2004

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Recommended Citation

Denning, John H.,II, "The effects of auditory distraction on attention performance in asymptomatic college students with a history of mild head injury" (2004). *LSU Doctoral Dissertations*. 2880.
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THE EFFECTS OF AUDITORY DISTRACTION ON ATTENTION PERFORMANCE IN ASYMPTOMATIC COLLEGE STUDENTS WITH A HISTORY OF MILD HEAD INJURY

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

In

The Department of Psychology

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August 2004

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ABSTRACT

Introduction: The majority of individuals experiencing a mild head injury (MHI) recover fully experiencing few residual symptoms. Some individuals who fully recover have shown evidence of residual, albeit subtle, brain functioning disturbances on tasks requiring high levels of cognitive effort. Also, memory complaints in MHI patients may be related to these subtle difficulties when cognitive resources are overwhelmed. This study assessed a group of asymptomatic college students with a history of MHI to determine if there were any residual attention difficulties as well as increased memory complaints. Method: One-hundred twelve college students with and without a history of MHI were administered several tests of attention. Participants were randomly assigned to a standard administration or distraction condition where they were exposed to distracting auditory stimuli. Memory complaints and subjective assessment of performance were collected after testing. Results: The MHI group showed significantly poorer performance on Trailmaking Test part A while under conditions of auditory distraction. There were no other differences between MHI and controls in the expected direction, but performance was slightly higher in the MHI group on Digit Span Backward and Symbol Search. There were no differences between MHI and controls for reported memory complaints, but the MHI group reported higher levels of stress when tested under distraction conditions. Conclusions: Even under distraction conditions, the MHI group performed within the average range across all measures of attention and were highly similar to a well-matched control group. Memory complaints were slightly higher in the MHI group tested under distraction conditions compared to the head-injured participants tested under standard conditions.

INTRODUCTION

Background

The incidence of mild head injury (MHI) in the United States has been estimated to be 350,000 to over 2 million per year accounting for about 80%-90% of all head injuries (National Head Injury Foundation, 1993). This estimate cannot be precise given the lack of uniform criteria for what constitutes a MHI, the many cases that go unreported, and the fact that many never receive any hospital-based care. Sosin, Sniezek, and Thurman (1996) reported an estimate of 1.3 million MHI cases per year based on a Census Bureau national household survey that only included those that reported a loss of consciousness (LOC) due to head trauma. Due to the possibility that a MHI can occur without any LOC, their estimated number of injuries may be rather conservative. Motor vehicle accidents frequently are the number one cause of traumatic brain injury (TBI) in younger individuals with approximately half of these accidents related to alcohol consumption (Sohlberg & Mateer, 2001). Falls are the most common cause of head injuries in children and older adults.

The large number of individuals experiencing a MHI creates a significant economic burden on societal resources and the healthcare system due to lost worker productivity and assessment and rehabilitative services (National Institutes of Health Consensus Development Panel on Rehabilitation of Persons with Traumatic Brain Injury, 1999). The human cost in emotional distress and interpersonal difficulties also takes a considerable toll on patients and their families. The estimated cost of MHI in the United States is approximately $25 billion per year (Interagency Head Injury Task Force Reports, 1994). Men suffer twice the rates of MHI than women with the majority of victims falling within the 15-24 year-old age range.

The typical length and extent of recovery from MHI remains unclear (Bernstein, 1999). Some researchers report that an uncomplicated MHI rarely elicits overt cognitive impairment (Dikmen, McLean, & Temkin, 1986; Levin et al., 1987; Segalowitz, Bernstein, & Lawson, 2001). However, good recoveries after MHI may actually reflect a behavioral adaptation rather than a return to pre-injury levels of functioning (Segalowitz, Bernstein, & Lawson). Patients may report continuing subjective symptom complaints, such as memory and attention problems, but relating these weaknesses to a known injury using standard neuropsychological measures has been difficult due to the lack of specificity of neuropsychological tests. Complicating the picture further is that subjective symptom reporting of attention and memory difficulties frequently is not correlated with neuropsychological test results (Raskin, Mateer, & Tweeten, 1998).

The most common neuropsychological impairments reported by MHI patients have typically been found on measures of complex attention, working memory, verbal learning, and time-dependent tasks (Raskin, Mateer, and Tweeten, 1998). However, this and other studies assessing MHI often neglect to use an appropriate non-head injured control group or any control group at all. There has been an increasing interest over the past several decades in the study of the cognitive symptoms, the length and extent of subjective complaints after injury, and predicting who will develop poor outcomes after MHI. It has been estimated that between 5 and 29 percent of MHI patients report significant long-standing symptoms and this group of patients has been referred to as the “Miserable Minority” (Ruff, Camenzuli, & Mueller, 1996). Drawing conclusions regarding the nature of MHI is often confounded by the heterogeneity of patient populations with the majority of patients recovering fully within a few months (Dikmen, McLean, & Temkin, 1986; Levin et al., 1987) whereas others report long-term disabling symptoms (Reitan & Wolfson, 1999). Research samples are often biased in the types of subjects that are enrolled in studies of MHI with the patients reporting significant symptom complaints more commonly found in clinical practice than in research samples. For example, prospective studies assessing all patients in a hospital setting may find that 80%-90% of MHI patients who recover fully tend to obscure the significant deficits of the minority of patients showing significant dysfunction. Reitan and Wolfson reported that conflicting results with regards to the clinical outcomes of MHI patients may be partially explained by this bias in patient sampling. One of the challenges of studying MHI and one of the reasons why there continues to be considerable controversy regarding the cause of persistent MHI symptoms is due to the heterogeneous criteria used to define MHI.

Diagnostic Criteria for MHI

More is known today about MHI than at any other time, but there remain a variety of definitions and classification methods used to identify MHI, which often creates confusion regarding its nature and typical course of recovery. Several methods and classification systems have been used to differentiate MHI patients from those with more severe injuries, but there has been no clear consensus as to which factors are most relevant. Alexander (1995) stressed the importance of defining head injury based on acute injury characteristics rather than based on assessment of symptoms at some convenient, but variable time after an accident. Classifying MHI based on physical signs and symptoms at the time of the injury reduces the confounding factors of compensatory coping mechanisms, development of emotional symptoms, the stress of litigation, and psychosocial factors that affect functioning several weeks to several months or years after the injury. However, at the time of an initial assessment, the presence of alcohol in many cases of MHI causes the degree of alteration of consciousness to look more severe than it actually is (Dikmen & Levin, 1993). The research criteria for Postconcussional Disorder (PCD) found in DSM-IV-TR (APA, 2000) designates loss of consciousness (LOC, >5 minutes) and post traumatic amnesia (PTA, >12 hours) to be characterized at the time of the accident, but additional criteria such as cognitive and somatic symptoms lasting for an additional 3 months is also required. This definition appears to be less sensitive to the heterogeneous nature of brain injuries where significant and often disabling symptoms can occur despite an absence of LOC or minimal or absent PTA. There tends to be agreement that a combination of Glasgow Coma Scale (GCS) ratings, PTA, LOC, presence or absence of neurological signs, and abnormal neuroimaging evidence should be taken into account when classifying a head injury as being mild in nature.

<u>Glasgow Coma Scale</u>. The GCS assesses the patient's eye opening, motor, and verbal responsiveness on a scale of 3-15 (Teasdale & Jennet, 1974). A score of 13-15 has typically been used by clinicians to determine that a head trauma is mild, but a score of 15 is also obtained in normal controls and appears to provide only a very general measure of head injury status (Goldberg, 2001). Individuals with the same score within the MHI range may be functionally different and factors such as the presence of abnormal imaging findings or intracranial lesions do not uniformly affect the total GCS score. However, abnormal imaging findings or motor and neurologic deficits have been shown to affect functional status and long-term outcome (Eisenberg & Weiner, 1987; Tellier et al., 1999). Alcohol intoxication at the time of injury appears to spuriously lower GCS scores so that patients may be inaccurately classified as having a more severe initial injury than warranted (Dikmen & Levin, 1993). It has been suggested that brain atrophy may be a more specific predictor of outcome after MHI (MacKenzie et al., 2002), but GCS scores were not found to correlate with brain atrophy after mild or moderate head trauma.

One of the inconsistencies of the GCS is that it is administered at some variable time of convenience after an accident when a medical professional is able to assess the patient, and cannot be determined retrospectively based on a patient's self-report. Many MHI patients have no record of a GCS due to their lack of medical care after an injury. To further complicate the reliability of using the GCS, it is possible that a patient assessed by an EMT worker en route to the hospital may find a GCS of 11, but by the time a physician assesses the patient the score may have improved to 14. Difficulties in deciding which score to use to determine initial injury severity (if these scores are even available for review several months or even years after the incident) create diagnostic confusion and may be unreliable altogether (Ruff & Jurica, 1999). The GCS appears to be a useful measure for physicians and surgeons to determine the extent of life-threatening complications and need for prompt surgical intervention in the emergency setting (Jennet, 1998), but the measure does not appear to be particularly sensitive to the heterogeneity found within the groups of MHI patients often presenting for treatment several months to several years later (McCullagh, Ouchterlony, Protzner, Blair, & Feinstein, 2001).

Loss of Consciousness. Another factor typically used to determine the severity of a head injury is the duration of LOC. However, both human and animal studies have found that structural damage and cognitive impairment can occur without any LOC (Abdel-Dayem et al., 1998; Hayes, Pavlishock, & Singha, 1992; Umile, Sandel, Alavi, Terry, & Plotkin, 2002; Varney & Varney, 1995). A variety of research protocols that have studied MHI patients have used a LOC of less than 30 minutes, less than 20 minutes, less than 5 minutes, 5-30 minutes, any alteration in mental state, or no LOC at all. It is apparent that the range of LOC in MHI samples can vary widely and there has been no clear consensus regarding the length of LOC (if any) required to be considered a mild injury. The issue of LOC in MHI studies is also rendered less reliable by the fact that as many as half the patients may not be able to accurately recall how long the duration of their altered state persisted (Ruff, 1999). LOC does not appear to be a necessary requirement for brain injury to occur, but a more consistent definition outlining the parameters of LOC for MHI classification is clearly needed.

Post Traumatic Amnesia. PTA refers to a period of time after regaining consciousness from a neurological insult where new memories cannot be consistently laid down and remembered (Loring, 1999). Typically, a PTA of less than 1 hour is necessary to be designated as a MHI, but a variety of guidelines have been used ranging from no PTA, transient confusion, zero to approximately 4 hours, and one minute to 12 hours. PTA has been used to measure the severity of brain injury, but this indicator of memory functioning does not appear to be a requirement for brain injury to be present (Borczuk, 1995). The length of PTA has been shown to be a reliable predictor of brain injury recovery across a range of severity (Levin, Benton, & Grossman, 1982); however, there are difficulties with obtaining an accurate assessment of PTA in MHI patients. Gronwall and Wrightson (1981) found that 25% of MHI patients changed their retrospective estimates of PTA over a period of 3 months. PTA is often not formally assessed and may be underestimated due to isolated and disconnected memory traces that do not reflect continuous memories (Sohlberg & Mateer, 2001). PTA may also be overestimated due to alcohol, drug or medication use before, during, or after an accident. PTA remains an often elusive neurological parameter that may be useful to predict recovery after head injury if clinicians can reliably and consistently record the duration of PTA. It is clear that a more consistent definition of MHI is needed in order to draw more definite conclusions about the nature and extent of a patient’s short and long-term complications and expected recovery patterns.

Definitions of MHI. The Mild Traumatic Brain Injury Committee of the Head Injury Specialty Interest Group of the American Congress of Rehabilitation Medicine (ACRM, 1993) has provided a classification of MHI that is somewhat more inclusive than previous definitions and attempted to provide consensus within MHI research. According to their definition, a MHI includes any one of the following: LOC not greater than 30 minutes; alteration in mental status immediately after the accident; loss of memory for activities before or after the accident not greater than 24 hours, and focal neurological signs. This definition also required a normal computed tomography (CT) or magnetic resonance imaging (MRI) scan and a GCS of 13-15. This definition provided a wider range of inclusion toward the less extreme end of the LOC and PTA continuum in order to take into consideration the heterogeneity of milder head trauma. However, the definition continued to provide an overly broad description of what constitutes a MHI (Goldberg, 2001), and research findings assessing the initial symptoms and long-term outcomes may be confounded by this overly broad categorization of MHI patients.

Ruff and Jurica (1999) have proposed a definition of MHI similar to the ACRM's description but continued a step further by subdividing three types of MHI based on the level of severity of the initial TBI symptoms. Type I classification required only a transient LOC or an altered mental state along with PTA of up to 1 minute. Type II included those with a definite LOC of less than 5 minutes and a PTA between 1 minute and 12 hours. Type III is described as a LOC of 5 to 30 minutes and a PTA greater than 12 hours. This classification system does not take into consideration the presence of focal neurological signs because it is often difficult to quantify these in actual practice (Ruff, 1999). This somewhat arbitrary division of MHI patients requires further validation because preliminary research was not able to differentiate these groups of MHI patients on such variables as subjective cognitive and emotional complaints, neuropsychological test performance, or pre-existing emotional risk factors (Ruff & Jurica, 1999). Overall, the classification system proposed by Ruff and Jurica appears to adequately address the range of brain injury severity typically designated as mild, but additional large-scale studies assessing the clinical usefulness of these classifications are needed.

Pathophysiology of MHI

In a substantial minority of MHI patients, cognitive, emotional, and somatic complaints persist for several months to several years after the initial injury. The patients reporting these postconcussion symptoms (PCS) may be diagnosed with Postconcussional Disorder according to DSM-IV-TR criteria if they report at least three designated symptoms that persist for at least 3 months (APA, 2000). Some of these MHI patients show verifiable brain tissue damage that may be partly responsible for these persistent complaints; therefore, it is important to understand the pathophysiological mechanisms of MHI and the brain areas most vulnerable to injury.

There are multiple sources of damage that can result in injury to the brain in cases of MHI. Mechanical forces often can damage the underlying brain tissue directly at the point of contact. Damage occurring at the site of impact is referred to as the coup damage site and damage occurring in a force vector directly opposite the site of impact is referred to as the contrecoup injury site. The brain is also subject to acceleration and deceleration forces when the head is abruptly stopped, but the brain continues to move forward within the skull. The underside of the skull contains sharp, boney protrusions that cause abrasions to the frontal and temporal lobes when the brain is thrust back and forth across this surface during acceleration-deceleration injuries. These contusions and abrasions are frequently accompanied by bleeding and swelling (Sohlberg & Mateer, 2001).

The brain injuries found in MHI patients are typically diffuse in nature. These non-localized areas of damage are sites where neurons may have been stretched and have become dysfunctional, but the neuron often remains alive. More permanent damage is thought to occur when the neurons are ruptured and cease to function (Echemendia & Julian, 2001). The physical stretching of the neurons at the time of the injury causes damage to a neuron's membrane structure and may result in a disruption of its normal neurochemical environment.

Neurochemical changes as a consequence of MHI may result in dysfunctional brain cell activity that may last for several days after the accident. Hovda (1999) described a neurochemical cascade of events that disrupts the neurons' functioning and is characterized by an increased demand for glucose while at the same time there is a reduction in cerebral blood flow (CBF). This decreased CBF results in an inability to transport the necessary oxygen and nutrients to areas affected by the neurological insult and recovery of normal physiological functioning in these areas is hindered. Within the first hour after the injury, there is an extracellular increase in glutamate released from the damaged cells that results in a series of chemical changes to compensate for this massive release. With the increased concentration of glutamate, potassium leaving the neuron increases and results in a decreased ability of the neuron to produce an action potential. Membrane ion pumps are then activated producing increased physiological stress on these damaged neural tissues. The neuronal functioning after the injury has been described as metabolically disturbed due to an imbalance between energy demand and production (Hovda).

Posttraumatic seizures and bleeding within the brain may create significant symptoms and contribute to poorer outcomes in MHI patients. Seizures within the acute stage after MHI are not uncommon, but continued seizure activity occurs in only about 5% of individuals (Yablon, 1993). The vascular system can also be compromised after a head injury and may result in secondary neuronal damage. For example, small blood vessels in the brain can be torn and bleeding can result in subdural or intracranial hematomas. Damage may be caused by the bleeding itself or the bleeding can increase pressure on other brain structures (Sohlberg & Mateer, 2001).

Diffuse axonal injury (DAI) is caused by the stretching and shearing of long axonal tracts connecting various areas of the brain resulting in the death of entire neurons. DAI can also damage neuron fibers that project through layers of cortical tissue as a result of these cortical tissue layers sliding back and forth and shearing the axons connecting various cortical structures. Supporting structures and other neurons that previously communicated with the damaged neuron also degenerate within 24 hours of injury. DAI shows a range of damage based on the location of the insult. The peripheral cerebral cortex is typically less vulnerable to damage than areas of the midbrain and central brain structures. Structures most affected by DAI include the medial frontal lobes, corpus callosum, and the cerebellar peduncles. DAI is closely associated with the severity of brain injury and long-term patient outcomes (Sohlberg & Mateer).

Orbital frontal cortex may be a common site of damage after MHI. This damage is caused by abrasions, lacerations, and contusions of the underside of the frontal lobes due to the contact it makes with the cribriform plate. Significant disruptions in executive functioning, mental inertia, and psychosocial functioning appear to be compromised in patients with damage to this area of the brain despite an injury deemed mild in nature (Varney & Menefee, 1993). Autopsy studies dating back to the 1800’s provided evidence that posttraumatic anosmia (or more typically, hyposmia), the loss or reduction of one’s sense of smell, is often associated with orbital frontal damage in patients with a MHI (Sumner, 1976). Anosmia has also been shown to be an indicator of hypometabolism in the orbital frontal cortex in patients that have shown poor psychosocial outcomes despite normal IQ, memory, language, and negative findings on MRI and CT (Varney & Bushnell, 1998). In a recent prospective study, MHI patients were assessed for olfactory functioning 2 weeks after head trauma (De Kruijk et al., 2003). They found 26% of the sample to have significant olfactory dysfunction (24 with hyposmia, 5 with anosmia), but these findings did not correlate significantly with other acute symptoms at admission (headaches, dizziness, nausea/vomiting) or biochemical markers of head injury severity (S-100B and Neuron-Specific Enolase). This study provided additional evidence for the presence of olfactory dysfunction following MHI and indirect evidence of possible orbital frontal damage in a significant percentage of these patients.

Psychogenic Explanations of Symptoms After MHI

There has been extensive debate regarding the etiology of persisting cognitive and emotional symptoms after a MHI and is often referred to as Postconcussion Syndrome or Postconcussional Disorder (according to the DSM-IV-TR). These symptoms include cognitive symptoms such as problems with attention, concentration and memory, as well as headaches, dizziness, fatigue, photophobia, depression and personality changes. Psychogenic explanations for reported symptoms after MHI support the idea that emotional and psychosocial factors play a significant role in persisting complaints. Two studies have found that postconcussion symptoms (PCS) were associated with daily stress levels and concluded that PCS after MHI may fluctuate based on a patient’s perceived level of stress (Gouvier, Cubic, Jones, Brantley, & Cutlip, 1992; Machulda, Bergquist, Ito, & Chew, 1998). Fenton, McClelland, Montgomery, MacFlynn, and Rutherford (1993) and Gerber and Shraa (1995) found a relationship between chronic PCS in patients who reported elevated pre-injury levels of social stress and suggested that these individuals may be at a greater risk of post-injury stress as well. However, there has been no consistent association between pre-injury psychiatric history and presence of PCS after MHI (Alves, Macciocchi, & Barth, 1993; Cicerone & Kalmar, 1995; Fenton et al., 1993; Gerber & Shraa 1995; Karzmark, Hall, & Englander, 1995). Evidence of an affective disorder along with MHI appears to increase the endorsement of PCS (Fann, Katon, Uomoto, & Esselman, 1995). Other studies have shown that clinically depressed individuals with no history of head injury reported higher rates of PCS compared to patients with a history of MHI (Trahan, Ross, & Trahan, 2001). Despite the overlapping of symptoms between clinical depression and PCS in the Trahan et al. study, this did not account for the fact that the depressed group endorsed many items not characteristic of depression.

Others have also found high rates of PCS endorsement in groups of neurologically normal adults (Chan, 2001; Gouvier, Uddo-Crane, & Brown, 1988), and the symptoms reported by MHI patients and individuals who had experienced only emotionally disturbing events are often quite similar and provide evidence of the non-specificity of postconcussion symptoms. Lees-Haley, Fox, and Courtney (2001) found that PCS endorsement rates were similar for a group of compensation-seeking individuals who experienced a stressful life event (e.g., sexual harassment, wrongful termination, exposure to horrifying incidents, discrimination) but no head injury. The authors cautioned about attributing symptom complaints to a previous head injury when in fact these symptom complaints are relatively common in patients with no history of head injury (see Gouvier et al., 1988).

Paniak et al. (2002) also found that PCS endorsement rates within one month of MHI were higher in patients than in controls, but the high variability within the patient group resulted in poor discrimination between groups based on regression analyses. A prospective study by

Bazarian et al. (1999) found that 25% of MHI patients reported significant PCS at 6 months, but 34% of a control group of non-head injured patients also reported PCS complaints. Some have proposed that PCS are a result of one's expectations for symptoms after incurring a MHI (Ferguson, Mittenberg, Barone, & Schneider, 1999; Mittenberg, DiGiulio, Perrin, & Bass, 1992). Individuals can accurately predict the types of symptoms that patients typically experience after suffering a MHI and it is hypothesized that MHI patients tend to selectively attend to these expected symptoms which are then misattributed to the head injury. Overall, the previous studies provide additional evidence suggesting that subjective symptom complaints (e.g., PCS) of MHI patients are not specific to head injury, are influenced by one's expectations of symptoms, and have been found in neurologically normal adults and patients with posttraumatic symptoms and depression.

Litigation status has also been proposed as an explanation of persisting symptoms after MHI despite several studies finding no association between litigation status and PCS (Bornstein, Miller & van Schoor, 1989; Gerber & Shraa, 1995; Karzmark, Hall, & Englander, 1995). However, a meta-analytic review of 7 MHI studies described compensation concerns as responsible for about 25% of post-injury symptoms (Binder & Rohling, 1996). Poor effort and malingering have been shown to be important variables to consider when testing patients within the context of litigation. A substantial percentage of MHI patients with financial incentives have been found to perform significantly worse on relatively easy forced-choice tests of recognition memory compared to patients with documented brain dysfunction (who were not seeking compensation) including hospitalized rehabilitation patients with moderate to severe head injury (Binder, 1993; Binder & Willis, 1991; Millis, 1992). Others have found that poor effort had a greater effect on test score performance than severe brain injury in those pursuing compensation claims (Green, Rohling, Lees-Haley, & Allen, 2001). It is clear that a patient's level of effort and motivation to fabricate or exaggerate symptoms can significantly affect neuropsychological test results and, therefore, should be assessed by using a variety of tests that measure the veracity of a MHI patient's symptom complaints. Because of the significant number of MHI patients often involved in litigation, the clinician should be aware of the likelihood of higher symptom endorsement rates and the increased tendency for exaggerated/fabricated neuropsychological deficits in this population. Contrary to clinical lore (Miller, 1961), MHI patients not seeking compensation for their injuries report symptoms similar to those who are involved in litigation, and resolution of these symptoms does not necessarily occur after litigation has ended (Fee & Rutherford, 1988; Varney, 1990).

Organic Basis of Symptoms after MHI

The etiology of persistent PCS has been described in the previous section as partially resulting from psychosocial factors, the patient's premorbid history, and level of stress in both MHI patients and those without a history of head injury. The following sections address the hypothesis that MHI results in significant, albeit at times subtle, neuropsychological, structural, electrophysiological, and biochemical disturbances that may be partially responsible for persistent deficits and symptom complaints following MHI. There are a lack of studies that have looked at the long-term cognitive effects of MHI in symptomatic and asymptomatic individuals (Bernstein, 1999), but Lishman (1988) and others have described a physiological basis for MHI symptoms that supports a physiogenic etiology of persistent PCS in MHI patients.

Neuropsychological Deficits. Deficits on a variety of cognitive tasks have been found when assessing MHI patients within days or months after injury. Brooks, Fos, Greve, and Hammond (1999) found that patients admitted to a trauma center and tested within 2-3 days of admission showed evidence of deficits on a variety of measures (paced serial addition task, Trailmaking Test parts A and B, and controlled oral word association test). All patients received an MRI and CT upon admission and, therefore, this sample of MHI patients may reflect a more severely injured group than is typically found in MHI samples. Dikmen, Machamer, & Temkin (2001) found only slight deficits on neuropsychological measures within a few days of injury and concluded that the effects of age often have a greater effect on neuropsychological test scores than the head injury itself and that long-term deficits are probably rare. However, there is evidence to suggest that long-term deficits in neuropsychological functioning remain possible (Leiniger, Gramling, Farrell, Kreutzer, & Peck, 1990). Compared to the previous studies that assessed MHI within a few days after injury, Leiniger et al.'s results may be confounded by a number of factors related to delayed assessment (e.g., psychological response to injury, expectations of recovery, poor coping abilities, malingering, etc.) that could be responsible for the deficits in cognitive functioning. By investigating the neuropsychological effects of MHI at admission and several weeks or months after injury, the symptom complaints and recovery patterns after MHI can be more clearly delineated.

Neuroimaging Abnormalities. With the advent of more sophisticated neuroimaging techniques in the past several decades, extensive information about the structure and functioning of the brain is now available. Unfortunately, the relationship between neuropsychological testing and functional neuroimaging in MHI patients has often been inconsistent. More methodologically rigorous research designs that include greater numbers of patients are needed before the usefulness and specificity of imaging data combined with neuropsychological testing results can be fully utilized to characterize MHI patients with and without persistent symptom complaints.

Patients with a MHI and structural lesions on CT or MRI have clinical outcomes that often resemble patients with moderate head injury (Van der Naalt, Hew, van Zomeren, Sluiter & Minderhoud, 1999). Tellier et al., (1999) reported that 31% of patients diagnosed with a MHI based on a GCS of 13-15 showed CT abnormalities with higher rates of negative CT findings with GCS of 14-15. It appears that using the GCS classification system may not be sensitive enough to detect MHI abnormalities and patients with positive CT findings represent a heterogeneous group at risk for significant neurological complications. Voller et al. (1999) assessed a very conservative group of MHI patients (GCS = 15) within 24 hours and at 6 weeks using MRI and neuropsychological testing. Patients showed deficits on tasks of verbal learning and recall, reaction time on the Stroop, and speeded simple arithmetic at both measurement periods. Those with MRI abnormalities (3 of 12 patients) showed deficits on phonemic verbal fluency and arithmetic. The findings highlight the fact that MRI and cognitive testing are sensitive to even very mild types of head injury that could result in significant long-term complications.

Cerebral atrophy also appears to be a marker of cognitive dysfunction as a result of the loss of actual brain matter due to a neurological insult or disease process, but there has been little attention paid to cerebral atrophy in MHI patients. Evidence of significant gross cerebral atrophy on MRI and CT were not present in several patients before or after MHI (Bigler & Snyder, 1995), but more recent evidence suggests that some atrophy 6 months after injury is possible (Hofman et al., 2001). More long-term studies using quantitative measures of brain volumes after MHI are needed in order to assess the relationship between cognitive functioning, atrophy, and severity of brain injury.

Another type of imaging technique is Magnetic Source Imaging (MSI) which combines MRI with measurements of electrical currents from neuronal dendritic activity. MSI abnormalities had been found in slightly over half of a symptomatic MHI group compared to roughly 10% of asymptomatic MHI patients and controls (Lewine, Davis, Sloan, Kodituwakku, Orrison, 1999). Even though MSI imaging shows some promise in characterizing MHI in two clinically different groups of MHI patients, assessment of these small patient groups occurred from 2 months to over 3 years after initial injury resulting in poor generalization to other samples. Other promising imaging techniques include methods that assess brain functioning during cognitive tasks rather than providing only a snapshot of the brain at rest.

Utilizing positron emission tomography (PET) to quantify cerebral metabolism in patients with postconcussion symptoms, Chen, Kareken, Fastenau, Trexler, and Hutchins (2003) studied 5 MHI patients 5 months to approximately 3 years after injury. Compared to controls, patients showed slight neuropsychological deficits along with decreased right hemisphere cerebral blood flow during a spatial working memory task despite performing normally on the task. It was suggested that a cognitively challenging task may be necessary to detect the subtle neurophysiological changes associated with postconcussion complaints following MHI because imaging results showed no differences when patients were at rest. However, sample size was small and there was substantial overlap with controls so caution is warranted in interpreting these results. It is unclear whether subjective distress could have been responsible for the functional and quantitative PET differences during the working memory and neuropsychological tasks rather than deficits attributed solely to neuronal dysfunction.

Neuroimaging using single-photon emission computed tomography (SPECT) and neuropsychological testing together provide information regarding cognitive functioning and the functional neuroanatomical correlates of these processes. SPECT provides evidence of cerebral metabolism and can be directly compared with MRI and CT information. Also, the neurophysiological processes thought to be disrupted during MHI may not show any structural damage on static imaging (MRI or CT), but may be found with SPECT. For example, the abrasions/lacerations typical of MHI damage in the area of the orbitofrontal cortex are often not picked up by CT or MRI due to the boney irregularities of the underside of the skull resulting in imaging artifacts which often obscure the precise lesion location in these areas (Newberg & Alvi, 1996). SPECT techniques have been used to detect functional brain abnormalities in MHI cases despite normal CT and MRI findings in the areas of the anterior orbital and medial pre-frontal regions (Varney & Bushnell, 1998; Varney, Pinkston, & Wu, 2001) and anterior temporal lobes of patients with disabling neuropsychological deficits (Varney et al., 1995).

Investigators have found that the sensitivity of SPECT in MHI patients with no LOC or abnormalities on CT have been useful in delineating the brain areas with abnormal functioning. Abdel-Dayem et al. (1998) found that in a group of MHI patients (no LOC or CT abnormalities), 68% showed hypoperfusion with 50% of the abnormalities found in the basal ganglia and 46% found in the frontal lobes. The relationship between neuroimaging abnormalities and memory performance was assessed by Umile, Sandel, Alavi, Terry, and Plotkin (2002) who retrospectively studied MHI patients with persistent PCS who had undergone MRI/CT and SPECT. Despite the sensitivity of SPECT compared to static imaging, the correspondence between memory tests and neuroimaging was variable with 30% of patients showing no relationship between functional imaging abnormalities and memory deficits. A major limitation of the Umile et al. (2002) study was that the time between injury and imaging/testing ranged from 1 month to almost 8 years. Sampling times should be held constant across subjects so that the time since injury, effects of litigation, psychological responses to injury, and other environmental factors are approximately equivalent across all subjects.

The sensitivity of SPECT and MRI in predicting brain atrophy and neuropsychological functioning was investigated by Hofman et al. (2001) who followed 21 consecutive patients for 6 months after MHI (GCS = 14-15). Initial abnormalities on MRI or SPECT predicted brain atrophy at 6 months, but agreement between MRI and SPECT, and SPECT with neuropsychological testing was poor. Neuropsychological test results were slightly lower at 5 days and 2 months after injury in those with initial MRI abnormalities; however, these differences were not statistically significant and were unrelated to lesion volume or brain atrophy. This study may have benefited from comparing the patient groups based on subjective cognitive complaints as suggested by Reitan and Wolfson (1999) instead of groupings based on MRI abnormalities alone.

Despite the promise of more detailed analysis of brain functioning, one of the limitations of functional neuroimaging continues to be its unreliability in discriminating between brain abnormalities caused by head trauma versus other medical, psychiatric, environmental, or pre-existing conditions (Ichise et al., 1994). For example, depression in MHI patients has been shown to reduce frontal lobe perfusion with the abnormal SPECT findings possibly reflecting emotional difficulties secondary to MHI, neurophysiological deficits resulting from the brain trauma itself, or some combination of these and other factors. Clinically depressed MHI patients were no different from depressed controls on the Beck Depression Inventory, various cognitive measures, or SPECT (Kant, Smith-Seemiller, Isaac, & Duffy, 1997). Cognitive functioning and SPECT abnormalities in a group of MHI patients showed no reliable differences on neuropsychological testing, but there were greater SPECT abnormalities in those reporting moderate to severe levels of depression (Umile, Plotkin & Sandel, 1998). Due to the apparent relationship between depression and SPECT abnormalities in MHI patients, controlling for psychiatric diagnoses/symptoms is essential in order to provide an accurate description of MHI pathophysiology rather than confounding results with psychiatric symptoms. The problems with interpreting many SPECT findings in MHI samples includes the small number of cases studied, the lack of correlation between abnormal findings and neuropsychological status, few follow-up studies, and the non-specificity of abnormal findings.

Even though the interpretation of abnormal functional neuroimaging findings frequently are poor at accurately predicting long-term behavioral symptoms, normal SPECT results appear to be a good predictor of positive outcomes. Negative CT abnormalities along with normal SPECT findings (Gray, Ichise, Chung, Kirsh, & Franks, 1992) show promise in providing good negative predictive power for mild to moderate head injury patients (Jacobs, Put, Ingels, & Bossuyt, 1996). Patients showing no SPECT abnormalities during initial assessment had good outcomes and no persistent complaints at 3, 6, or 12 months. Overall, SPECT appears to be sensitive to a variety of head injury and non-head injury conditions (e.g., depression), but it’s greatest utility with MHI may be in ruling out the likelihood of patients reporting long-term symptom complaints.

There remains a lack of strong evidence showing a relationship between persistent neuropsychological complaints and identified brain lesions with neuroimaging techniques due to the lack of well-designed investigations and small sample sizes. These studies also frequently confound subjective complaints, subtle cognitive deficits, and psychiatric co-morbidities which have been shown to produce abnormalities on functional neuroimaging. Binder (1997) stated there were no current neurodiagnostic techniques that were sufficiently specific to the effects of

MHI, other than static methods such as CT or MRI, to be of diagnostic value for neuropsychologists. However, as neuroimaging techniques become more precise and research methodology becomes more sophisticated with regards to controlling for psychological and environmental variables, there may be a place for neuroimaging in the assessment and clinical management of MHI. Due to the neurophysiological cascade of events that often occurs as a consequence of MHI, methods of quantifying biochemical changes, subjective symptom complaints, and neuropsychological functioning may provide additional evidence regarding the nature of MHI.

<u>Biochemical Markers.</u> Brain specific proteins such as S-100B and Neuron-Specific Enolase (NSE) are released into the circulation after traumatic brain injury (TBI) and have been reported to be markers of cell damage in the central nervous system (CNS). NSE is found mostly in neurons but also in smooth muscle and adipose tissue. S-100B is highly concentrated in glial cells and is more specific to lesions of the CNS than NSE. Serum S-100B levels are higher in patients with intracranial pathology and these levels correlate with clinical outcome and severity of brain damage (Romner, Ingebrigtsen, Kongstad, & Borgesen, 2000). Also, undetectable S-100B levels are predictive of normal intracranial findings on CT and with higher clinical ratings on the GCS and the Glasgow Outcome Score in severe head injury patients (Romner, Ingebrigtsen, Kongstad, & Borgesen). Measuring S-100B levels soon after a MHI may also have utility as a biochemical marker of initial brain injury severity that could be used to predict long-term outcomes in these patients.

Higher concentrations of S-100B have been found within 6 hours of a MHI compared to controls (De Kruijk, Leffers, Menheere, Meerhoff, & Twijnstra, 2001). Traumatic damage to other body parts showed no association with S-100B levels and provides evidence ruling out the possibility that damage to peripheral nerves or other soft tissues caused increased levels in these patients. Subjective complaints of forgetfulness and headaches at 6 months (De Kruijk et al., 2002) and neuropsychological deficits at 2 weeks and 6 months (Herrmann et al., 2001) were significantly associated with S-100B or NSE levels at hospital admission. Interpretation of the Hermann et al. study is complicated by the high patient attrition (over 50%) and MHI patients were not separated from those suffering more severe injuries. Therefore, the results allow us to only draw conclusions about the relationship between S-100B levels at admission and head injury in general. Ingebrigtsen, Waterloo, Jacobsen, Langbakk, and Romner (1999) also had a high rate of patients lost to follow up. They found a slight trend for decreased neuropsychological test performance within 2 days and 3 months after MHI injury on all 19 tests in patients positive for S-100B levels compared to patients with non-detectable levels at admission. Depressive symptoms were no different between these groups thus eliminating psychiatric symptoms as a possible cause of lower test scores in the S-100B-positive patients. Waterloo, Ingebrigtsen, and Romner (1997) also assessed patients at the time of admission and found that 20% of the MHI patients had elevated S-100B levels and these levels were correlated with symptom complaints and impaired neuropsychological performance.

Asymptomatic MHI patients have shown lower levels of biochemical markers of CNS damage after injury. Patients with no initial clinical complaints and no elevated S-100B levels at admission reported no symptom complaints at 6 months (De Kruijk et al., 2002). Similar to the outcomes found with initial SPECT imaging after head injury (Jacobs, Put, Ingels, & Bossuyt, 1996), negative initial S-100B levels may also show good negative predictive power, but additional studies are needed to confirm the predictive value of this technique in prospective studies of MHI patients.

Overall, initial S-100B levels appear to hold promise in providing an early marker for brain tissue damage soon after MHI, but additional studies with lower rates of patient attrition and long-term follow up are needed. Neuronal damage (and higher levels of S-100B) resulting from MHI appears to be more likely in white matter as a consequence of diffuse axonal injury and would be consistent with divided attention problems often reported soon after injury. More study is needed to ascertain whether these biochemical markers can be considered reliable predictors of persisting symptoms 6 months to a year or more after a MHI. Since low levels of S-100B suggest an absence of structural damage to the brain, clinicians may be able to tease apart the psychosocial effects from the biological effects of head trauma.

Electrophysiological Abnormalities. Standard electroencephalographic (EEG) techniques are typically not useful in identifying MHI and were primarily developed to identify gross changes in the integrity of the CNS such as large lesions and epileptic activity. Cognitive event-related potentials (ERP) appear to be more sensitive to MHI and have the advantage of being noninvasive, less expensive than other imaging techniques, and relatively easy to administer (Gaetz & Bernstein, 2001). However, there is no single electrophysiologic technique or neuropsychological test that is sensitive enough to detect the often subtle nature of cognitive deficits in the heterogeneous population of MHI patients.

Visual disturbances after MHI are not a frequent complaint compared to problems with headaches, fatigue, attention/concentration and memory, but they have been shown to persist for more than a year after initial injury. Visually-evoked cortical potentials (VECP) correlate highly with visual neuroanatomy, provide a neural representation of retinal functioning, and trace the integrity of the visual pathway from the retina to the visual cortex. Freed and Hellerstein (1997) studied MHI patients with documented visual disturbance (e.g., diplopia, photophobia, spatial distortions) assessed less than 2 years after injury and followed up 12-18 months later. Seventy-five percent of patients not receiving comprehensive optometric rehabilitation were twice as likely to show (VECP) dysfunctions at follow up compared to patients receiving treatment. This study provides evidence that some mild head injuries can result in long-term neurophysiological disturbances in the visual system if left untreated.

Patients reporting a variety of co-morbid psychiatric or postconcussion symptoms have been studied to assess neurophysiological deficits not always evident on neuropsychological testing. Solbakk, Reinvang, and Nielsen (2000) found that symptomatic MHI patients showed intact differential allocation of attentional resources based on evoked-related potential (ERP) data; however, slowed reaction time, decreased accuracy of responses, and P300 amplitude attenuation suggested an inefficient allocation of attentional resources. Similar conclusions were reached by Solbakk, Reinvang, Nielsen, and Sundet (1999) with a group of symptomatic MHI patients where ERP data during a dichotic listening task also showed an inefficient allocation of attentional processes. Trudeau et al. (1998) found subtle neurophysiological abnormalities in addition to attention problems on a computerized attention task in a population of chronic PTSD patients with a history of blast concussion. Quantitative EEG (QEEG) abnormalities similar to a normative group of patients with a history of MHI were found in the patients with a history of blast injury only. The patients with a history of blast injury appear to have suffered injuries consistent with a MHI as suggested by their abnormal QEEG measures. Patients reporting symptom complaints may be an unusual MHI group given that the majority of patients report no persisting symptoms 6 months or more after injury. By studying patients that have completely recovered from a MHI (e.g., no symptom complaints), the confound of pre-existing psychiatric disorder and psychological adjustment/stress after injury may be excluded as a possible cause of subtle cognitive deficits.

Asymptomatic college students who had experienced a MHI on average 6 years earlier showed greater deficits on two out of four complex auditory discrimination/divided attention tasks with an accompanying decrease in P300 evoked potential amplitude (Segalowitz, Bernstein, & Lawson, 2001). A decreased P300 amplitude reflects an increased level of mental processing required for more complex cognitive tasks. Both groups showed comparable results on electrophysiological measures of information processing speed (P300 latency) and there were no differences on neuropsychological tasks or self-report measures of memory and attention difficulties. It appears that even high functioning MHI college students may show subtle cognitive deficits on more demanding divided attention tasks reflected by their lowered ERPs. Potter and Barrett (1999) also assessed asymptomatic MHI patients within 3 years of injury and found mild deficits on memory and cognitive flexibility tasks along with a reduced frontal lobe ERP negativity during the PASAT. These findings reflect an activation of selective attention circuits with subtle abnormalities in allocating cognitive resources despite normal processing speed. It appears that subtle neurophysiological differences are found in symptom-free individuals with a history of MHI when exposed to highly demanding cognitive tasks.

College athletes are a unique group to study given their high motivation to perform well, good overall general health, and their relative homogeneity with regards to educational and intellectual level. Slobounov, Sebastianelli, and Simon (2002) studied 6 symptomatic college athletes 10-20 months after injury on a task of fine motor control and coordination. As the task load (force applied) increased, the MHI participants had more difficulty regulating motor responses with corresponding movement-related potential (MRP) attenuation. The deterioration in performance and MRP activity during demanding motor coordination tasks reflected a decreased recruitment of cognitive resources under demanding conditions. This study would have benefited from a larger, more clearly defined sample of MHI athletes compared with non-head injured control subjects reporting similar levels of postconcussion symptoms. In the future, the usefulness and convenience of electrophysiological procedures in clinical practice may allow for a more reliable discrimination between organic versus psychological factors affecting tasks of complex attention that require high levels of cognitive effort.

Neuropsychological testing of symptomatic and asymptomatic MHI patients may reveal subtle cognitive deficits in attention and short-term memory. However, many studies have found no evidence of neuropsychological deficits due to possible recruitment bias or because of many other factors (e.g., age, education, alcohol/drug use, psychiatric symptoms, litigation status, learning disorders) that can often mask or mimic the effects of MHI (Dikmen, Machamer, & Temkin, 2001). By utilizing a variety of research methods and combining neuropsychological testing with electrophysiological recording, functional neuroimaging, and biochemical sampling, the "miserable minority" may be more reliably predicted and then targeted for early intervention to minimize residual cognitive deficits.

Stress-Induced Cognitive Deficits and Symptom Complaints in MHI

Higher levels of perceived stress often increase the number of symptom complaints in normals and those with a history of MHI (Gouvier, Cubic, Jones, Brantley, & Cutlip, 1992; Machulda, Bergquist, Ito, & Chew, 1998). Symptomatic MHI patients often are regarded as more susceptible to the effects of general stress or experimentally-induced stress than are non-head injured controls during tasks requiring high levels of working memory/attentional resources. Neuropsychological performance also appears to be negatively affected by high levels of psychological or external stress when a patient's cognitive coping resources cannot adjust to the increased demands of the task (Bohnen, Houx, Nicolson, & Jolles, 1990). An early study by Ewing, McCarthy, Gronwall, and Wrightson (1980) studied mildly head injured asymptomatic college students to assess their abilities under normal testing conditions and at a simulated altitude of 3,800 meters (hypoxic stress condition). Performance on a vigilance task and incidental memory task during hypoxic stress resulted in lower scores for MHI subjects compared to controls. Results provided evidence of the persisting effects of MHI that may be subtle and only emerge under conditions of physical, hypoxic stress. The present study focuses on whether psychological stress results in a similar decrement in cognitive functioning among the understudied asymptomatic majority (80%-90%) of MHI victims.

Reaction time tests have shown deteriorating scores in MHI patients compared to controls as the behavioral task demands increase (Hugenholtz, Stuss, Stethen, & Richards, 1988; Slobounov, Sebastianelli, & Simon, 2002). The cognitive vulnerability of apparently recovered MHI patients exposed to stressors during a vigilance task also provides evidence of the negative effects of stress on cognitive functioning in MHI patients compared to controls (Bohnen, Jolles, Twijnstra, Mellink, & Sulon, 1992). Experimental stress in the form of intrusive auditory stimuli combined with a mental arithmetic task also appears to negatively affect working memory performance in college students reporting a high level of postconcussive complaints several years after a MHI (Hanna-Pladdy, Berry, Bennett, Phillips, & Gouvier, 2001). It appears that the subtle neurophysiological and neuropsychological differences typically found in MHI patients are more likely to be noticeable during more complex and challenging cognitive tasks that require significant mental effort (Chen et al., 2003). Due to the subtle nature of deficits on neuropsychological testing, electrophysiological recordings, or functional neuroimaging, significant differences between MHI patients and controls may not be clinically or statistically different when tested under standard conditions or in a low-stress environment. However, these differences may be revealed when vulnerable participants are subjected to physical (Ewing, McCarthy, Gronwall, & Wrightson, 1980) or psychological (Hanna-Pladdy, Berry, Bennett, Phillips, & Gouvier) stressors within the context of the testing session.

Neuroimaging and electrophysiological recordings have found disturbed functioning in a significant portion of MHI patients with normal neuropsychological test findings, but many of these patients continue to report significant cognitive complaints. McAllister and colleagues (1999, 2001) used functional MRI (fMRI), which assesses blood flow changes in the brain, during an auditory working memory task of increasing difficulty to assess functional differences between controls and MHI patients within a month of injury. As the difficulty level of the working memory task increased, there was a stepwise increase in brain activation in controls, but MHI patients showed the greatest functional increase during the medium difficulty trial with a decrease in activation on the most challenging trial. It was concluded that brain activation differences in patients were associated with a decreased working memory capacity and/or an inefficient allocation of attentional resources due to brain trauma. Anxiety and depressive complaints and neuropsychological testing showed few differences; however, patients reported higher rates of subjective cognitive complaints (e.g., memory, attention/concentration, job difficulties) than controls.

Increased memory complaints can arise for a variety of reasons. Early work by Treat, Poon, Fozard, and Popkin (1978) showed that memory complaints in elderly individuals are more highly correlated with indices of mood disorder than with actual memory performance on neuropsychological measures. Alternatively, task difficulty can contribute to perceived memory problems as well. MHI patients may have difficulties in efficiently recruiting the cognitive resources necessary for demanding tasks and view these difficulties as general problems with memory. McAllister et al. (1999, 2001) hypothesized that a disruption in the normal ability to activate or allocate processing resources in response to challenging working memory tasks may be associated with cognitive complaints after MHI. In other words, patients may be aware that they are expending more effort to maintain their previous level of performance and this increased effort results in frustration due to the subjective inability to cope effectively with environmental demands (Van Zomeran & Van den Burg, 1985). However, these subtle cognitive deficits resulting in symptom complaints may not be apparent under normal conditions, but only noticeable in more cognitively demanding situations. The cognitive deficits often observed in patients with MHI within a month of injury may be more a result of organic factors such as structural tissue damage or neurophysiological abnormalities with factors such as the patient’s psychosocial response to injury playing a less prominent role in symptom presentation. Psychogenic factors such as environmental stressors, coping abilities, and litigation status in combination with residual brain dysfunction may be responsible for subjective symptom complaints several months to years after injury.

In order to assess long-term (greater than 6 months) working memory and attention difficulties in MHI patients, it seems imperative that subjective symptom complaints be controlled for so that psychosocial factors can be ruled out as a primary cause of working memory/attention difficulties. Also, standard neurocognitive tasks may not be sensitive enough to separate the effects of MHI from other factors that may affect test performance (e.g., psychiatric diagnosis, substance abuse, sleep disturbances, etc.). Therefore, administering cognitively demanding tasks requiring high levels of effortful processing under stressful conditions may be necessary to expose the subtle differences between high functioning individuals with a history of MHI and those without a history of injury. Also, assessing subjective symptom complaints after undergoing a series of cognitively demanding neuropsychological tasks may provide additional information regarding the subjective effects of stress on one’s perception of their cognitive abilities.

METHODS

Participants

One-hundred thirty-six college students who were at least 18 years old were recruited for the study and were provided extra credit for their anonymous participation. Twenty-four were excluded as a result of meeting at least one of the exclusion criteria leaving 112 participants for the final analyses. Information collected included demographic information, details of any previous head injuries or other major medical treatments/disorders, and current or past psychiatric treatment for emotional or substance abuse problems. Information regarding the presence of learning or attention disorders, current grade point average, American College Test (ACT) score, prescription drug use, and tobacco/alcohol use were collected. Participants' were excluded from the study if they reported: any significant history of neurological disorder other than MHI, current or previous history of psychiatric diagnosis/treatment, current or previous diagnosis of ADHD or learning disability, or a head injury considered more severe than a MHI. Those who reported a MHI within 6 months of the study and those reporting significant symptoms ($\geq$ 70) on a standardized checklist of postconcussion complaints were excluded from study participation. MHI criteria was based on guideline set forth by the American Congress of Rehabilitation Medicine (1993).

Instruments

Neuropsychological Tests. Participants were administered four subtests from the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) which included two tasks comprising the Working Memory Index (e.g., Digit Span and Letter-Number Sequencing) and both subtests from the Processing Speed Index (e.g., Digit-Symbol Coding and Symbol Search). The Stroop Color-Word Test, Auditory Consonant Trigrams Test, Trailmaking Test, and d2 Test of Attention are tasks typically administered as part of a flexible battery approach to neuropsychological testing and assess attention and working memory abilities. Each measure to be administered is described below.

Digit Span (DS; Wechsler, 1997) is part of the WAIS-III Working Memory Index and is made up of two parts: digit span forward and digit span backward. DS forward requires the participant to repeat a series of numbers of increasing length immediately after being spoken by an examiner (Groth-Marnat, 2000). This task measures attention and immediate auditory recall and sequencing. DS backward requires similar cognitive demands as DS forward but includes an additional working memory component requiring the participant to recall the digits in reversed sequence. DS forward and backward scores are combined to provide a total combined score on this task despite evidence that these two tasks reflect slightly different cognitive operations (Lezak, 1995). Therefore, raw scores for DS forward and backward were analyzed separately, but both scores were also combined according to standard scoring procedures.

Letter-Number Sequencing (LNS; Wechsler, 1997) is another measure that compromises part of the Working Memory Index of the WAIS-III. Participants listen to a series of random numbers and letters and then recite the numbers in ascending order followed by the letters in alphabetical order. This task requires auditory attention skills, short-term memory, and the ability to organize/manipulate information for immediate recall (Groth-Marnat, 2000).

Digit-Symbol Coding (DSC; Wechsler, 1997) is one of the two tasks that comprise the Processing Speed Index of the WAIS-III. This is a timed paper and pencil test requiring rapidly transcribing symbols that have been paired with digits. It is one of the most sensitive measures of brain dysfunction due to the number of complex cognitive abilities required (Groth-Marnat, 2000). Sustained and focused attention, response speed, and visuomotor coordination play important roles in performing well on this task (Lezak, 1995).

Symbol Search (SS; Wechsler, 1997) is the other task that makes up the Processing Speed Index of the WAIS-III. This measure is a pencil and paper measure requiring the participant to scan multiple lines of symbols for the presence or absence of designated targets and to mark “yes” or “no.” This task taps abilities such as visuomotor coordination and speed, rapid decision-making, and sustained/selective attention (Groth-Marnat, 2000).

The Stroop Color-Word Test (Golden, 1978) measures selective and focused attention, response inhibition, susceptibility to distraction, and information processing speed. Three pages are placed in front of the participant with the first page containing columns of words, the second containing columns of colored X’s, and the third page containing columns of color words printed in different colored ink. Each of the three trials gives the individual 45 seconds to read the stimuli aloud as quickly as possible. The third trial typically provides the greatest cognitive interference and has been shown to be sensitive to a variety of neurological disorders (Groth-Marnat, 2000).

The Trailmaking Test parts A & B (TMT: A & B; Reitan, & Wolfson, 1993) tap into several functions including motor coordination, visual search, mental flexibility, processing speed, divided attention, and response inhibition. In part A, the participant is presented with a sheet of paper with a series of numbered circles and is required to connect them in correct order as quickly as possible. Part B consists of a series of circles that contain numbers in half the circles and letters in the other half of the circles. On this trial, the participant connects the circles as quickly as possible while alternating between the numbers and letters (Spreen & Strauss, 1998). This test is one of the most sensitive indicators of brain dysfunction (Reitan, & Wolfson).

The d2 Test of Attention (d2; Brickenkamp & Zillmer, 1998) is a letter cancellation task that requires participants to quickly cross out the letter ‘d’ surrounded by two dashes and at the same time ignoring distractor letters and dashes. This test measures selective/sustained visual attention, psychomotor processing speed, response inhibition, and has been shown to be sensitive to a variety of medical, psychiatric, environmental, and attention difficulties (Brickenkamp & Zillmer).

The Auditory Consonant Trigrams task (ACT; Spreen & Strauss, 1998) assesses divided attention, short-term/working memory, and information processing capacity. The participant is verbally given a three letter cluster (e.g., ABC) followed immediately by a three digit random number and asked to begin counting backward from the given number by three’s for a specified period of time. The participant is then required to recall the three letter cluster. There are three delay periods consisting of five trials each. This task has been shown to be sensitive to the effects of mild brain injury (Stuss, Stethem, Hugenholtz, & Richard, 1989).

The North American Adult Reading Test (NAART; Blair & Spreen, 1989) is frequently administered as a means of providing a general estimate of premorbid intellectual level. The NAART consists of 61 irregularly spelled words and participants are asked to read as many words as possible. An equation developed by Blair and Spreen (1989) provides a means of predicting WAIS-R Full Scale IQ scores.

<u>Distraction Procedure.</u> Participants randomly assigned to the distraction condition listened to distracting verbal stimuli while completing the attention/working memory tasks. The nature of the distraction stimuli were relatively consistent with the qualities of the task being completed and were presented via audiocassette through headphones. For example, a series of random numbers (1 though 9) were presented one at a time at an interval of two numbers per

second during the following tasks: TMT A and B, ACT, SS, DSC, DS, and LNS. In addition, during each trial of the Stroop task random words that matched the colors on the answer sheet were presented at the rate of about two colors per second. The distraction stimuli during the d2 test consisted of the words ‘d’, ‘p’, or ‘slash’ in a random sequence (one per second) and is consistent with the test stimuli and response choices/distractors. It was felt that using distraction stimuli relevant to the specific tasks would provide the greatest level of interference and result in increasing the cognitive demands of these tasks. The random numbers and the other distractor stimuli were presented at the time the participants are required to provide a response and not during stimulus presentation.

<u>Self-report Measures.</u> The Memory Complaints Inventory (MCI) is a self-report measure that includes a variety of both plausible and relatively rare memory complaints and has been used to distinguish between head injured patients and those suspected of exaggerating symptom complaints (Green, Allen, & Iverson, 1999).

The Postconcussion Syndrome Checklist (PCSCL; Gouvier, Cubic, Jones, Brantley, & Cutlip, 1992) is a self-report measure of current complaints commonly associated with symptoms after head injury. The scale allows participants to rate the frequency, intensity, and duration of symptoms and has been shown to be a reliable and valid measure of symptoms of the postconcussion syndrome.

Self-assessment measures allowed the participant to report their level of effort, nervousness, the stressfulness of the test procedures, and their estimated performance across all tasks. These self-assessment measures were based on a 1 to 10 Likert-type scale.

Procedure

A consent form was read and explained to participants and a brief explanation of the study and requirements for participation were provided. After signing and consenting to participate, a brief interview was completed which asked about general demographic information including history of head injury and a variety of other academic and general medical information. A brief measure to estimate intellectual level (NAART) and a self-report measure to assess for current postconcussion complaints (PCSCL) was then administered. Regardless of head injury status, participants were randomly assigned to either the standard or distraction condition. The standard condition included several working memory and attention tasks administered according to standardized testing procedures by trained examiners. The distraction condition included the same tasks administered in the same manner, but participants wore headphones and listened to the distraction tapes while completing the tasks. Tests were administered in random order with the first three tests (estimated to be the least demanding) always being the TMT, d2, and SS. Test order was randomized in order to minimize order effects as well as provide the participant a chance to become familiar with some of the elements of the general distraction procedure. Participants were asked to provide their best effort across all measures. After the tasks were completed, a self-report measure of memory complaints was administered along with the self-assessment measures. The participants were then debriefed about the nature of the study.

Data were scored and entered into a computer database. This procedure had been rigorously evaluated during a pilot study of this project in an effort to standardize administration, scoring, database management, and the distraction procedure. Raw data were analyzed and scores were adjusted using published normative databases and transformed into standardized scores based on age, education, and gender variables.

RESULTS AND DISCUSSION

Results

General demographic information of the four groups is presented in Table 1. There were no significant differences between groups on variables such as age, ACT score, GPA, and PCSCL score. Those in the distraction group had significantly higher levels of education, *F*(1, 104) = 5.53, *p* = .021 and the control group tested under distraction conditions had higher NAART IQ scores compared to controls tested under standard conditions, *t*(60) = 2.52, *p* = .015. There was a higher percentage of females in all groups, but these differences did not reach statistical significance in the MHI group tested under standard conditions $\chi^2(1, 25) = 1.00$, *p* = .317. More participants admitted regular alcohol consumption across all groups except for the MHI group tested under standard conditions $\chi^2(1, 25) = 1.96$, *p* = .162. Overall, more participants reported abstaining from cigarette smoking $\chi^2(1, 112) = 69.14$, *p* = .000. The ethnicity of the current pool of participants was primarily Caucasian as opposed to African American $\chi^2(1, 110) = 34.95$, *p* = .000, with less than 5% of the participants being identified as Indian, Asian, or Eastern European. Prescription drug use included medications for contraception (62%), allergies (20%), and acne (15%).

Table 1

Demographic Characteristics

		Testing Condition	
		Distraction (n = 57)	No Distraction (n = 55)
Age:	Controls	21.75 (SD = 4.07)	19.83 (SD = 1.39)

(Table 1 continued)

	MHI	21.84 (SD = 5.15)	22.36 (SD = 6.17)
Gender:	Controls	m = 5, f = 27	m = 3, f = 27
	MHI	m = 5, f = 20	m = 10, f = 15
Ethnicity:	Controls	C = 28, B = 4	C = 22, B = 8
	MHI	C = 14, B = 10, O = 1	C = 21, B = 2, O = 2
NAART IQ:	Controls	106.62 (SD = 5.81)	103.13 (SD = 5.06)
	MHI	104.48 (SD = 6.60)	106.40 (SD = 8.05)
Education (yrs.):	Controls	14.47 (SD = 1.10)	13.73 (SD = .94)
	MHI	14.32 (SD = .85)	14.24 (SD = 1.23)
GPA:	Controls	3.23 (SD = .54)	3.18 (SD = .48)
	MHI	2.93 (SD = .54)	3.14 (SD = .60)
ACT:	Controls	24.29 (SD = 3.12)	23.43 (SD = 3.40)
	MHI	23.87 (SD = 2.67)	25.35 (SD = 3.39)
PCSCL:	Controls	48.49 (SD = 9.42)	53.00 (SD = 8.40)
	MHI	50.96 (SD = 10.24)	50.60 (SD = 10.26)
Alcohol use:	Controls	69%	73%
	MHI	76%	64%
Tobacco use:	Controls	0%	1%
	MHI	20%	24%
Prescription Drugs:	Controls	50%	40%
	MHI	56%	32%

(Table 1 continued)

Note. NAART = North American Adult Reading Test. GPA = Grade Point Average. ACT = America College Test. PCSCL = Postconcussive Syndrome Checklist. C = Caucasian, B = Black, O = Other ethnicity. m = male, f = female.

Demographic Variables and Attention Tests

Pearson correlation coefficients (alpha set at .05 level, two-tailed) were used to assess the association between attention test performance and background variables such as age, educational level, grade point average, ACT score, NAART IQ, and PCSCL score. Age showed a significant negative correlation with d2 Concentration Performance (r = -.20), and educational level showed a significant negative correlation with TMT A (r = -.22) and TMT B (r = -.26). High school ACT score was associated with a variety of attention test measures including: TMT B (r = .19); ACT 9-second (r = .30), 18-second (r = .28) and 36-second (r = .21) delay trials; DS forward (r = .23), backward (r = .22), and DS scaled score (r = .28); and LNS (r = .30). Undergraduate GPA was positively associated with ACT 18-second delay (r = .19), Stroop Word (r = .21), and DSC (r = .21). NAART IQ was used as a general estimate of overall intellectual functioning and was found to be positively correlated with TMT B (r = .20), ACT 9 (r = .50), 18 (r = .53), and 36 (r = .43) second delay. The NAART was also positively associated with: Stroop Color (r = .21), Word (r = .22), and Color-Word (r = .22) trials; DSC (r = .25); DS forward (r = .44), DS backward (r = .23), and DS scaled score (r = .40); and LNS (r = .41). Self-report of postconcussive symptoms (PCSCL) showed no correlation with any attention measure; therefore, only age, educational level, GPA, ACT score, and NAART IQ were entered as covariates in future analyses of attention test performance.

The association between gender, ethnicity, alcohol and tobacco use, and attention test performance was assessed with independent samples *t*-tests. MHI females tested under distraction conditions performed significantly better than males on the ACT 18-second delay task, *t*(23) = 2.52, *p* = .019; however, there were significantly more females than males in that group (20 vs. 5 respectively) which could have been responsible for the large group differences. African Americas scored lower than Caucasians on the ACT 36-second delay, *t*(108) = 2.76, *p* = .007, and the Stroop color-word trial, *t*(108) = 3.21, *p* = .002. Across all groups, reporting of alcohol use was associated with significantly poorer performance on DS forward, *t*(111) = -2.90, *p* = .004, and DS scaled score, *t*(111) = -2.83, *p* = .006. Within the MHI and distraction group, alcohol users showed better performance on d2 Total Number, *t*(23) = 2.56, *p* = .017, and Stroop Color-Word trial, *t*(23) = 2.16, *p* = .041 compared to those not reporting alcohol use. Alcohol users in this same group (MHI and distraction) performed more poorly on the ACT 9-second delay, *t*(23) = -2.33, *p* = .029, 18-second delay *t*(23) = -2.98, *p* = .007, as well as DS forward, *t*(23) = -2.42, *p* = .024, and DS scaled score, *t*(23) = -2.28, *p* = .045 compared to non-drinkers. Mildly head injured alcohol users under standard testing conditions performed better on the Stroop Color trial, *t*(23) = 2.33, *p* = .029, compared to those reporting no regular alcohol intake. Controls in the standard test condition who reported alcohol use performed more poorly on DS forward, *t*(23) = -2.18, *p* = .038, DS backward, *t*(23) = -2.35, *p* = .026, and DS scaled score, *t*(23) = -2.96, *p* = .006. Due to the relatively small percentage of those reporting tobacco use (11%), no individual group differences were assessed; however, tobacco users in general performed more poorly compared to nonsmokers on TMT B *t*(111)= -2.75, *p* = .007. Because of the relative effects of gender, alcohol and tobacco use on attention performance, all three variables were added as covariates in future analyses.

Effects of Demographic Variables on Self-Report Measures

The relationship between age, education, GPA, ACT, and NAART IQ on self-report measures of postconcussive symptoms (PCSCL) was assessed using Pearson's two-tailed correlation analyses. Only GPA was significantly related to the total score on the PCSCL ($r = -.22$, $p < .05$). It was noteworthy that a significant relationship between GPA and PCSCL score was found despite the restricted range of possible scores on the PCSCL (< 70). Independent samples *t*-tests (two-tailed) were used to compare gender, ethnicity, alcohol, and tobacco use with PCSCL score. There were no significant differences between any of these variables and PCSCL total score.

The effects of demographic and background variables on reported memory complaints (MCI total score) was assessed with correlational analyses and two-tailed *t*-tests to determine what factors may have affected self-reports of memory problems after the testing session. Age ($r = -.21$, $p = .024$) and educational level ($r = -.26$, $p = .006$) were negatively associated with reported memory complaints while PCSCL score was positively associated with memory complaints ($r = .29$, $p = .002$). Alcohol or tobacco use and gender were not significantly related to MCI total score. Therefore, future analyses assessing group differences with the MCI will enter age, educational level, and PCSCL score as covariates.

Self-assessment measures administered at the completion of testing asked participants to rate their level of effort, nervousness, performance, and the stressfulness of the testing procedure. The relationship between demographic variables and self-report measures was assessed with correlational analyses and two-tailed *t*-tests. Age and NAART IQ were not associated with any self-reporting patterns. Educational level was positively associated with participants' perceived performance on the tests ($r = .23$, $p = .016$). Level of effort was positively associated with ACT score (*r* = .22, *p* = .022) and GPA (*r* = .20, *p* = .035). PCSCL was negatively related to perceived level of performance (*r* = -.27, *p* = .004) and positively related to the stressfulness of the procedure (*r* = .19, *p* = .044). There was no significant relationship between self-report measures and gender, ethnicity, or reported alcohol or tobacco use. From these analyses, covariates for future analysis of self-assessment ratings will include educational level, PCSCL, ACT score and GPA.

Characteristics of the Mild Head Injury Sample

Injury characteristics of the overall MHI sample are shown in Table 2. Eighty-four percent reported a single MHI, with those reporting 2 (8%) or 3 or more (8%) MHIs representing a minority of the current sample. The majority of participants reported a MHI occurring in the context of playing sports (68%). Falls (16%), automobile accidents (8%), assaults (2%), and other accidents (6%) accounted for the rest of the injuries. About a third of the participants in the MHI group reported a LOC that they were aware of (based on their own memories of the incident or others' reports at the scene) with approximately 88% reporting a LOC of 5 minutes or less. Despite the reported difficulties with obtaining PTA and the often unreliability of retrospective reports of PTA from patients (Gronwall & Wrightson, 1981), almost 75% of the current MHI sample reported a PTA of greater than 10 minutes but less than one hour. These figures for PTA should be interpreted with caution given the small number of participants that reported any length of PTA (11 out of 50 MHI participants). A majority of the MHI sample (96%) reported some combination of disorientation, headaches, and dizziness soon after the injury with 70% of the sample reporting symptoms lasting less than 30 minutes. A much smaller percentage (15%) reported symptoms lasting longer than 24 hours. Approximately half of the head injuries occurred more than 5 years ago with about one-third occurring 2 to 5 years ago.

Only about one-third of those reporting a MHI sought any type of medical care for their head injury.

Table 2

Head Injury Characteristics of Participant Sample

	Testing Condition	
	Distraction (n = 25)	No Distraction (n = 25)
Number Head Injuries		
One	88%	80%
Two	4%	12%
Three or More	8%	8%
Injury Type		
Sports Related	80%	56%
Falls	8%	24%
Motor Vehicle	8%	8%
Assault	4%	0%
Other Accident	0%	12%
Duration of LOC		
None	72%	64%
< 1 min	8%	20%
1 - 4 min	16%	12%
5 - 30 min	4%	4%

(Table 2 continued)

Duration of PTA		
None	76%	80%
< 1 min	0%	4%
1 - 10 min	4%	4%
11 - 29 min	16%	4%
30 - 60 min	4%	8%
Symptoms		
None	8%	0%
Disoriented	28%	52%
Dizziness	12%	20%
Headaches	20%	16%
Fatigue	4%	0%
Disoriented & Dizzy	12%	4%
Disoriented & Headaches	16%	8%
Symptom Duration		
< 5 min	31%	52%
6 - 29 min	26%	32%
30 - 59 min	4%	8%
60 min - 5 hrs	4%	0%
6 - 24 hrs	13%	8%
> 24 hrs	22%	8%
Time Since Injury		

(Table 2 continued)

6 - 12 mos	4%	20%
13 - 23 mos	4%	8%
2 - 5 yrs	38%	28%
> 5 yrs	54%	44%
Received Medical Treatment		
Yes	22%	40%
No	78%	60%

Note. LOC = Loss of Consciousness. PTA = Post traumatic Amnesia.

Effects of Distraction and MHI on Attention Performance

Group differences on the attention tests were assessed with a two-way MANCOVA (head injury x test condition). Results can be found in Table 3. Age, educational level, ACT score, GPA, and NAART IQ were entered as covariates for the analyses. The initial MANCOVA revealed a significant main effect of head injury status *F*(17, 81) = 1.80, *p* = .042. For TMT A, there was a significant main effect of test condition, *F*(1, 97) = 5.04, *p* = .027. In the distraction condition, participants were slower when completing TMT A (*M* = 49.21, *SD* = 8.7) compared to those in the standard testing condition (*M* = 53.36, *SD* = 9.5). Post-hoc pairwise comparisons with Bonferroni correction showed that participants with a history of MHI scored lower than controls when both were exposed to auditory distraction (*p* = .042). In addition, the MHI group in the distraction condition also performed more poorly than the controls tested under standard conditions (*p* = .024).

There was also a significant main effect of MHI for SS *F*(1, 97) = 4.21, *p* = .043 and for DS backwards, *F*(1, 97) = 6.60 *p* = .012. Contrary to expectations, on DS backward those with a history of mild head injury (*M* = 7.48, *SD* = 2.12) performed significantly better than the control group (*M* = 6.29, *SD* = 1.94, *p* < .05). Post-hoc pairwise comparisons with Bonferroni correction showed that the MHI group tested under standard conditions outperformed the controls tested under distraction conditions (*p* = .004). Similar to the results for DS backward, those in the MHI group (*M* = 12.46, *SD* = 2.46) outperformed those in the control group (*M* = 11.56, *SD* = 2.77, *p* < .05) on SS. Post-hoc group comparisons with Bonferroni correction found no significant differences between each of the four groups for this test.

Table 3

Attention Test Performance by Group and Test Administration Condition

	Test Condition	
	Distraction (n = 57)	No Distraction (n = 55)
Test Measures	Mean (SD)	Mean (SD)
TMT: A (t-score)		
Controls	51.36 (7.98)	53.69 (10.17)#
MHI	46.52 (8.75)*#	53.48 (8.75)*
TMT: B (t-score)		
Controls	57.55 (8.85)	56.62 (11.05)
MHI	58.08 (11.44)	57.52 (8.23)
d2: CP (t-score)		
Controls	47.82 (6.15)	49.10 (7.48)
MHI	48.24 (7.24)	49.12 (5.72)

(Table 3 continued)

d2: TN (t-score)		
Controls	44.15 (7.52)	43.62 (10.68)
MHI	43.84 (9.74)	44.40 (8.81)
d2: Errors (%)		
Controls	3.01 (2.57)	2.33 (1.72)
MHI	2.62 (2.32)	2.27 (1.92)
ACT: 9 sec (t-score)		
Controls	45.42 (9.42)	42.38 (13.15)
MHI	46.20 (12.87)	46.64 (12.49)
ACT: 18 sec (t-score)		
Controls	46.33 (11.65)	45.21 (7.55)
MHI	46.56 (10.26)	46.88 (11.65)
ACT: 36 sec (t-score)		
Controls	50.42 (7.40)	47.52 (10.18)
MHI	49.60 (11.83)	49.76 (12.55)
Stroop: Word (t-score)		
Controls	47.39 (7.58)	48.55 (11.31)
MHI	47.64 (13.29)	53.44 (9.54)
Stroop: Color (t-score)		
Controls	48.42 (12.01)	51.24 (14.46)
MHI	49.76 (13.68)	53.04 (10.40)
Stroop: Color-Word (t-score)		

(Table 3 continued)

Controls	54.58 (11.50)	55.07 (11.50)
MHI	54.00 (13.73)	56.56 (9.19)
Symbol Search (Scaled Score)		
Controls*	11.88 (3.03)	11.21 (2.40)
MHI*	12.44 (2.43)	12.48 (2.54)
Digit-Symbol Coding (Scaled Score)		
Controls	12.52 (2.82)	12.28 (2.00)
MHI	11.68 (2.34)	12.20 (2.14)
Digit Span: Forward (Raw score)		
Controls	11.45 (1.68)	11.76 (2.12)
MHI	11.24 (2.24)	11.76 (2.50)
Digit: Span: Backward (Raw score)		
Controls**	5.85 (1.86)*	6.79 (1.93)
MHI**	7.24 (2.24)	7.72 (2.01)*
Digit Span (Scaled Score)		
Controls	9.91 (1.99)	10.72 (2.31)
MHI	10.84 (2.93)	11.52 (2.74)
Letter-Number Sequencing (Scaled Score)		
Controls	9.79 (2.70)	10.41 (1.64)
MHI	10.12 (2.57)	10.52 (2.82)

Note. * = $p < .05$. ** = $p < .05$. # = $p < .03$.

Sixty-five percent (11 out of 17) of the test scores were in the expected direction with lower scores in the distraction condition (Table 4). Most of the differences between the distraction and the standard administration group were less than one *t*-score or raw score point (except for TMT A which was a 4 *t*-score point difference). It should also be noted that those in the distraction group showed absolute values reflecting better performance on TMT B, ACT 9, 18, and 36-second delay, and DSC, but these differences were not significant. Overall, the mean performance of all groups fell within the average range across all attention tests and reflect a population free of any cognitive deficits/limitations.

Table 4

Overall Attention Performance Based on Test Administration Condition

	Test Condition	
	Distraction (n = 57)	No Distraction (n = 55)
Test Measures	Mean (SD)	Mean (SD)
TMT A	t = 49.21 (8.66)*	t = 53.36 (9.54)*
TMT B	t = 58.07 (9.79)	t = 57.09 (10.31)
d2: CP	t = 48.04 (6.64)	t = 49.24 (6.67)
d2: TN	t = 44.12 (8.51)	t = 44.18 (9.80)
d2: Errors (%)	2.89 (2.44)	2.34 (1.80)
ACT: 9 sec	t = 45.68 (11.03)	t = 43.56 (14.06)
ACT: 18 sec	t = 46.46 (9.75)	t = 45.51 (10.14)
ACT: 36 sec	t = 49.96 (9.53)	t = 48.09 (11.70)

(Table 4 continued)

Stroop: Word	t = 47.70 (10.30)	t = 50.78 (10.62)
Stroop: Color	t = 49.19 (12.68)	t = 51.95 (12.58)
Stroop: Color-Word	t = 54.46 (12.47)	t = 55.76 (10.33)
Symbol Search	SS = 12.14 (2.80)*	SS = 11.82 (2.53)*
Digit-Symbol Coding	SS = 12.18 (2.65)	SS = 12.05 (2.55)
Digit Span: Forward (raw score)	11.40 (1.92)	11.67 (2.35)
Digit: Span: Backward (raw score)	6.47 (2.14)*	7.16 (2.04)*
Digit Span	SS = 10.35 (2.46)	SS = 11.00 (2.60)
Letter-Number Sequencing	SS = 9.96 (2.64)	SS = 10.45 (2.22)

Note. * $p < .05$. SS = Scaled Score. TMT A = Trailmaking Test part A. TMT B = Trailmaking Test part B. d2 = d2 Test of Attention. d2: TN = Total Number. d2: CP = Concentration Performance. d2: Errors = Percentage of Errors. ACT = Auditory Consonant Trigrams.

Effects of Distraction and MHI on Memory Complaints

After the completion of testing, memory complaints were assessed with the MCI using a two-way univariate ANCOVA (head injury x test condition) with age, educational level, and PCSCL score entered as covariates (see Table 5). There was no significant main effect of test condition, *F*(1, 105) = .05, *p* = .831, head injury status, *F*(1, 105) = 1.58, *p* = .212, or interaction, *F*(1, 105) = .18, *p* = .671.

Effects of Distraction and MHI on Self-Assessment Ratings

Participants rated themselves at the completion of testing on level of effort, perceived performance, level of nervousness, and stressfulness of the testing procedure on a 1 to 10 scale (see Table 6). The effects of MHI and test condition were analyzed with a two-way (head injury

Table 5

Memory Complaints by Group and Test Administration Condition

	Test Condition	
	Distraction (n = 57)	No Distraction (n = 55)
MCI (Total Score)	Mean (SD)	Mean (SD)
Controls	15.13 (7.58)	20.10 (12.06)
MHI	19.48 (9.03)	18.88 (15.00)
Total	17.04 (8.47)	19.55 (13.36)

Note. MCI = Memory Complaints Inventory.

x test condition) MANCOVA with GPA, ACT score, PCSCL, and educational level as covariates. The initial multivariate analysis revealed a significant main effect of test condition $F(4, 98) = 3.66$, $p = .008$. There was a significant main effect of test condition for level of effort, $F(1, 101) = 4.91$, $p = .029$, level of performance, $F(1, 101) = 4.35$, $p = .040$, level of nervousness, $F(1, 101) = 4.36$, $p = .039$, and level of stress $F(1, 101) = 4.98$, $p = .028$. There was no significant main effect of MHI or interaction between MHI and test condition. Those in the distraction condition reported higher levels of effort ($M = 8.61$, $SD = 1.02$) than those in the standard administration condition ($M = 8.08$, $SD = 1.72$). Post-hoc group comparisons with Bonferroni correction showed no significant between group differences for level of effort. Self-reported performance on the attention tests was lower in the distraction condition ($M = 5.52$, $SD = 1.40$) compared to those in the standard administration condition ($M = 5.75$, $SD = 1.36$). Post-hoc comparisons found no significant differences between individual groups. Self-reported nervousness during testing was significantly higher in those tested under conditions of distraction (*M* = 5.16, *SD* = 2.19) compared to those in the standard condition (*M* = 4.51, *SD* = 2.31). Follow-up analyses found no significant differences between individual groups. The stressfulness of the testing procedure was rated higher under distraction conditions (*M* = 4.73, *SD* = 2.51) compared to those tested under standard conditions (*M* = 3.79, *SD* = 2.65). Post-hoc group comparisons with Bonferroni correction showed that the MHI group tested under distraction conditions reported the testing procedure as generally more stressful (*M* = 5.16, *SD* = 2.64) compared to the MHI group tested in the standard condition (*M* = 2.80, *SD* = 2.18, *p* = .009). Also, the control group tested under distraction conditions rated the procedure as more stressful (*M* = 4.50, *SD* = 2.44) than the MHI group tested under standardized conditions (*M* = 2.80, *SD* = 2.18, *p* = .046). All of the current analyses were consistent with the hypothesis that the auditory distraction test conditions would be rated as subjectively more stressful compared to the standard testing condition.

Table 6

Self-Reported Assessment of Performance After Completion of Testing

	Test Condition	
	Distraction (n = 57)	No Distraction (n = 55)
Self-Report Ratings	Mean (SD)	Mean (SD)
Level of Effort:		
Controls	8.72 (1.11)	7.93 (1.87)
MHI	8.56 (0.82)	8.28 (1.46)

(Table 6 continued)

Total	8.61 (1.02)*	8.08 (1.72)*
Level of Performance:		
Controls	5.94 (1.13)	5.47 (1.22)
MHI	5.20 (1.56)	6.24 (1.51)
Total	5.52 (1.40)**	5.75 (1.36)**
Level of Nervousness:		
Controls	5.00 (2.36)	4.93 (2.50)
MHI	5.40 (2.18)	3.72 (2.05)
Total	5.16 (2.19)***	4.51 (2.31)***
Level of Stress:		
Controls	4.50 (2.44)[2]	4.47 (2.78)
MHI	5.16 (2.64)[1]	2.80 (2.18)[1,2]
Total	4.73 (2.51)****	3.79 (2.65)****

Note. *p = .025. **p = .040. ***p = .039. ****p = .038. [1] p = .009. [2] p = .046.

Discussion

The present investigation experimentally manipulated testing conditions in an effort to elicit differences in attention performance between those with and without a history of MHI. Measures of complex attention and working memory were administered using standard procedures or under conditions of auditory distraction. Auditory distraction was used to increase the attentional demands of the tasks and tease apart any effects head injury status may have had on performance. The attention tests were all commonly used neuropsychological measures that have been well validated in a variety of patient populations (Lezak, 1995). The purpose of using these measures was to provide the practicing clinician the most ecologically valid findings that could be used to inform clinical decision making. All participants (MHI and controls) tested under standard conditions were not expected to display any significant deficits and this would be consistent with a non-impaired college student population. It was hypothesized that those tested under distraction conditions would perform more poorly than those tested under standard testing conditions. Specifically, it was expected that those reporting a history of MHI would perform more poorly (under distraction conditions) than those without such a history. Finally, it was predicted that those with a history of MHI would report more general memory complaints after completion of testing and rate their level of distress higher than those without a history of head injury.

The overall effects of the distraction procedure were somewhat consistent with the expectation that participants, regardless of group status, would perform worse under auditory distraction conditions. However, the effect of this subjectively intrusive procedure was relatively small with only TMT A showing the expected drop in performance in the distraction condition. The distraction procedure did appear to increase the difficulty of some of the tests as evidenced by the fact that scores on 11 of 17 test measures were lower in the distraction condition. Consistent with expectations, all participants, regardless of group or test condition, scored within the average range. It is possible that the distraction condition did require more cognitive effort, but this may have elicited increased arousal/effort from participants and, thus, they became more motivated to perform well. The use of distraction stimuli that was consistent with test stimuli did not appear to be a sufficient stressor to impact test performance in a statistically significant way for most tests. Future studies may need to increase the distraction component across several modalities simultaneously (e.g., auditory, visual, tactile/pain) in order to increase the cognitive complexity of these tasks.

There were few significant differences across the attention and working memory tasks and this was not consistent with several studies observing poorer performances in asymptomatic adults with a history of MHI (Bernstein, 2002; Potter & Barrett, 1999; Segalowitz, Bernstein, & Lawson, 2001). Several studies have found differences on standard neuropsychological tests between MHI and controls as task difficulty increased (Ewing, McCarthy, Gronwall, & Wrightson, 1980; Hanna-Pladdy, Berry, Bennett, Phillips, & Gouvier, 2001; Hugenholtz, Stuss, Stethen, & Richards, 1988; Slobounov, Sebastianelli, & Simon, 2002). The current study did not expect to find significant differences between MHI and control participants under standard testing conditions, but there was an expectation that the auditory distraction procedure would provide a sufficiently greater cognitive challenge and result in a more divergent performance pattern. The reasons for finding few significant differences between groups may have been a function of the distraction procedure as well as the sample of MHI participants tested. The current sample was recruited from undergraduate psychology classes and was considered to be average to above average in academic and cognitive functioning. Furthermore, the current sample of MHI individuals were not included in the study if they reported significant cognitive complaints or psychiatric disorder/treatment. By restricting our sample to this relatively “clean” pool of subjects, much of the variance in scores may have been removed and individuals with more serious (and lasting) cognitive difficulties as a result of a MHI may have been excluded. Also, the sample of participants were not typical of the larger pool of MHI patients because there were significantly more females (75% of sample) represented. It is possible that there are gender differences in the rate and extent of recovery from MHI and that the current sample had recovered better than would be expected due to the high proportion of females. However, there is evidence that females typically report higher rates of postconcussive symptoms after head injury and may have poorer outcomes compared to males (Farace & Alves, 2000).

After being tested under standard or cognitively demanding test conditions, those with a history of MHI did not differ from controls in the severity of memory complaints. The subjective reporting of increased cognitive/memory complaints (not psychiatric) by those with a history of MHI was shown by McAllister et al. (1999, 2001) to be unrelated to actual performance on challenging cognitive tasks. They concluded that self-report of memory and attention problems in samples of MHI patients may be a result of the individual's increased effort required to produce normal neuropsychological testing results. This increased effort was postulated to be a function of the patients' inefficiency in recruiting the adequate cognitive resources needed for demanding mental tasks. Because those experiencing high levels of psychiatric symptoms (Treat, Poon, Fozard, & Popkin, 1978) or chronic pain complaints (Smith-Seemiller, Fow, Kant, & Franzen, 2003) with no history of head injury tend to report high levels of cognitive and memory complaints, individuals with high scores on the PCSCL were eliminated from the study. By doing this, the effect of any co-morbid psychiatric difficulties was eliminated as a possible confound of memory complaints after testing. Despite the restricted range in scores of individuals reporting PCS, there remained a significant positive correlation between pre-test PCSCL score and post-test MCI score. Future investigations should attempt to replicate the hypothesis of McAllister et al. (1999, 2001) that those with mild injuries report higher levels of subjective cognitive complaints independent of psychiatric complaints and neuropsychological test performance. In addition, a more comprehensive measure of cognitive complaints or general psychiatric (e.g., Beck Depression Inventory) or psychosocial difficulties (e.g., Personality

Assessment Inventory) may be more sensitive to subtle changes in cognitive difficulties and psychological complaints after those with a MHI are tested in a high-stress environment.

Self-report measures were administered after testing in order to gain a general understanding of the participants’ assessment of their performance. Specifically, it was important that the distraction procedure was perceived as more “stressful” than the standard administration condition by both groups in order to verify the aversiveness of this procedure. Results showed that controls and MHI participants in the distraction condition reported putting forth more effort than those tested under standard testing conditions. Also, the groups exposed to the auditory distraction stimuli reported that the testing conditions were more stressful and their level of nervousness was higher than those in the normal testing environment. The MHI sample did not report greater negative perceptions of their performance in the more stressful condition compared to controls, and were similar to controls in that they reported similar levels of nervousness, stress, and perceived effort. The group of MHI participants did appear to be especially vulnerable to the effects of increased cognitive stress because they reported higher levels of stress in the distraction condition compared to the MHI group tested under standard conditions. Previous investigations have hypothesized that some MHI patients may report higher levels of cognitive complaints (compared to controls) long after the injury despite normal neuropsychological test scores (McAllister et al., 1999, 2001). It was hypothesized that the higher rates of self-reported cognitive difficulties was due to the MHI patients becoming frustrated by their inability to cope with increased environmental demands as a result of their subtle decreases in cognitive efficiency (Van Zomeran & Van den Burg, 1985). The current study was somewhat consistent with this hypothesis because there were higher levels of perceived stress despite negligible differences in test performance. It is conceivable that the current study may have elicited subtle neurophysiological differences despite relatively normal test results in the MHI group, but neuroimaging was not available for the current study. Future investigations may benefit from the use of multiple methods of assessment (e.g., neuropsychological, neuroimaging, electrophysiological, biochemical) to tease apart the subtle differences in neurological processing that has been found in MHI patients.

One of the limitations of the current study was the relatively mild nature of the head injuries that the participants experienced. Approximately 88% of the sample reported a LOC of less than 5 minutes, roughly a third reported receiving medical care for their injuries (none developing any neurological complications), and about 80% reported that the injury occurred 2 or more years ago with many reporting symptoms lasting less than 30 minutes. Also, unlike previous samples of MHI patients, the majority of those in the current sample suffered injuries as a result of sports-related activities (68%) and not motor vehicle accidents (8%). Females were over-represented in the MHI group and this most likely affected the percentage of injuries occurring in a sports-related setting rather than due to automobile accidents where males are more likely to be injured. Another reason the injuries of the current MHI sample are relatively mild compared to previous samples is the fact that high velocity impacts as a result of body to body, or body to ground contact in sports is typically substantially lower than the velocities and accelerations experienced during the impact of a vehicle traveling at much higher rates of speed (Varney & Varney 1995). Therefore, it would be consistent that the current sample did not have very severe symptoms at the time of the injury and any symptoms typically abated within a few minutes. It is also possible that differences between the MHI group and controls was washed out by the mild nature of the injuries, the lack of a sufficiently challenging series of attention tasks, and the fact that those currently reporting any significant cognitive, affective, or physical symptoms (who may have had actual post-concussive symptoms from the injury) were not the focus of the current investigation.

In summary, the current study failed to find strong evidence of any significant differences in performance between MHI and control participants across a wide array of common neuropsychological tests typically used to assess attention and working memory abilities. Under conditions of auditory distraction, MHI participants did not show the expected decreases in test performance (except on TMT A). All participants reported higher levels of nervousness and greater levels of effort expended when subjected to the auditory distraction test condition. Those with a history of MHI exposed to auditory distraction reported higher levels of subjective distress compared to the MHI group tested under standardized conditions. Asymptomatic college students with a history of MHI several years earlier performed within the average range on highly demanding attention tasks under distraction conditions, and their performance showed minimal differences compared to a control group of college students with no history of head injury.

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