in the extremely low range on general intelligence (WAIS-III FSIQ = 64), mild to moderately impaired range on attention and concentration (Trail A t-score = 38; Trail B t-score = 36; Stroop C/W t-score = 22), and moderately impaired on new learning (CVLT trials 1-5 t-score = 31). There was no clear indication of cognitive exaggeration on classic SVTs such as the PDRT (68/72 total) or TOMM (46/49/49). However, RDS (7) was borderline for poor effort (Heinly et al., 2005) and processing speed (65) from the WAIS-III was below levels associated with malingering in ambiguous injures (Etherton, Bianchini, Heinly, & Greve, 2006). Additionally, the patient had four index scores from the WMS-III below 75, a finding associated with 97% specificity for malingering in mild TBI patients (Ord, Greve, & Bianchini, 2007). Considering that internal validity indicators are thought to be more resistant to the effects of coaching (Mathias, Greve, Bianchini, Houston, & Crouch, 2002), this pattern of good effort on classic SVTs and poor effort on internal validity indicators raises the possibility that this patient, who has had multiple neuropsychological evaluations over the course of a six year legal dispute, may be specifically avoiding exaggeration on the easily identifiable forced-choice format indicators.

An examination of clinical MMPI-II scales indicated high levels of hypochondriasis (90), depression (87), hysteria (96), psychopathic deviance (84), paranoia (90), psychasthenia (98), and schizophrenia (96). These could be interpreted to reflect antisocial and hostile dispositions that could considerably impact the testing situation. There were also indications of an attempt to manipulate MMPI-II responses to create good impressions of personal characteristics (L = 74) and exaggerate emotional / psychological symptoms (F = 79, Fb = 96). Additionally, the patient's score of 25 on FBS suggested a preoccupation with physical symptoms and elevations in scales 1 (90) and 3 (96) have been associated with somatic malingering (Larrabee, 1998). These results from the MMPI-II strongly suggest that psychological complications are likely affecting this patient's recovery and having a negative impact on measured cognitive abilities.

Perhaps most pertinent to WCST performance, the patient's antisocial and hostile traits were very apparent during testing. The patient's generally interaction with the tester was described as "not friendly" and "unagreeable". The patient's demeanor during some of the more difficult tests was described as "aggravated" or "frustrated". On the category test, a test of executive function, the patient became frustrated and refused to look at the pictures, guessing randomly instead. This pattern of refusal to cooperate and lack of motivation seemed to be reflected in his WCST performance by a failure to adjust to feedback resulting in high perseveration. In addition, the patient had 11 "other responses", which in this case seemed to indicate either a lack of motivation to complete the task or a failure to understand the task demands. Overall, the patient's performance on the WCST appeared to clearly reflect a combination of low premorbid functioning, indicated by 9 years of completed education, and psychological factors that prevented full cooperation and motivation during testing.

Case 7040. The patient's performance on the WCST was in the 1st percentile on TE, PR, PCLR, and CAT; and the 2nd percentile on NPE. There was no significant impairment seen on FMS or T1C. The patient was a 29 year old male with 15 years of education involved in a work-related head injury. The patient was seen for neuropsychological evaluation approximately 13 months post-injury reporting problems with pain, memory, attention, mood swings, depression, planning, and confusion. A previous neuropsychological examination performed approximately 2 months post injury reported “significant deficits in verbally-based learning and memory, as well as significant deficits in executive planning. Furthermore, motor functions controlled by the left hemisphere were impaired as were sensory functions controlled by his right hemisphere.” It was also noted that depression was likely magnifying these symptoms.

A factor that may have contributed to this patient’s poor performance on the WCST was that the head injury may have in fact been mild-complicated. Records from a MRI done approximately two months post injury reported “a nonspecific focus of gliosis versus ischemia in the posterior limb of the high right internal capsule. A soft tissue process in the left maxillary and left frontal sinuses was noted. No mass effect was indicated.” While two separate neuropsychologists determined the injury to most likely be “mild”, neither was able to review ambulance or hospital records from the day of the accident, meaning patient report had to be relied upon. Considering the inconsistency in the patient’s report (e.g. reported duration of unconsciousness ranged from “a few seconds” to a few minutes” depending on the evaluation), these injury characteristics may have been unreliable. The patient was left in the mild TBI group because no mass effects were observed and the time between the head injury and the MRI made it difficult to be certain of the cause of gliosis. However, even given that the case may have been a mild-complicated injury, neuropathology can not fully account for the severity of impairment observed on the WCST.

On the current evaluation, the patient’s measured intelligence (WAIS FSIQ = 122) and attention / concentration (Trails A t-score = 80, Trails B t-score = 72, Stroop C/W t-score = 69) were above average. New learning (CVLT trials 1-5 t-score = 41) was lower, but within normal range. Measures of executive function were mixed, with WAIS similarities (13), matrix reasoning (13), and comprehension (12), all above average while scores on the booklet category test were in the low range (t = 42).

There was no indication of cognitive exaggeration on the PDRT (41 of 43 correct, qualifying for abbreviated administration), TOMM (50/50/50), or RDS (9). However, results from the MMPI showed some indication of psychological or emotional exaggeration (Fb = 87), a tendency to focus on physical symptoms (FBS = 24), and depression (scale 2 = 87). Results from the Millon Clinical Multiaxial Inventory – 3rd edition (MCMI-III) also suggested depressive traits with large elevations in schizoid (96) and depressive (96) scales. Importantly, signs of a non-physiologic degradation of performance were observed on finger tapping, which was more impaired 13 months post-injury than it was 2 months post-injury. These findings indicate that depression and other psychological complications likely contributed to poor motivation during test administration. Taken together, this patient's poor performance on the WCST likely reflected a combination of injury-related complications that were magnified over time by depressive personality characteristics.

Moderate-to-severe TBI Cases

Four cases (10.3%) from the MS TBI group scored in the 1st percentile on PR (cases 1453, 7096, 7079, and 3110). All four cases were clearly severe head injuries resulting in observable neuropathology. Three of the four were completely unresponsive on admission to the hospital (GCS = 3), and the last only displayed basic unconscious reflexes (GCS = 6). Length of coma varied from a few days to over a year.

General cognitive impairments were consistently observed, with mean WAIS-III FSIQ scores (75) and mean WMS-III primary indices (74) showing moderate-to-severe impairments. It is interesting to note that despite severe brain injuries and significant neuropathology, none of the patients failed the PDRT, RDS, or TOMM. On the MMPI-II, no indications of physical symptom exaggeration were observed on FBS. One patient (case #3110) had elevations on F (120) and Fb (116); however, the patient's inconsistent responding (VRIN = 92) precludes interpretation of these scores.

All of these patients showed similar patterns of perseveration on the WCST resulting in significant impairments on PR, TE, PCLR, and CAT. As would be expected given the factor structure, milder deficits were observed on NPE (t-scores ranging from 27-48) and only one FMS was observed across all four patients. No patient missed a perfect match; however, one patient had a slight elevation of *other responses* (4). Taken together, the results indicated that WCST deficits in the m-sTBI group were directly tied to TBI severity, with severe impairment only seen in injuries at the most severe end of the spectrum.

Discussion

In order to understand the relationship between TBI severity and executive dysfunction, it is crucial to consider the effects of secondary factors, such as effort during testing. Many studies examining executive function in TBI have failed to adequately control for these factors when incentives to perform poorly are present. This may be leading to improper attributions of measured impairments and a failure to identify factors that could slow or prevent recovery. The present study sought to examine executive function, as measured by the WCST, in post-acute TBI patients while controlling for effort given during testing, as measured by the PDRT. Mild and moderate-to-severe TBI patients were examined, along with a clinical dementia group and a demographically matched control group.

As was hypothesized, results indicated a clear dose-response relationship between TBI injury severity and WCST impairment in patients providing good effort during testing. In agreement with other studies of cognitive dysfunction that have controlled for effort, mild TBI was found to have no observable persistent effects on WCST performance. Moderate-to-severe TBI was associated with some impairment in WCST performance, particularly following very severe injuries. Dementia patients showed the highest level of impairments across all of the WCST measures. Poor effort during testing was responsible for most observed impairments in mild TBI and effort produced a larger effect on WCST scores than moderate-to-severe TBI or dementia.

Executive Dysfunction in TBI

Mild TBI

The mTBI good effort group performed essentially identically to the matched local control group. Mean scores for both of these groups were slightly lower than those presented by Heaton et al. (1993); however, this most likely reflects sample differences given the discrepancy in general intellectual function (Heaton et al. group FSIQ = 117; mTBI good effort group FSIQ = 95). False negatives (i.e. poor effort patients classified as good effort) may have also contributed to this difference, as the PDRT is reported to miss approximately 29% of malingerers at the cutoffs used (Greve & Bianchini, 2006). Additionally, an examination of low performance outliers in the mTBI good effort group suggested that psychological complications may impair WCST performance even when no clear signs of cognitive exaggeration are present. Despite these potential complications, results indicated that mild TBI produces no observable effect on WCST performance.

Moderate-to-Severe TBI

Moderate-to-severe TBI had a larger impact on WCST performance; particularly on measures related perseveration, where medium effect sizes were observed. Mean scores where similar to those reported by Lehtonen et al. (2005) for post-acute TBI patients with focal injuries. Rates of impairment were higher than the mild TBI or control groups, but lower than the dementia group; and overall patterns were very similar to those reported by Heaton et al. (1993) for the clinical TBI group. An examination of extremely impaired performances in this group found that all were tied directly to brain injuries at the most severe end of the spectrum. Interestingly, overall rates of psychological and physical symptom exaggeration were lower in the m-sTBI group than in the mTBI good effort group.

WCST Considerations

Interpretation

As previously discussed, the assessment of executive function is a particularly challenging neuropsychological issue. While the WCST is the most used and perhaps best validated measure of executive function, many issues are still present which complicate both individual evaluations and group comparisons. Despite measures on the WCST often being presented as independent measures of performance, they are in fact dependent on each other and hierarchical in nature. As an example, the four dementia patients who scored lowest on PR (t-scores < 22) scored at the highest level on NPE (t-scores > 80). Patients display this pattern because these measures are exclusive; if too many perseverative errors are made then the nonperseverative variable has nothing left to measure. Another example is FMS, which can only be validly measured if patient performance is good enough to produce consecutive runs of at least 5 responses. This is not to say that variables such as NPE and FMS are useless, just that they are not sensitive measures of impairment, especially in patients showing perseveration.

Group comparisons are particularly difficult for these higher factor variables as the large variability seen in WCST performance can overwhelm the low sensitivity of these measures. Thus, when examining impairments in a group study, WCST performance becomes primarily a measure of perseveration and associated Factor I processes such as mental flexibility and response to feedback. This is partly due to the hierarchical nature of the measures, which makes it difficult to measure higher functions when perseveration is present, and partly due to the nature of the administration, which creates a situation that is very conducive to eliciting perseveration. This has been reflected in previous literature which has reported measures of perseveration to be the most sensitive to brain injury (Heaton et al., 1993) and account for the majority of variance in factor analyses (Greve et al., 2005). Results from this study supported these findings as moderate-to-severe TBI, dementia, and effort all had a much larger effect on Factor I measures than on Factor II (NPE) or Factor III (FMS).

Identifying Impairment

Identifying impairment on the WCST is complicated by a number of issues. First, individual differences produce large variations in WCST performance, even in normal populations. Heaton et al. (1993) reported that demographic factors, particularly age and education, account for as much as 20% of the variance in WCST scores. Second, the WCST, like many measures of executive function, is particularly sensitive to brain pathology. Complicating this matter, different degrees and severities of brain pathology can produce different patterns of impairment across the variables (Greve, Love, Sherwin, Mathias, & Ramzinski et al., 2002). Finally, the unstructured nature of the testing format can make it difficult in many situations to determine which performances should be considered to reflect functional impairment. A blind reliance on the standard scores may fail to take into account important observational or qualitative factors of WCST performance. Situations can occur where seemingly small lapses in problem solving or mental flexibility can produce extremely impaired scores. An example of this is when a subject is unable to “see” a particular matching principle (e.g. form), which can result in extremely low scores that may not accurately reflect true functional impairment. Another example is when relatively high functioning subjects “over-think” the test and attempt to identify complex matching patterns or predict category changes ahead of time, leading to respective deficits on NPE or FMS. These examples stress the need to take into account observational or qualitative factors when evaluating WCST performance, along with the patient’s history and general cognitive abilities, to establish “impairment”.

Factors Related to Persistent Impairments

Brain Pathology

Initial injury characteristics, used to determine TBI severity, are broadly considered to be the best indicators of resulting neuropathology (Gaetz, 2004). Numerous studies have reported that the severity of the injury, and thus the severity of brain pathology, directly correlates with resulting deficits in cognitive function (Rohling et al., 2003). Results from this study indicated that deficits in executive functions show the same dose-response relationship with severity of injury. In moderate-to-severe TBI, extremely impaired performances were only found in injuries at the severe end of the spectrum. In mild TBI cases, where neuropathology could not explain observed deficits, most cases showing impairment were found to be giving measurably poor effort during testing and the remaining cases indicated signs of psychosocial complications that best accounted for poor WCST performance. Thus, when impairments in executive function can not be attributed to neuropathology, secondary factors affecting measured performance during testing should be considered as a likely explanation.

Exaggeration

Cognitive impairment. Poor performance on the PDRT in the context of external incentives is generally attributed to intentional exaggeration of cognitive deficits (i.e. malingering). Malingering is defined by The Diagnostic and Statistical Manual-IV as "the intentional production of false or grossly exaggerated physical or psychological symptoms, motivated by external incentives such as avoiding military duty, avoiding work, obtaining financial compensation, evading criminal prosecution, or obtaining drugs" (American Psychiatric Association, 1994, p. 476). According to results reported by Mittenburg, Patton, Canyock, and Condit (2002), the rate of malingering / exaggeration in mild TBI cases with incentive can be conservatively estimated at 35%. Because most neuropsychological measures rely on patient cooperation and motivation, malingering can have a large impact on measured ability (Green et al., 2001). Results from this study indicated that the rate of measured impairment in mTBI poor effort cases was 2 to 3 times higher than in mTBI good effort cases and controls.

Psychological / physical symptoms. The MMPI-II provides what are probably the most commonly used measures of psychological (F and Fb) and physical (FBS) symptom exaggeration. In the mild TBI groups, the rates of exaggeration on these measures was approximately three times higher in poor effort (Fb = 57.1%; FBS = 65.7%) compared to good effort cases (Fb = 20.4%; FBS = 24.1%), suggesting a clear link between exaggeration of psychological and physical symptoms and poor effort on cognitive measures. Of the three impaired mTBI good effort cases, two (66%) showed exaggeration on Fb and all three had FBS scores of 23 or higher. Contrastingly, of the three impaired m-sTBI cases with valid MMPI profiles (VRIN < 80), none showed exaggeration on Fb and all had FBS scores of 16 or lower. This pattern suggests that psychological exaggeration may only show a strong association with measured executive impairments in mild TBI populations. Between the good effort mTBI and m-sTBI groups, similar rates of psychological exaggeration were observed (mTBI = 20.4%; m-sTBI = 21.1%), but the mTBI group showed a considerably higher rate of physical symptom exaggeration (mTBI = 24.1%; m-sTBI = 2.6%). This finding suggests that mild TBI and moderate-to-severe TBI patients who are seen for post-acute neuropsychological evaluation may show discernible differences in their approach to physical symptomology.

Exaggeration of psychological and physical symptoms is often associated with patients who develop chronic disabilities following relatively minor or ambiguous injuries (Miller & Donders, 2001). In conditions such as chronic pain, indications of exaggeration in these domains are considered sufficient to diagnose malingered pain-related disability (MPRD; Bianchini, Greve, & Glynn, 2005). In TBI, significant exaggeration of these symptoms is an indication of malingering but, according to the Slick et al. (1999) criteria, is not sufficient to diagnosis malingering in the absence of negative response bias. However, modification of these criteria to account for TBI-related psychological or physical exaggeration in a manner similar to the MPRD has been suggested (Larrabee, Greiffenstein, Greve, & Bianchini, 2007).

Somatization and Psychosocial Factors

Performance on measures of executive function may also be significantly impacted by complications related to somatization, depression, personality traits, and even temperament. Somatization and depression have long been associated with poor outcome following injuries (Barsky, Orav, & Bates, 2006) and poor performance on neuropsychological measures (Ilonen et al., 2000; Larrabee, 2003b). Elevations in MMPI-II scales associated with somatization (1 and 3) and depression (2) seem to show a particularly strong association with malingering in populations of patients with mild or ambiguous compensable injuries (Larrabee, 1998; Larrabee, 2003b; Miller & Donders, 2001). In this study, at least one elevated score (> 80) on these scales was observed in all three of the impaired good effort mild TBI cases; while no elevations in these scores were observed in the four impaired moderate-to-severe TBI cases.

Researchers have also reported deficits in executive function associated with personality traits such as obsessive-compulsiveness (Moritz et al., 2002) and antisocial or hostile tendencies (Gorenstein, 1982). Of the three impaired good effort mild TBI outliers, one showed strong indications of obsessive compulsive tendencies (#5104) and one showed very high levels of antisocial and hostile tendencies (#3107). A detailed examination of these mild TBI outliers suggested that psychosocial complications may be associated with WCST impairments even when other standard measures of cognitive function are in normal ranges and no indications of negative response bias are observed. Researchers and clinicians are only beginning to understand the full impact that these factors can have on recovery from an injury and neuropsychological evaluation, especially in the context of financial incentive.

Effort on Measures of Executive Function

Many studies, this one included, have confirmed that effort during testing has an observable impact on measures of executive function. However, reported effect sizes for executive function measures are consistently smaller than those reported for most other areas of cognitive assessment (Green et al, 2001). In this study, largest observed effect size (PR Cohen's d = 0.717) was considerably smaller than the average reported effect size of exaggeration on neuropsychological measures (Cohen's d = 1.1; Iverson, 2005). However, a closer look at the results from this study suggested that these reported differences may be misleading and measures such as the WCST may in fact be particularly sensitive to even small differences in motivation that would be unlikely to impact most measures.

The observed incongruencies in effect sizes may be explained by examining how poor effort actually impacts measured performance on these tests. One reason that classic SVTs such as the PDRT and TOMM show a larger measured "effort effect" is that poor effort on these tests produces a one dimensional effect. The design of these measures intentionally limits the strategies that malingerers can take so that the degree of feigned impairment shows up clearly as the number of incorrect responses. Contrastingly, the effect of effort on the WCST is multidimensional and dependent on a number of factors such as the patient's ability to understand and perform on the task and the malingering strategy taken. These factors interact in a complex way that produces different patterns of "effort effects" across measures. For example, a high functioning patient intentionally responding incorrectly after a run of correct responses will show a completely different effort effect than a low functioning depressed patient who is apathetic about trying to form a working strategy. What makes the identification of these patterns of effects even more difficult is that true brain pathology also produces different patterns of effects depending on severity and location of injury. What this suggests is that studies such as this one, which look at group scores in a linear fashion, are likely underestimating the true effect that poor motivation and effort has on individual WCST performances. Larger examinations of the patterns of impairment that TBI causes in the context of various secondary factors could help clarify the overall effects of effort on measures such as the WCST.

Limitations

Group Characteristics

Several methodological limitations regarding this study are important to mention. First, these samples represent populations of patients who are being seen for neuropsychological evaluation one year post-injury, with most being involved in litigation or workers compensation cases. Of all persons who suffer a TBI, these cases represent a relatively small sub-population of patients who are more like to show measured impairments and disabilities. As such, these reported rates of impairment should be considered representative of this population of patients and not of the TBI population at large.

Second, while the groups were selected randomly in regards to the dependent variables, some elements of subject selection were made for convenience. Thus, the groups should not be considered representative of population base rates for independent variables such as poor effort or TBI severity. Third, the relatively small size of these groups should be considered when interpreting results at the extreme ranges of impairment where low frequencies are expected, especially considering the large natural variability in WCST scores. Finally, the dementia group was defined only by the nature of the examination referral. A positive diagnosis of dementia was not used as a criterion for this group to avoid potential problems with dependent / independent variable contamination; as a diagnosis of dementia depends heavily on neurocognitive testing, including results from the WCST.

Effort During Testing

Using just one measure of effort, the PDRT, provides only a rough estimate of effort given during administration of the WCST. First, the PDRT's sensitivity to malingering using these cutoffs has been estimated at 71% in mild TBI and 56% in moderate-to-severe TBI (Greve & Bianchini, 2006). Thus, the rate of false-negatives (i.e. poor effort patients in the good effort group) would be expected to be 29% in the mTBI good effort group and 44% in the m-sTBI group. Second, poor effort on a single forced-choice memory test provides only a general estimate of the effort given during a categorically different measure such as the WCST. Finally, the results of this study suggested that the WCST may be particularly vulnerable to psychosocial complications, which were not specifically taken into account when establishing the groups. Future studies using more indicators of poor effort along with systematic methods to analyze the effects of psychological complications may provide us with a better understanding of these interactions.

Statistics

The nature of WCST variables provides a unique challenge for statistical analysis and the methods employed in this study were chosen to provide the best combination of validity and applicability. All reasonable attempts were made to exclude analyses that could violate statistical assumptions and to clearly indicate when reported results may have been impacted by irregularities in the WCST variables. Analyses of WCST performance using more complex multivariate methods to examine patterns of effects for both brain pathology and effort were unfortunately beyond the scope of this study.

Applicability to the Real World

Difficulties in the measurement of executive function also make it difficult to predict the functional impacts of executive dysfunction. Executive functions are crucial for a number of complex functions and impairments can be very difficult to quantify. The relatively modest deficits observed in moderate-to-severe TBI and dementia could reflect much larger impairments in day-to-day functioning. This may be especially true in populations with less cognitive reserve, where minor impairments may result in considerably more functional impairments relatively to the normal population. An examination of functional outcome following TBI, while considering secondary psychological and contextual factors, may provide us with a better understanding of the implications of these results.

Summary

This study examined the persistent effects of TBI on executive function while considering effort given during testing. As hypothesized, a direct relationship between TBI severity and subsequent executive dysfunctions was observed. Executive dysfunction in moderate-to-severe injuries was primarily associated with the severity of injury while dysfunction in mild TBI was primarily associated with poor effort during testing. The results of this study, along with many other recent studies of TBI outcome, continue to demonstrate the need to consider secondary factors, such as effort during testing, to accurately measure impairments following compensable injuries.

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Appendix

Table A1

Indicators Used to Determine Status for Malingered Neurocognitive Dysfunction

Indicator/Test	Cut-off	Below Chance	Reference for Cut-off
B2 Criterion			
Portland Digit Recognition Test			
Easy	< 22	< 12	
Hard	< 20	< 12	Binder, 1993
Total	< 44	< 28	
Test of Memory Malingering			
Trial 2	< 45	< 18	Tombaugh, 1996
Retention	< 45	< 18	
Wechsler Adult Intelligence Scale - Revised or 3rd edition			
Reliable Digit Span	< 7		Mathias et al., 2002
C5 Criterion			
Minnesota Multiphasic Personality Inventory - Revised			
F	> 80		
Fb	> 80		Greve et al., 2006
FBS	> 27		
Meyers Index	> 5		Meyers, Millis, & Volkert, 2002

Note. F = Infrequency; Fb = Infrequency-back; FBS = Fake Bad Scale

Table A2

Raw Means and Standard Deviations for Demographically Corrected Scores by Group

WCST Variable			Controls	Mild TBI Good Effort	Mild TBI Poor Effort	M/S TBI Good Effort	Dementia
TE	*(Raw)*	M	30.35	27.48	42.09	35.85	61.66
		SD	18.47	20.42	22.19	20.58	22.72
PR	*(Raw)*	M	15.55	15.41	28.97	21.08	46.32
		SD	8.73	14.35	20.84	15.09	30.16
NPE	*(Raw)*	M	16.20	13.54	17.63	16.90	23.15
		SD	11.58	10.27	10.20	10.11	15.25
PCLR	*(Raw)*	M	66.55	67.19	54.57	60.66	36.05
		SD	17.41	21.05	21.74	19.73	21.60

Note. M/S = Moderate-to-severe; NPE = Nonperseverative Errors; PCLR = Percent Conceptual Level Responses; PR = Perseverative Responses; TBI = Traumatic Brain Injury; TE = Total Errors; WCST = Wisconsin Card Sorting Test

Vita

Jonathan Ord received a Bachelor of Science from Evergreen State College in 1999. During this period he worked at Omni Vocational Services as a psychometrist under Ginger Hurt. In the fall of 2005, Jonathan began working with Dr. Greve at the University of New Orleans in the Applied Biopsychology Doctoral program. He is currently working on research projects related to validity of neuropsychological performance and factors that influence outcome in chronic pain and traumatic brain injury populations.