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EXECUTIVE FUNCTIONING AND METACOGNITIVE MONITORING IN MODERATE TO SEVERE TRAUMATIC BRAIN INJURY

A Thesis in

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Abstract

Metacognition and executive functioning are two higher order cognitive processes that share similarly structured theoretical models, as well as common areas of associated neural networks. Despite the similarities, little research has been done to investigate the potential relationship between these two congruent processes. This current study aims to empirically and objectively examine the relationship between executive functioning and metacognition using a sample of adults with moderate to severe traumatic brain injury. Participants were recruited to complete a neuropsychological battery that included tests of both metacognition and executive functioning that would provide the data necessary to determine the nature of the relationship between the processes. Results suggest that the participants in the traumatic brain injury sample performed as well as healthy individuals on tasks of metacognition, and that performance on executive functioning tasks that involve a problem solving component were associated with metacognitive ability.

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Introduction

A potentially unique feature of human cognition is the ability to reflect upon one's own knowledge and experiences. Psychologists as early as William James have observed such subjective, introspective capabilities and, in the following 120 years, psychological theory and complementary experimental tasks have been developed to describe the phenomenon of introspection. Examination of self-reflective processes later led to hypotheses regarding the neural substrates responsible for these "higher order" cognitive processes, as examiners speculate that the frontal lobes play a significant role in introspective processes (Budson et al. 2005; Jarman and Varvarik 2005). Interestingly, the frontal lobes have also been identified as areas related to executive functioning, another system that governs cognitive processes. Due to the regulatory nature of both systems, some researchers (Fernandez-Duque, Baird and Posner 2000; Shimamura 2000) have drawn a parallel between executive functioning and processes of self-reflection. The hypothesis of a relationship between executive functioning and self-reflective processes is further supported by studies of populations characterized by deficits in executive functioning also demonstrating corresponding deficits in introspective processes (Hanten, Bartha & Levin, 2000; Schneyer, et al., 2004). Future findings regarding the relationship between executive function and processes of self-reflection will not only aid in the understanding of human cognition, but may have implications for clinical populations where insight and introspection are lost. The goal of this thesis is to examine the relationship between performance on executive functioning tasks and metacognitive ability in a sample of adults who have sustained moderate to severe traumatic brain injury.

Defining Awareness and Metacognition

One difficulty in studying the nature of cognitive introspection lies within the ambiguity of its definition. Commonly, the words insight, self-consciousness, and self-awareness have been used interchangeably to describe the process of cognitive reflection. Although these words all encompass a theme of self-reflection, each has an idiosyncratic definition based upon author and context. For example, two independent authors may use the term "impaired self-awareness," but one may refer to an individual's obliviousness in regards to cognitive deficits in one case, and the other to one's non-compliance to treatment. Baier, Murray, and McSweeney's (1998) review of psychiatric literature resulted in at least ten varying definitions of insight, as well differing methods of measurement. In addition to the lack of a universal definition, these words are often used interchangeably despite their differences in meaning; the absence of standardized terminology complicates attempts to communicate, summarize and compare findings across the literature.

In order to efficiently convey ideas that pertain specifically to the self reflection of cognition (as opposed to reflection of motor abilities, compliance in treatment, or unawareness of illness), the literature today widely accepts and uses the term “metacognition.” First coined by Flavell (1979), this term has become generally accepted to mean the ability to have cognitions about cognitions. Broadly, it is the ability to have beliefs and interpretations regarding one’s own perceptions, memories, decisions and actions. The term metacognition, and importantly its universal definition, has been consistently used in, but not limited to, the areas of social, developmental, and cognitive psychology.

Due to the fact that is it possible to have different cognitions to reflect upon, metacognition can be divided further into categories; for example, the metamemory refers to thoughts regarding one’s own memory, while metacomprehension refers to thought’s regarding one’s ability for comprehension. Other categories that fall under the term metacognition include the metacognition of olfaction, which is the ability to name odors (Jonsson and Olsson, 2003), and metacognitive control of action (Augustyn and Rosenbaum, 2005). Although these different categories have been examined independently, no study to date has investigated their relation to each other. Further, no study to date has examined the concept of meta-mental flexibility, identified as the ability of reflection regarding one’s cognitive flexibility in problem solving. The proposed study intends to use the term metacognition in reference to the ability to interpret multiple types of cognitions, metamemory to indicate one’s interpretations of memory, and meta-mental flexibility as one’s interpretation of cognitive flexibility in problem solving skills.

An Introduction to Metacognitive Theory

Although Flavell was credited with being the earliest to investigate metacognition from a psychological perspective, later psychologists contributed to the development of metacognition and the theory of its underpinnings as they are understood today. Flavell’s (1979) earliest model proposed that metacognition is composed of four parts: metacognitive knowledge, metacognitive experience, goals and action. In his conceptualization, metacognitive knowledge refers to knowledge an individual has of which different factors may influence cognitive undertakings, as well as how the factors are influential. On the other hand, cognitive and affective experiences that accompany cognitive endeavors are known as metacognitive experiences. Goals and actions refer respectively to the objectives of cognitive enterprises and the behaviors acted upon to achieve them.

Following the introduction of Flavell's definition of metacognition, alternative theoretical models developed and one well established model was posed by Nelson and Narens (1990). In this model, metacognition is comprised of two levels: the object level and the meta-level. Based upon this model, the object level contains basic, primary cognitions, while the meta-level serves as a governing mechanism of the object level. According to Nelson and Narens, the meta-level contains knowledge of goals and ways to achieve the goal; and thus operates accordingly. In order to illustrate the two distinct levels, Nelson (1996) provides this common example in which a reader is asked to evaluate the truth value of the following sentence: "Thiss sentence contains threee errors." The reader will notice two errors at the object level: the explicitly incorrect spelling of "this" and "three." At the meta-level, the reader will notice the error that the structure of the sentence contains only two errors and not three. Furthermore, Nelson and Narens (1990) propose that information processed through these levels of metacognition is fluid. Information must be able to pass from the object level to the meta-level, and back down to the object level. This communication between levels occurs in two ways: 1) the meta-level becomes aware of the object level through monitoring processes, 2) the meta-level then utilizes control processes to influence actions that will affect the object level.

Empirically Measuring Metacognition

The model proposed by Nelson and Naren (1990) offers testable hypotheses for studying metacognition. The crux of their theory rests on the separateness of two operating levels and the processes between their interactions; thus the validity of their model is based upon the identification of a manner in which these processes can be empirically and systemically measured. Several measurements, including feeling of knowing, ease of learning, judgment of learning, and confidence judgments, have been developed and used for examining the monitoring processes, while duration of study time has been used in measuring the control processes of metacognition.

One method for examining metacognition has been to decompose the theoretical construct of "monitoring" into identifiable and testable components. For example, the monitoring processes of metacognition have been divided into retrospective and prospective monitoring. The former refers to judgments made regarding a previous response to a stimulus, while the latter refers to judgments made in the moment with regards to future responses. A retrospective confidence judgment (RCJ) is the most common example of retrospective monitoring, where one must decide the certainty of a decision made in the past. There are three measurements of prospective monitoring: 1) ease of learning (EOL) judgments; 2) judgments of learning (JOL); and 3) feeling of knowing (FOK) judgments.

EOLs are predictions made before one attempts to learn something; they are judgments made by the individual regarding the ease of learning the subject matter. In contrast, JOLs are obtained either during or after the process of content acquisition or learning, and refer to predictions about future test performance on items recently studied; in other words, JOLs measure how well individuals feel they have learned the content. Traditionally, studies examining JOLs have consisted of a sequence in which the participant studies given material, is asked to make a JOL, and then is tested using a free recall format of the previously learned material. Recently, Nelson, Narens and Dunlosky (2004) proposed that an additional step be added to this sequence in order to more accurately analyze measurements of JOL. They suggested that immediately following the study stage, the participant should be asked to make a pre-JOL recall response. By testing the participants before they make their JOL, researchers have a better idea if the material was accurately learned during the acquisition trial thus allowing for an accurate analysis of the JOL.

FOK judgments occur during or after acquisition tasks of recall and recognition. These tasks usually require the subject to learn a list of word pairings. The subject is then asked to recall these pairings. On items that the subject is not able to recall the words, they are asked to make a judgment of how likely they would be able to recognize the answer. This judgment refers to the FOK judgment. Hart (1965) pioneered the empirical study of monitoring processes by examining FOK judgments using a "recall-judgment-recognition" paradigm. In his study, he asked participants to first attempt to generate answers to fifty general information questions. The participants then made judgments regarding their FOK—how likely they would be able to recognize answers to the test they had just taken. Finally, the accuracy of their judgments was measured by a recognition test in which participants were required to circle the correct answer among five choices. Hart found that participants' accurate judgments corresponded to the better performance on the recognition task. This match of judgment and performance suggests that FOK judgment is an accurate indicator of monitoring. These findings of accuracy in FOK judgments were replicated and expanded upon by comparing them against studies using normalized stimuli (Nelson, Leonesio, Landwehr & Narens, 1986).

Metacognitive control processes thus far in the literature have been studied in the context of learning tasks. These tasks usually engage the participant in deciding upon a goal, engaging in the goal-driven activity, and then comparing their current performance to their goal (Nelson 1996). Commonly used is Miller, Galanter & Pribram's (1960) test-operate-test-exit (TOTE) model of mental processes; tasks using this model are designed for the participant to monitor their current performance, make a comparison between it and a desired goal state, and finally initiate control processes in order to aid in reaching the goal state. From studies utilizing the TOTE model, examiners have identified allocation of study time and termination of study time as components of the control process of metacognition. These studies generally involve testing the participant on various subject matter, asking for a JOL measurement, giving them a chance to study the tested material, and a final re-test. The length of time devoted to studying is seen as a control process because it is implied that a manipulation of time devoted to studying will influence outcome, or desired performance. Not surprisingly, Nelson and Leonesio (1988) found that participants allocated more study time to items that were judged as more difficult according to EOL and FOK measurements. However, it appears that these increases in self paced study time did not improve performance. Findings by Son and Metcalfe (2000) suggest other variables, such as length of study material, may affect allocation of study time. Further, it has been suggested that the strength of intentions to achieve a goal may also be another variable that influences control processes (Gollwitzer and Schaal 1998). These finding suggest that while metacognitive processes are complex and yet to be fully understood, components of both metacognitive monitoring and control can be independently manipulated and tested.

Neural Anatomical Correlates of Metacognition

The neural anatomical correlates of metacognition are speculated to be primarily localized in the frontal lobes. In a study directly examining FOK accuracy, Schneyer et al. (2004) found that participants with frontal lobe damage demonstrated significantly less accurate FOK judgments. Budson, et al. (2005) also found localization of metacognitive processes in the frontal lobe in work examining the false recognition rates. Budson et al. (2005) describe the ability to distinguish between experiences that did or did not occur (a false recognition) as the "distinctiveness heuristic." This distinctiveness heuristic is further believed to depend on metacognitive processes. In their study, participants were initially presented with target stimuli, and after a delay, were asked if the shown response stimuli were the same as the targets. Participants with frontal lobe lesions were more likely to make false recognition errors in which they claim to recognize a response stimulus that was not initially shown to them as a target. It is hypothesized that the frontal lobe lesions affected metacognitive processes, which in turn impaired functioning of the distinctiveness heuristic. The findings indirectly suggest that insult to the frontal lobe may influence metacognitive functioning.

From a developmental perspective, the development of complex psychological processes appears to correspond with frontal lobe development (Anderson, Levin, and Jacobs, 2002). It has also been noted that both more refined brain structures and complex psychological abilities develop in tandem to each other. In cortical development, the process of structural maturation is hierarchical with tertiary associations in the frontal lobe developing last (Klingberg, Vaidya, Gabrieli, Moseley and Hededus, 1999). In parallel, complex psychological processes that involve monitoring and manipulation also develop later than more basic mental processes (Stuss and Anderson 2004). These findings are confirmed by the studies of pediatric brain injury; depending upon the developmental stage at which frontal injury occurs, different aspects of metacognitive functioning are affected (Stuss and Anderson 2004). The observation of similarities in developmental patterns of cortical structures and corresponding psychological function suggest a relationship between metacognitive processes and the frontal lobes.

A Parallel Supervisory System-Executive Function

Models and Theory

Metacognition is not the only supervisory system in the brain that regulates cognitive and affective functioning. Executive functions are a group of well researched cognitive abilities also thought to manage and direct more simple cognitions. Early studies in working memory helped to formulate Baddeley's (1986) framework of the central executive system which today serves as a comparative model for executive functioning. Baddeley's model is based upon three components: two "slave" systems: the phonological loop and the visuospatial sketchpad, and one executive system. The phonological loop and visuospatial sketchpad are responsible for maintaining speech based information and visual spatial information, respectively. The executive system is then responsible for the regulation of cognitive processes. The Supervisory Attentional System (SAS), proposed by Norman and Shallice (1986), further organizes the regulation of cognitions. According to the Norman and Shallice (1986), schemas (a unit of thought), can be influenced directly by environmental (perceptual) cues or regulated by an executive system. This executive system monitors schemas, and based upon the individual's intentions or goals, provides feedback that will manipulate the schema to better achieve the goal. Interestingly, this model is quite similar to the metacognitive model proposed by Nelson and Narens (1990). Both models seem to operate on two levels: a lower level that is comprised of the most basic cognitions, and a higher order level which plays a supervisory role in regulating the basic processes. Due to the similarity of a regulatory nature found in both theoretical models, it has been suggested that the two systems are related (Fernandez-Duque, Baird and Posner, 2001; Shimamura, 2000).

Components

Executive functions are recognized as higher-order mental processes of the brain. These processes are responsible for more complex tasks such as goal directed behavior, organization, and problem-solving. Historically, there has been debate surrounding the components that comprise this construct. Some believe in a unitary measure that underlies the ability to carry out such tasks (Kimberg and Farah, 1993), while others believe in a conglomeration of diverse components that together define executive function (Miyake, et al. 2000; Stuss and Alexander, 2000). Proponents of the diversity hypothesis suggest that executive functions require the abilities to select/inhibit, maintain and update, and set shift (Miyake et al., 2000; Shimamura, 2000). Selection/inhibition refers to the ability to select and attend to pertinent stimuli, and being able to inhibit other distracting stimuli. A hallmark test of inhibition that is often used by neuropsychologists is the Stroop color word task (Stroop, 1935); the individual is given a list of color words that are printed in different colors, on a given trial, they are asked to attend to one aspect of the stimulus (e.g. read the printed word) forcing them to inhibit the other aspect (e.g. ignore the color that the word is printed in). In order to update, one must be able to not only hold information "online," but also be able to manipulate the information; for example, solving a math problem mentally requires one to not only maintain the numbers "online," but perform some sort of function with them. Lastly, set shifting is being able to flexibly change between certain sets of rules; for instance, an elementary school student would need to know how to change between following classroom rules (being quiet, using indoor voices, raising a hand to speak) to playing behavior outside during recess (rough and tumble play is allowed, use of outdoor voices, not being restricted to when s/he can speak).

Using structural equation modeling techniques of these identified components, it has been found that performance on these individual components is independent (Miyake et al., 2000). This means that doing well on one measure does not predict performance on another; for example, being able to selectively attend to certain stimuli does not mean one will be able to effectively manipulate the information. The low intercorrelations between different measures of executive functioning suggest that they indeed can be separated and thus executive functioning is not unitary in nature; rather, executive functioning exists as several individual components working collectively to execute higher order processes.

Associated Neural Networks

The frontal lobes have been found to be integral to executive functioning (Collette, Hogge, Salmon & Van Der Linden, 2006). Findings from studies utilizing tasks that test the common executive functioning components of selection/inhibition, information updating, and set shifting have suggested a common association with the frontal lobes (Collette et al., 2006). Using high density event related potentials (ERP), a study showed that performance of the Stroop task (the color word test that requires skills of inhibition that was discussed earlier) activated the left prefrontal cortex and anterior cingulate gyrus in healthy subjects (Markela-Larenc et al., 2004). When examined using functional magnetic resonance imaging (fMRI) techniques, findings of activation in the left prefrontal cortex and anterior cingulate during the Stroop task were supported (Chen, Wei & Zhou, 2006).

In studying the process of updating information, Sauseng, Klimesch, Schabus & Doppelmayr (2005) manipulated a task of visual working memory. Participants in the study were first exposed to a set of abstract patterns; in a task of only maintenance, the participants were asked to mentally imagine the pattern, in the task of updating the information, the participants were asked to manipulate the pattern. Measuring neural activity using electroencephalography (EEG), the findings suggested involvement of the prefrontal area while participants completed the manipulation task.

Finally, the frontal cortices have also been thought to play a critical role in tasks requiring "set switching" or the ability to switch attention between two or more sets of stimuli (e.g. when preparing a meal, being able to go from chopping up vegetables, to stirring the pot of soup on the stove, back to the chopping of vegetables). Wylie, Javitt, & Foxe (2003) designed a study in which participants were exposed to a string of colored letters (including both vowels and consonants) and numbers (including both even and odd). These stimuli were presented in either red or purple ink. In order to create "sets" of rules, when the stimuli were red, the participants were asked to pay attention only to the letters, and when the stimuli were purple, they were to pay attention to the numbers. The participants were to make a response only when they noticed a vowel or an even number. ERP findings indicate that the frontal cortices were involved in the set-shifting task.

Current Evidence for the Link Between Metacognition and Executive Function

Attempts to study the relationship between metacognition and executive function have been made using participants from diverse populations including the elderly, mountain climbers, and those with neurodegenerative diseases. Studies in the geriatric literature have directly examined the correlation between metacognition and executive function. A study of FOK, JOL, and executive functioning in elderly persons found that FOK predictions were correlated with executive functioning (Souchay, Isingrini, Clarys, Taconnat, and Eustache, 2004). FOK decline in old age was confirmed to be mediated by executive function in studies of memory recall and recognition (Perrotin, Isingrini, Souchay, Clarys, and Taconnat, 2006). Investigations of control processes, specifically allocation of study time, have also been found to be correlated with tests of executive function (Souchay and Isirgrini, 2004).

Studies in various neurological disorders have also been conducted; however, a comprehensive review by Pannu and Kaszniak (2005) reveals the results of investigations of metacognition and cognitive skills in multiple sclerosis, Alzheimer's disease, Parkinson's disease and Huntington's disease to be inconsistent. While most patients in these groups demonstrated declines in cognitive function, they were not always accompanied by deficits in metacognition. These inconsistencies in the literature should be addressed in future studies by considering the interpretation of results when comparing one type of monitoring process to a control process (instead of another monitoring process), as well as differences in task loads across studies.

While the aforementioned studies have tested metacognitive accuracy and neuropsychological functioning based upon comparisons of healthy controls and populations in which disease is not specifically localized in the brain, other studies (to be discussed shortly) have capitalized on testing populations that undergo natural or imposed changes particularly in the frontal lobes. Differences that arise in measures of metacognition and executive function in these populations can then be concluded to have arisen from deficits of the frontal lobe, confirming its role as the neural network for both systems. These findings of a commonly affected physiological feature are of great importance because they provide a hypothesis of a common neural substrate for the each of these processes. Furthermore, there is an extensive neuropsychological literature examining the role of the frontal networks in executive functioning. If these processes share a structural component, one may question if metacognition and executive functioning are related in such a way that damage in the frontal lobes causing executive dysfunction may also lead to metacognitive deficits.

Korsakoff's syndrome is a condition that causes global deficits, including processes associated with the frontal lobes. The syndrome is caused by thiamine deficiency and symptoms of the disorder are often related to loss of memory and poor insight. In comparing Korsakoff's patients with those with Alzheimers, it was found that despite affected memory in both conditions, only those with Korsakoff's had difficulty making judgments regarding their memory (Shimamrua and Squire, 1986). The authors suggest that the pathology of Korsakoff's causes more widespread impairment, including those of monitoring and control tasks located in the frontal lobes, compared to the impairment seen in Alzheimers.

Frontotemporal dementia (FTD) is a unique neurodegenerative disease in which Pick's bodies are present, and there is a mutation on chromosome 17. The primary origin of this pathophysiology is in the frontal lobes. Due to the insult imposed on the frontal lobes, patients with FTD often experience executive dysfunction. Using the modified Brock Adaptive Functioning Inventory, Apathy Evaluation Scale, and Interpersonal Reliability Index, Eslinger et al. (2005) found that FTD patients with profound executive impairments tended to overestimate their own abilities in emotional, social and cognitive domains. This evidence supports the notion that executive functioning and metacognition are related, however, it should be noted that the tests used in this study were based on self-reports of daily activities of functioning, and not direct measures of metacognitive processes in the moment.

Disease and injury are not the only ways in which changes in the frontal lobe can occur. A review of studies based upon populations of mountain climbers concluded that evidence exists for performance changes in frontal lobe functions at high altitudes (Virués-Ortega, Buela-Casal, Garrido, and Alcázar, 2004). Specifically, FOK judgments were affected when climbers were tested at high altitudes (Nelson et al. 1990); frontal lobe deficits, such as cognitive inflexibility were also found in climbers (Regard, Oelz, Brugger, and Landis, 1989).

The previously mentioned studies were all conducted using different populations; however, a common thread between these populations was a deficit in executive functioning that was characteristic to each condition, disorder, syndrome, or disease. Finding deficits in metacognition in groups that have impaired executive functioning supports the hypothesis that a relationship may exist between the two processes; as executive functioning declines, so should metacognitive abilities. Individuals with traumatic brain injury (TBI) are highly susceptible to frontal lobe damage and often experience impairments in executive functioning. The characteristic damage to the frontal lobes and consequential executive dysfunction makes this population of particular interest in the proposed study.

Traumatic Brain Injury

Demographics

TBI is a significant concern of health care and policy as 1.5 million Americans sustain TBI yearly, and 5.3 million live with resulting disabilities (CDC, 2006). The hospitalization and lifetime costs of those who sustain TBI have increased substantially from $37.8 million in 1985, to $56.3 billion in 2001 (CDC, 2006). The age distribution of those who sustain TBI is bimodal with peaks in the 15-24 and 65-75 age brackets, further, the number of males sustaining injury outnumber females by a ratio of 2:1 (Whyte and Rosenthal, 1993). Surveys show that about half of these injuries occur from transportation causes (e.g. motor vehicle accidents), and others are accounted for by falls, firearms, and assaults, among others (Whyte and Rosenthal, 1993; CDC, 2006). Alcoholic intake has been the most commonly studied risk factor related to TBI and more recent studies are now examining pre-injury personality disturbances, family discord and antisocial behavior (Whyte and Rosenthal 1993).

Injury Severity and Outcome

Clinical severity of TBI is categorized as mild, moderate, and severe with corresponding implications for symptomology and recovery. Injury severity is commonly measured by three variables: a Glasgow Coma Scale (GCS) rating, the duration of coma (defined by the ability to open eyes, obey commands, and speak comprehensible words), and duration of post-traumatic amnesia (PTA) (Whyte and Rosenthal 1993). A coma that lasts six hours or more is commonly regarded as severe injury (Whyte and Rosenthal 1993). The Glasgow Coma Scale is a tool used to evaluate three components of wakefulness: eye opening (E), best motor response (M), and best verbal response (V). These components are measured independently, and scores from each are added together to yield a composite score (EMV). These EMV scores can range from a minimum of 3 to a maximum of 15. Based upon this scale, scores of 8 or less constitute severe injury, scores 9-12 suggest moderate injury, and scores 13 or greater are considered mild (Teasdale and Jennett, 1974). The other measurement used in determining severity, PTA, was termed by Russell and Nathan (1946) as a phase of confusion and amnesia that occurs immediately after the injury in which the patient is unable to remember ongoing events. The duration of PTA is measured from the time of injury until memory capabilities are regained. The Galveston Orientation and Amnesia Test is a scale that was developed by Levin, O'Donnell and Grossman (1979) to better quantitatively describe PTA. This test is based on a maximum score of 100 points, with 76-100 indicative of nearly recovered orientation, 66-75 borderline, and 65 as below as impaired.

Injury severity is not only an important descriptor, but it is also a predictor of patient outcome. Measurements of injury severity such as the GCS rating and PTA duration have been used to predict outcome; scores of 8 or lower on the GCS and over 14 days of PTA are usually indicative of poor outcome and/or greater likelihood of disability (Whyte and Rosenthal 1993; Levin, Benton and Grossman 1982). Furthermore, PTA that endures for more than 7 days may triple the chance for moderate to severe disability (Jennett, 1976). Other factors that may predict outcome include: multimodal evoked potential measurements, pupil reactivity, presence of oculovestibular responses, creatine kinase levels, hyperglycemia, decreased thyroid hormone levels, preinjury medical and psychological factors, and preinjury substance abuse (Whyte and Rosenthal 1993). The prognosis of outcome determined by PTA has important implications for rehabilitation as it often predicts neuropsychological functioning, employment status, and/or alterations in personality (Prigatano, et al., 1986). Recovery rates from TBI may vary significantly depending on the individual; Millis et al. (2001) measured cognitive functioning between one and five years post injury and found that performance varied across individuals. Studies do show that injury severity may contribute to the time it takes to recover; cognitive functions such as processing speed, constructive abilities, and verbal memory were found to be better recovered for those who had suffered mild to moderate injury versus severe injury when measured six to twelve months post injury (Novack, Alderson, Bush, Meythaler & Canupp, 2000). Schretlen and Shapiro (2003) found similar findings regarding recovery and injury severity. In their study of mild and moderate brain injury, not only did the moderately injured group perform three times worse than the mild group on tests of cognitive function, but the slope of recovery looked different as well. The study showed that recovery occurred most rapidly during the first week post injury and performance returned to baseline by one to three months later in mild TBI. Those with moderate TBI showed the majority of recovery during the first two year post injury, and little improvement was made thereafter. The rate of recovery also differs by domain; dysfunction in physical abilities, speech and language usually improve quicker, while it may take 6 months for verbal abilities to recover, and 12 months for perceptual motor abilities to rebound (Whyte and Rosenthal 1993).

Mechanics

There are two primary mechanisms resulting in TBI. Injuries can be identified as penetrating (missile) injuries, or non-penetrating (non-missile, closed head) injuries depending on the presence of a laceration of the scalp and skull (Whyte and Rosenthal 2003; Levin, Benton and Grossman 1982). Penetrating injuries suggest that there are lacerations on the scalp and in the skull, and most probably penetration of brain tissue caused either by skull fragments or a foreign object. Non-penetrating injuries, on the other hand, are usually caused by acceleration and deceleration forces, or direct strikes against the head. In an accelerative force, the injury is caused when the head is hit by an object gaining momentum (e.g. a baseball bat striking the head); conversely, in a decelerative force, the injury is caused when the head is in motion and hits a stationary object (e.g. head striking against windshield). Although non-penetrating injuries imply that a foreign object does not permeate the scalp and skull, it is possible that bone fragments from the skull penetrate the brain tissue as a result of the accelerative/decelerative blow (Levin, Benton, and Grossman 1982).

Injuries that occur immediately upon impact are referred to as primary injuries (Whyte and Rosenthal 2003; Levin, Benton and Grossman 1982). Primary injuries can include diffuse axonal injury (DAI), cerebral contusions, and blood clots within the skull, also known as intracranial hematomas (Levin, Benton and Grossman 1982). Diffuse axonal injuries refer to damage to cerebral white matter; the shearing of nerve fibers occurs from acceleration/deceleration and rotational forces and thus is a common contributor to closed head injuries. DAI can be found dispersed throughout the brain, however, is most likely to occur in the connecting fibers of the frontal and temporal lobes (Holbourn, 1943), pons, and corpus callosum (Whyte and Rosenthal, 2003; Levin, Benton and Grossman. 1982). Cerebral contusions are described as cortical bruises that result from coup and contrecoups (instances in which the brain bumps against the skull). A coup injury occurs when the brain hits against the skull and injury is at the site where contact was made. Due to the intercranial space between the skull and the brain, the brain has space to move; a contrecoup injury occurs when impact is made with the skull, but the brain moves about and injury occurs as it hits a different part of the skull. For example, an individual may have a fall in which the back of his skull makes contact with a hard surface, but suffer from a contrecoup injury as a result of the brain bouncing and hitting up against the front of the skull. Contusions tend to be more focal than DAI and can be found primarily on the undersurface of the frontal and temporal lobes (Whyte and Rosenthal 2003). Other focal lesions that can occur in the brain as a result of torn blood vessels include: extradural hematomas, subdural hematomas, subdural hygroma (cerebrospinal fluid in between the dura and arachnoid layer), intracerebral hematoma, traumatic subarachnoic and intraventicular hemorrhage, hypothalamic-pituitary lesions, and injuries to specific cranial nerves (Levin, Benton, and Grossman, 1982).

Secondary injuries are additional injuries that may occur following the initial injury. These can include additional intracranial hematomas, edema in white matter (swelling due to excess water in brain tissue), diffuse brain swelling, ischemic brain damage (resulting from ischemic hypoxia—insufficient cerebral blood flow), raised intracranial pressure, and brain shift and herniation (Levin, Benton and Grossman 1982). It is usually a combination of primary and secondary injuries that causes the heterogeneity in TBI populations (Levin, Benton, and Grossman, 1982).

Cognitive Impairments in TBI-Executive Functioning

Almost universally, individuals sustaining TBI experience longstanding residual cognitive or physical impairments. Despite the heterogeneity in the nature of injuries sustained by patients, it has been observed that common patterns of cognitive impairment exist in the areas of attention and concentration, learning and memory, judgment and perception, and most pertinent to the proposed study, executive function (Whyte and Rosenthal 2003; Prigatano and Fordyce 1986). Deficits in executive functioning are evidenced in the loss of ability to appropriately plan, reason and problem solve. Several studies have documented the presence of executive dysfunction following TBI. Neuropsychological tests (e.g. Trail-making A and B, Stroop Color and Word test, Wisconsin Card Sort Test, Tower of Hanoi) that are sensitive to detecting impairment in aspects of executive functioning have been administered to TBI populations. Findings indicate that TBI participants perform worse than healthy controls (Dikmen, Machamer, Winn, & Temkin, 1995; Fork et al. 2005). In tasks of inhibition, such as a go/no-go task, TBI participants performed significantly worse than control participants; further, abnormal EEG recordings from the TBI participants corresponded with the impaired inhibition performance (Roche et al., 2004). Another study of inhibition in TBI participants using functional magnetic resonance imaging (fMRI) techniques found that not only did the TBI population perform worse than controls, but as task load increased, so did activation in the frontal lobe (Scheibel et al., 2003). Interestingly, a study of problem solving after TBI using the Tower of Hanoi and fMRI found that as participants performed worse on the task, activation in the frontal lobes decreased (Cazalis et al., 2006). Both studies demonstrate some level of change in activation in the frontal lobe during an executive function task, thus confirming the association of the frontal lobes with such processes in TBI participants. These differences in functional neuroanatomy for tasks requiring inhibitory and problem solving skills likely reflect the multidimensional nature of executive function. Despite some differences in functional activation patterns in imaging studies, the results examining discrete executive functions still share critical involvement of the frontal lobes.

Cognitive Impairments in TBI-Metacognition

In addition to executive dysfunction, the existence of impairment in self-appraisal specifically following injury has been established. In a comparison of orthopedic patients and TBI patients to healthy controls on tasks of self-awareness, it was found that orthopedic patients differed little from healthy controls, but TBI patients performed significantly worse (Garmoe, Newman, & O'Connell, 2005). Trahan, Pépin, and Hopps (2006) also found that TBI patients underestimated their emotional and cognitive behavioral disabilities when compared to a group of spinal cord injury patients. Deficits in metacognitive processes specifically, have been observed following TBI in both children and adults. Studies to date have focused more on the elements of metacognitive monitoring. Hanten, Bartha and Levin (2001) studied 9 TBI pediatric cases and found that despite performing equally well on a recall test, children with TBI had less accurate EOL and JOL predictions. Similar findings were reported in adults; in studies examining JOL predictions, adults with TBI were noted to be less accurate especially when making immediate predictions (Kennedy and Yorkston 2000; Kennedy, Carney and Peters 2003). Kennedy (2001) investigated another measure of metacognitive monitoring, RCJ, and found that while these judgments were relatively accurate when compared to healthy controls, TBI participants tended to be overconfident on answers to questions they were uncertain about while their healthy counterparts erred on the side of being under-confident. These findings suggest that the accuracy of metacognitive monitoring processes have been compromised following TBI.

Imaging studies conducted with TBI participants have supported the notion that frontal lobes are associated with self-evaluative processes. These studies involved giving participants self-evaluative tasks to complete while in a scanner; results showed activation in the prefrontal cortex during completion of these tasks (Johnson et al. 2002; Kelley et al. 2002; Zysset, Huber, Ferstl & Yves von Cramon, 2002; Schmitz, Kawahara-Baccus, & Johnson, 2004; Schmitz, Rowley, Kawahara, & Johnson, 2006). Although these studies examined self-evaluative processes, the tasks used were based upon subjective report and reports of accuracy of performance were not reported; thus "awareness" was not directly investigated. Other authors suggest that the presence of lesions in the brain may influence the quality of self-evaluative processes. For example, one study using computerized tomography scans found that the number of lesions, regardless of the localization, predicted performance on a self-appraisal task (Sherer, Hart, Whyte, Nick & Yablon, 2005).

Linking Executive Function and Metacognition in TBI

The abnormalities evidenced in the frontal lobes and corresponding deficits in both executive functioning and metacognition that are found in previously mentioned populations, such as Korsakoff's and FTD, suggest a relationship between the processes of metacognition and executive function. These characteristics of frontal lobe damage and impairments of higher order processing can also be found in TBI populations, making it another potential population that provides evidence for the existence of a relationship between executive functioning and metacognition. Numerous studies in the literature have identified deficits in executive functioning and metacognitive processes independently following TBI; however, only recently have researchers begun looking for a relationship between the two in the brain injured population. Furthermore, many studies do not examine metacognition as defined by a theory; rather, the broadly defined term of self-awareness is used. Nonetheless, these studies suggest a relationship between capabilities of self-awareness and executive functioning. Hart, Whyte, Kim and Vaccaro (2005) had TBI participants complete the Self and Significant Other Questionnaire, Dysexecutive Questionnaire (DEX), and Cognitive Failures Questionnaire (CFQ); which they used as measures of self-awareness. They then compared results on these questionnaires to performance on a battery of neuropsychological tests that aimed to measure executive functioning. Results showed that TBI participants scored poorer on the tests of executive function compared to healthy controls, and had higher scores on the DEX and CFQ indicating that the moderate to severe TBI participants reported more dysexecutive symptoms. When these were compared to reports made by their spouses or family members, there were greater discrepancies on judgments of functioning between the TBI and their significant others versus the significant others and the healthy controls. The larger discrepancy between the TBI participants and their significant others suggests that they are less accurate at judging their own abilities to function. In another study, the scores from the DEX and the Self Awareness of Deficits Interview (SADI) were compared to results of a go-no-go task, the Victoria Stroop Test, and the Self-Ordered Pointing Test (Bogod, Mateer and Macdonald 2003). A strong relationship between the tests of executive functioning and the SADI was found through regression analyses. Ownsworth, McFarland and Young (2002) also used the SADI as a measure of impaired self-awareness, as well as the Self Regulation Skills Interview (SRSI). They measured volition and purposeful behavior (both considered as components of executive functioning) using the Health and Safety Subtest from the Independent Living Scale (ILS) and the Tinkertoy Test (TTT) respectively. A main effect was found between volition and both the SADI and SRSI, and a main effect of the TTT was found on the SRSI only. Although the SADI and SRSI are existing tests that have been used to measure introspective processes, they are based upon subjective reports. In many studies, reports from significant others and/or clinicians are obtained and used for comparison to reports made by the participant with TBI; however, the reports are still based upon some aspect of subjectivity of the reporter. The subjectivity that is associated with the results of these interviews makes it difficult to examine the accuracy of these introspective judgments; including an objective measure of performance as a point of comparison would better measure one’s awareness.

Studies conducted thus far in participants with TBI provide further support for the notion that a relationship exists between executive functioning and phenomenon regarding the ability to have thoughts about the self; however, much is still to be learned. Although self-awareness has been studied in conjunction with executive function, these studies have focused on “awareness” in a broadly defined manner and have not directly examined metacognition in TBI. Studying the theoretical processes, such as specific monitoring and control mechanisms, thought to underlie metacognition provides a structured framework for understanding the relationship between executive functioning and metacognitive processes. As noted, in much of the work to date, measures of self-awareness have been based on subjective reports originating from the participant, clinician, spouse, or relative. These results make it difficult to judge the accuracy of an individual’s awareness.

Limited research examining both metacognition and executive functioning in TBI has been conducted using objective measures (such as FOK and EOL) that have been used to establish self awareness in other populations. For example, Schneyer et al. (2004), investigated FOK, confidence judgments, recall/recognition, and frontal lobe dysfunction in participants with TBI, including individuals sustaining TBI and injury secondary to stroke and aneurysm. The findings suggested mixed results when comparing FOK to frontal lobe tasks; one statistical comparison (using gamma's coefficient) suggested a correlation between FOK and frontal lobe dysfunction, while another analysis (using Hamann's coefficient) did not find a significant relationship. With regards to tasks of memory, it was found that while the group with TBI was more impaired on the tests of recall and recognition, the accuracy of their confidence judgments regarding their memory did not differ from healthy controls. On the other hand, they did differ from controls by showing more impaired accuracy of FOK. By including an imaging component to the study, it was found that FOK impairment was associated with damage to the right medial prefrontal cortex. While this heterogeneous sample provided findings that support the prefrontal cortex as an area of interest, it did not address variables that are characteristic to TBI that could potentially alter results, such as a predilection for prefrontal injury and significant executive dysfunction. The heterogeneous demographics and clinical variables that are associated specifically with TBI (such as length of time since injury, age at injury, history of previous injury) may also potentially be important factors that influence functioning, and remain to be studied.

Importance of Studying Metacognition in TBI

Although much is still to be learned about introspective processes such as metacognition, what has been established thus far has significant clinical implications. Findings from studies of awareness and metacognition may carry beneficial rehabilitative implications specific to certain clinical populations, such as patients with TBI. An individual's ability to reflect upon his own mental capabilities has been related to the outcome of psychopathology, psychotherapeutic outcomes, and functioning of daily life after neural deficits (e.g. neurological disease or brain trauma). Some studies have shown a connection between depression and level of insight. Using a dual process approach to depression, Teasdale et al. (2002) found that depressed individuals with low levels of metacognitive awareness were less likely to implement adaptive reflective information processing skills, leading to a perpetuation of dysphoric mood. As much as metacognitive factors may play a role in the etiology of psychopathology, they also may contribute to its remission through therapy. Grant (2001) suggests that metacognitive awareness is an important factor in determining the success of therapy. He poses that metacognition is closely related to psychological mindedness, which in turn is an important mediator of therapeutic outcome.

Each year, TBI leaves 5.3 million Americans with disability (CDC 2006). This staggering statistic is a reminder of the importance of improving daily life functions for those that recover and survive after injury. The level of insight people have of their deficits has been suggested to affect quality of rehabilitative outcome, such as the likelihood for re-employment, and adjustment to life after injury (Flashman and McAllister 2002). Trahan, Pépin & Hopps (2006) found that TBI patients who demonstrated low levels of awareness of their deficits often had poor adherence to their given medical regimen, which could influence their outcome of recovery. With regards to vocational potential following injury, TBI patients who overestimated their abilities were seen to have lower probabilities of employment (Sherer, et al., 2003). Supporting the notion that self-awareness may be correlated with employability, findings made by Kervick and Kaemingk (2005), suggested that accurate appraisal of deficits actually led to better occupational and independent living outcomes. A relationship between level of awareness and emotional adjustment has also been suggested (Sawchyn, Mateer and Suffield 2005). Development of psychopathology appears to depend upon awareness of cognitive deficits following injury; patients may or may not experience depression in response. Godfrey, Partridge, Knight & Bishara (1993) examined the relationship between the onset of emotional dysfunction and improved insight; finding that accurate self-awareness of deficits was moderately associated with an increase in depression, perhaps as a result of the patient becoming aware of the discord between pre-and post-injury functioning. On the other hand, Prigatano (1997) found contradicting results; concluding that patients with more accurate appraisal of their deficits were better equipped to compensate for their understood limitations, implying less depression. Similarly, Ownsworth and Fleming (2005) found that lower levels of insight were associated with higher levels of cognitive impairment and increased feelings of hopelessness. They further found that feelings of depression resulting from low levels of insight predicted poor psychosocial functioning. Evans, Sherer, Nick, Nakase-Richardson & Yablon (2005) found similar findings that self-awareness was related to subjective well-being. These numerous yet contradictory findings that exist further support the notion that not only is the phenomenon regarding introspective processes and capabilities related to many psychosocial issues facing the clinical population, but more research is still needed to provide clarification.

The Current Study

This study aims to further examine the relationship between executive function and metacognition. Based upon the parallel theoretical models of metacognition by Nelson and Narens (1994), and executive function by Norman and Shallice (1986), it is has been suggested that the two processes are related; both metacognition and executive function are considered higher order processes that operate based upon a system of levels. The hypothesis that the two processes are related is further supported by the identification of a common neural substrate, the frontal lobes, which are associated with both executive functioning and metacognition. Previous studies using populations with compromised function of the frontal lobes found deficits in both executive functioning and metacognitive abilities. This study seeks empirical validation of the relationship between the two processes by examining the correlation between measures of executive function and metacognition in TBI, a population that is prone to frontal lobe impairment. Findings of a correlation between performance on neuropsychological measures of executive functioning and objective measures of metacognition will strengthen the speculation that the two systems are indeed related.

The current literature cites common localization in the frontal lobes as strong evidence for the relationship between the two processes, making the enlistment of participants with a high likelihood of frontal lobe injury crucial. TBI often (>70% of the time; Hillary, Moelter, Schatz & Chute, 2001) results in injury to the prefrontal areas and is therefore a good model for examining comorbid deficits in executive functioning and metacognition. To date, no study has yet examined the relationship between the two in an exclusively adult TBI population using objective performance evaluation measures. The literature investigating this relationship in TBI has been marked by inconsistent terminology and is largely based upon self-report measures thus making it difficult to compare the findings in the literature and generalize conclusions. The proposed study suggests the use of a universally accepted definition of awareness (metacognition) based upon theory and objective measures that minimalize bias in order to generate findings that may be comparable to existing metacognitive literature.

Another facet of the proposed study will be to investigate the potential for independent categories of metacognition. Although studies have been conducted using concepts of metamemory and metacomprehension, categories of metacognition have not been fully identified; there may be other categories of metacognition that exist. Further, studies have examined categories such as metamemory and metacomprehension independently, however, no studies to date have investigated the relationship between such categories, or whether the type of awareness used in these processes is the same. An exploratory component of the proposed study will be to investigate a category of metacognition defined as meta-mental flexibility, the awareness of one's ability to think flexibly in problem solving situations. The relationship between categories of metacognition will be investigated by comparing metamemory with meta-mental flexibility.

Aims:

1. Determine differences in performance on executive functioning and metacognitive tasks in participants with TBI and healthy adults.
2. Identify the relationship between executive functioning and metacognition.
3. Identify if categories of metacognition are independent; are metamemory and meta-mental flexibility dissociable?
4. Investigate the influence of emotional or trait variables on metacognition.

Based upon these aims, the proposed study posits the following hypotheses:

1) Individuals with TBI have historically demonstrated impaired executive functioning and metacognitive abilities. Similar results are expected in the proposed study where scores of executive functioning and metacognition will be lower for TBI participants than their healthy counterparts.
2) A comparison of Norman and Shallice's (1986) model of executive functioning and Nelson and Naren's (1990) model of metacognition suggests a relationship between the two processes as denoted by a similarity of the presence of two levels of operation. If the two processes are indeed related, impairments in one process would imply impairments in the other. Individuals with TBI commonly demonstrates deficits of executive impairment, thus performance of executive functioning is expected to be positively correlated with metacognitive abilities.
3) Metacognition has been used as an umbrella term encapsulating more specific processes such as metamemory and metacomprehension. The modular hypothesis of metacognition

will be supported in the proposed study by evidence of low correlations between scores of metamemory and meta-mental flexibility.

4) Human behavior is dictated by an interaction of cognitive and affective function. Previous studies have demonstrated that impaired cognitive function is associated with emotional dysfunction (Janeck, Calamari, Riemann & Heffelfinger, 2003; Weiland-Fiedler et al. 2004; Harvey et al., 2005). It is thus hypothesized that depression and/or anxiety will be negatively correlated with metacognitive performance.

Methods

Participants

Participants with TBI and healthy individuals who were matched for age and education were recruited from the central Pennsylvania region. Individuals who had a history of color blindness, psychiatric illness and/or substance abuse that required hospitalization were excluded from the study. The sample of participants with TBI consisted of 8 females and 9 males, and all were right handed. The average age was 33.9 years (standard deviation (*SD*) = 14.0) and the average years of education was 13.9 (*SD*= 2.6). All participants with TBI had sustained a moderate to severe TBI; according to chart reviews, all had a Glasgow Coma Score between 3 and 12, and positive signs of injury on neuroimaging scans. The average amount of time since the injury occurred was 5.7 years (*SD*= 5.4). The sample of healthy individuals consisted of 7 males and 13 females, and two were left-handed. The average age of the healthy individuals was 38.2 years (*SD*= 15.4) and they had an average of 14.8 years of education (*SD*= 2.3). There was no significant difference in age or education between the two groups. Demographic information is presented in Table 1.

Procedures

Testing was conducted in a well lit, quiet room with minimal distractions. The purpose and procedure of the study was explained to the participant and informed consent was obtained. The researcher explained that the participant would be completing various paper and pencil tests of cognition, and asked for the participant's best effort toward completing the tasks. Particiapnts were warned that they may encounter feelings of frustration, boredom, fatigue, and/or anxiety while completing the tests; in the event that any distress occurred, the participant could opt to take a break or terminate the study. Participants were given the opportunity to ask any questions before getting started. Prior to formal cognitive testing, a brief interview was conducted to collect information regarding demographics (age, education, employment history, medical and psychiatric history) and, in the sample with TBI, information pertaining to their injury was collected (e.g. age at time of injury, amount of time since injury, and cause of injury). A battery of neuropsychological tests was then administered to the participants; all participants received the identical battery of tests. With the exception of one set of metacognitive tests (Matrix-Ordered and Matrix-Random, described below), all tests were administered in the same order for each participant.

Materials

The neuropsychological tests that were administered were chosen based upon their ability to measure basic cognitive functioning (including working memory and attention), executive functioning, and metacognition; a test assessing learned information (crystallized intelligence) was also administered to provide a measure of pre-morbid intelligence (the tests that were included in each of these categories are listed and described below). The tests of basic cognition and executive functioning were administered according to the publisher's instructions. The tests of metacognition were modified so that item-by-item retrospective confidence judgments could be obtained. During the administration of these metacognitive tests, after each response, participants were required to report the certainty of their answers by using a 6 point Likert scale. The participants were asked to answer this question: "I am ______ that my answer is correct," and given these choices to fill in the blank: completely certain, certain, somewhat certain, somewhat uncertain, uncertain, completely uncertain. The participants were reminded to consider all six choices before giving an answer. Prior to completing any metacognition tasks in the battery, the participants were given a list of trivia questions and required to make confidence judgments on each item. This list of questions was given in order for the participant to become familiar with using the Likert scale and making confidence judgments. The battery included the following tests:

Tests of Basic Cognition:

-Digit Span subtest from the Wechsler's Adult Intelligence Scale-III (WAIS-III) (Wechsler, 1997a). This test requires participants to hold and manipulate a series of digits "online" and is considered a test for working memory.

-Visual Search and Attention Test (Trenerry, Crosson, DeBoe & Leber, 1990). This is a speeded cancellation task that requires participants to pay attention and scan visual stimuli; it is commonly used to test for attentional skills.

Test of premorbid functioning:

-Information subtest from the WAIS-III (Wechsler, 1997a). This is a test of stored information and crystallized intelligence. Crystallized intelligence is considered to remain fairly intact despite injury or pathology; thus it is able to provide a measure of premorbid functioning.

Tests of Executive Functioning:

-**Trailmaking A and B Tests** (Army Individual Test Battery, 1944; Reitan & Wolfson, 1985). This is a speeded task that requires participants to attend to different aspects of visual stimuli simultaneously and requires cognitive flexibility and sequencing.

-**Verbal fluency subtest from the Delis-Kaplan Executive Functioning System (DKEFS)** (Delis, Kaplan & Kramer, 2001). This task requires participants to generate different types of word lists based on several stated rules. It is commonly used to measure the ability to generate novel responses and set shifting. As published, this test generates four separate scores for letter fluency, category fluency, total categorical responses, and category switching accuracy. In order to simplify the data analyses to be made, these scores were averaged into one general DKEFs score.

-**The Stroop Color Word Test** (Trenerry, Crosson, DeBoe, & Leber, 1989). This task requires attention to a specific aspect of the stimulus. It is commonly used to identify the ability to inhibit distracting stimuli. The stimuli include two pages of color words (e.g. tan, red, blue, green) that are printed in different colored inks. Participants are first required to read a page of color words (not paying attention to the color of the ink), then, they must read aloud another page of words, but this time list the color of the ink that the word is printed in. In this published version of the Stroop task, scores are based upon the correct number of words indicating ink color that is recited by the participant.

Tests of Metacognition (These tests were modified by asking the participants to rate how certain they were of their responses):

-**Matrix reasoning subtest from the WAIS-III** (Wechsler, 1997a). This test involves a picture of a pattern with a piece missing; the participant is required to choose the missing stimulus that best completes the pattern or sequence from 5 choices. This task assesses visuo-spatial perception, problem solving, and cognitive flexibility. This task was further modified by splitting the original 26 stimuli into two groups of 13 stimuli. In one group (Matrix-O), consistent with the standardized administration, item difficulty increased incrementally over the course of the test administration. In the second stimuli grouping (Matrix-R), the level of difficulty of the stimuli followed no particular pattern of difficulty. Finally, the total 26 items were collapsed to create an additional composite measure of executive functioning.

-**Abstraction subtest from the Shipley's Institute of Living Scale** (Shipley, 1946). This task requires participants to fill in numbers and letters that would complete a given pattern; it is another measurement of cognitive aptitude and sequence completion. The responses to items on this test were also used as a measure of executive functioning.

-**Verbal paired associates recall and recognition from Wechsler's Memory Scale-III** (Wechsler, 1997b)**.** This test requires the participants to learn pairs of semantically unrelated words, then, they are tested on their recall and recognition abilities. In addition to the confidence judgments made after each item, this test was further modified by decreasing the number of learning trials administered (2 trials were administered instead of the 4 that are in the published instructions). Standardization in administration was broken in order to achieve greater variability in participants' ability to recall stimuli and their confidence judgments.

-**Hopkins Verbal Learning Test-R** (Benedict, Schretlen, Gronigner, & Bandt, 1998) **.** This test requires participants to learn a list of words that can be semantically clustered. After the initial learning trial, participants were read a list of 24 words and were required to identify the words they had previously learned. This task was modified from the published testing instructions in order to achieve greater variability in participant responses; only one learning trial was administered instead of the four trials in the standard administration.

Test of Psychological Functioning:

-Beck's Depression Inventory-II (BDI) (Beck, Steer & Brown, 1996). The BDI consists of 21 items that are meant to measure depressive symptoms and experiences. The BDI uses a four point scale that describes the severity to which a person feels s/he experiences the depressive symptom in question over the past 2 weeks. The sum of the responses to the scale then falls between scores that dictate minimal, mild, moderate, and severe depression.

Note: there is overlap in several of the tests that are used to evaluate both executive functioning and metacognition. For clarification purposes, all tests will be labeled '(EF)' when indicating a test of executive functioning [e.g. Shipley's (EF)], and they will be labeled '(M)' when referring to tests indicating metacognition [e.g. Shipley's (M)].

Data Analysis

Measurements

Scores for tests of executive functioning and basic cognition were converted into standardized z- scores. Test scores were standardized using published normative data. Statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS).

Tasks of metacognition were coded so that an item received a score of 1 if it was correct and 0 if it was incorrect. Confidence judgments based upon a Likert scale were coded in the following manner:

Completely certain	--	6
Certain	--	5
Somewhat certain	--	4
Somewhat uncertain	--	3
Uncertain	--	2
Completely uncertain	--	1

Thus, each item of the four metacognition tasks received a score indicating correct/incorrect response, and a score indicating the subject's confidence rating. These pairs of scores were used to calculate Goodman and Kruskal gamma coefficients. This gamma coefficient is a statistic used to compare the association between dyads (2 pairs) of data. Dyads can be concordant, discordant, or tied. A dyad is concordant when both variables of one pair of data are greater or less than the other pair. For example, items A and B on a test are considered a dyad, the dyad is concordant when both the coded response of the item and the confidence judgment of item A is greater than item B, i.e., a correct response score of 1 on item A and 0 on item B (1>0), and a confidence score of 6 on item A and 2 on item B (6>2). A discordant dyad occurs when both variables on one pair are not greater or less than the other pair. For example, item A receives a response score of 1 and item B receives a score of 0 (1>0); however, item A has a confidence score of 2, and item B has a score of 6 (2<6). It is possible to have a tied score, when a variable of the two pairs is equal; for example, when both items receive either the same response score or the same confidence score. Gonzalez and Nelson (1996) note that the "ties" in the data are not able to accurately capture the degree of concordance; thus, they labeled these ties as "ambiguous" in nature and suggest that they not be considered as part of the measurement. The gamma coefficient accounts for "ties" by eliminating tied dyads and essentially measures only the surplus of concordant pairs to discordant pairs. Gamma coefficients fall between the range of -1 and 1; scores closer to 1 mean that there is a higher probability of concordant dyads, and scores closer to -1 mean a higher probability of discordant dyads. For this study, gamma coefficients for each test of metacognition were calculated for all participants. A Fisher's r to z transform was then used to convert gamma coefficients into z-scores when metacognitive scores were being compared to executive functioning, psychological functioning, and basic cognition tests.

The gamma coefficient is considered to be a relative measure of association in that it measures the amount of awareness from item to item; but it cannot determine the directionality of judgment (i.e. under or over estimation). Higher gamma coefficients can indicate that an individual has awareness to whether s/he is answering correctly overall; however, this measurement does not provide indication as to direction of the judgements (i.e., whether the participant is responding overconfidently or underconfidently). In order to address this issue, an absolute measure (AM) value can be obtained by directly comparing the percent of items an individual answers correctly with the average of his/her confidence ratings (Kennedy 2001). To conduct this analysis the 6 confidence judgment rankings were coded into percentages:

6	--	100%
5	--	80%
4	--	60%
3	--	40%
2	--	20%
1	--	0%

An average "percent of certainty" for each metacognitive task, was calculated for each participant. The percentage correct on that task for each participant was then subtracted from his/her average percent of certainty. Thus, a score of greater than 0 indicates that the participant is overconfident (higher percentage of rated confidence compared to actual correct score), while a negative score indicates that the participant is underconfident (lower percentage of rated confidence compared to actual correct score).

Data analyses and Results

Hypothesis 1: Participants with TBI will perform worse on tasks of executive functioning and metacognition. The mean score and standard deviation for each executive functioning task performed by the two groups were computed and are presented in Table 2. In order to determine differences in performance on executive functioning, the z-scores from the Stroop(EF), Trailmaking B(EF), Matrix reasoning(EF), DKEFs(EF), and the Shipley's(EF) tests were used in an independent samples t-test (the results are presented in Table 3). The participants with TBI performed significantly worse than the healthy individuals on Verbal fluency ($t(24) = -3.62$, $p = 0.001$) and the Trailmaking B Test ($t(19) = -2.21$, $p=0.039$. Performance on the Shipley(EF), Stroop(EF) and Matrix reasoning(EF) tests did not differ significantly between the two groups.

Differences in metacognitive ability as measured by gamma coefficients were tested by performing an independent samples t-test on scores calculated from the Matrix-O(M), Matrix-R(M), Shipley's(M), and HVLT(M) (the results of the t-test are presented in Table 5). No significant differences between groups were found at the $p=0.05$ level. Although the differences were not found to be significant, healthy individuals had higher gamma coefficients on the Matrix-O(M) (0.84 compared to 0.69) and HVLT(M) (0.25 compared to 0.14) metacognition tasks (see Table 4 for a complete list of mean gamma coefficients).

In order to examine differences between the directionality of judgments (overconfidence vs. underconfidence) in the two groups, an independent samples t-test was performed using the AM values obtained from subtracting percent correct from average confidence judgment (see

Table 7 for results). Again, no significant differences were found between groups at the p=0.05 level. A qualitative examination of the means of AM for each group (presented in Table 6) on the various tests shows that healthy individuals had higher AM values on the Shipley's(M) and Matrix-O(M) metacognitive tests, as well as a lower value on the HVLT(M) test. Only on the Matrix-R(M) test did the participants with TBI score higher than the healthy individuals.

Differences in metacognitive performance were noted between the Matrix-O(M) and the Matrix-R(M) tasks; a 2 X 2 analysis of variance (ANOVA) was conducted in order to determine the effects of group membership (i.e.,TBI or healthy adult) and ordered item difficulty on metacognitive performance. This analysis also allowed for an examination of any potential interactions between the factors of group membership and order of difficulty on the Matrix Reasoning subtest. When the gamma coefficient was used as the dependent variable, there was a statistically significant main effect of order of item difficulty on metacognitive performance (F(1, 68)=18.9, p=0.000). Group membership was not found to be a statistically significant main effect on gamma coefficient scores (F(1, 68)=2.05, p=0.157). Furthermore, no significant interactions were found between group membership and order of item difficulty (F(1, 68)=2.21, p=0.14). When the AM value was used as the dependent variable, no statistically significant main effects or interaction were found. Order of item difficulty was not found to be a significant main effect (F(1, 70)=2.85, p=0.10) on AM values; group membership was also not found to be a significant effect (F(1, 70)=0.20, p=0.66). No significant interaction was found between order of item difficulty and group membership (F(1, 70)=2.85, p=0.10).

Hypothesis 2: Better performance on executive functioning tasks will predict better performance on metacognitive tasks. This study proposed to examine the relationship between executive functioning and metacognition. In order to so efficiently, neuropsychological tests were collapsed to create composite indices. The tests of executive functioning were thus divided to create three indices: 1) Switching/inhibition-Index (the averaged scores from the Trailmaking B test and the Stroop task), 2) Problem-solving-Index (the averaged scores from the Shipley's (EF) and Matrix reasoning (EF) tests), and 3) Verbal fluency (the DKEFS score). The tests of metacognition were split into two groups based upon domain membership: 1) Metamemory (scores from the HVLT(M)), and 2) Meta-mental flexibility (averaged scores from the Shipley's(M), Matrix-O(M), and Matrix-R(M)).

A Fisher's r to z transform was used to convert all gamma coefficients into z-scores. The AM value scores were also changed into z-scores using the means and standard deviations obtained from the healthy individuals on each test. A correlation was then performed for all participants using the 3 indices of executive functioning (Switching/inhibition, Problem-Solving, and Verbal Fluency) and the 2 measures of metacognitive functioning (Metamemory and Meta-mental flexibility) as the variables. Switching/inhibition tasks were not significantly correlated with any gamma coefficients or AM values at the p=0.05 level. Verbal fluency also was not found to be significantly correlated with gamma coefficients or AM values at the p=0.05 level. However, Problem-solving was found to positively correlated with the Metamemory AM value (r= 0.46, p=0.004), and both the gamma coefficient and AM values of Meta-mental flexibility (r=0.35, p=0.032; and r=0.361, p=0.028, respectively).

When this analysis was repeated with data from only the TBI group, the only significant findings were Problem-solving being correlated with the Metamemory gamma coefficient (r=0.55, p= 0.022), and the Meta-mental flexibility AM value (r=0.53, p=0.029).

When this analysis was repeated with data from only the healthy adult group, the only significant findings were Problem-solving being correlated with Metamemory gamma coefficient (r=0.52, p=0.018), and Switching/inhibition being correlated with Metamemory AM value (r= 0.471, p= 0.036).

Hypothesis 3: Different domains of metacognition are related to one another. In order to examine if there was any relationship between the different domains of metacognition, 2 correlation analyses were run using all participant scores from the Metamemory and Meta-mental flexibility tasks. For the gamma coefficients, no significant relationships between Metamemory and Meta-mental flexibility were present at the p=0.05 level (r= 0.068, p=0.70). For the AM values, no significant relationships were found between Metamemory and Meta-mental flexibility (r=0.30, p=0.068).

However, to correct for the fact that the same participants were taking all four of the metacognition tests, a repeated measures analysis of variance (ANOVA) was also conducted. For the gamma coefficients, a significant difference was found between the two domains, F(1,34)=26.1, p<0.000. However, a repeated measures ANOVA conducted on the AM values from the different domain tests indicated no significant difference from one another, F(1, 36)=0.36, p=0.553.

Hypothesis 4: Psychological functioning may affect the ability to accurately make confidence judgments. In order to first determine if there were any differences in rates of depression between the healthy adults and the adults with TBI, an independent samples t-test was first conducted using the z-scores from the BDI. Although the scores did come close ($t(16)= -1.9$, $p=0.075$), no statistically significant difference was found between groups. The z-scores from the BDI, and the transformed gamma coefficients and AM values of the Metamemory and Meta-mental flexibility tests were entered into a correlation matrix. The only significant finding was a positive correlation between depression scores and the Metamemory AM value ($r=0.40$, $p=0.020$). However, when the two sample groups were examined independently, only the data from the adults with TBI demonstrated a significant positive correlation between depression scores and the Metamemory AM value ($r=0.563$, $p= 0.046$).

Supplemental analyses: Differences in basic cognition and premorbid functioning. Differences on tasks of basic cognition and premorbid unctioning(VSAT, Digit span subtest, and Information subtest) between participants with TBI and healthy individuals were examined by performing an individual samples t-test on z-scores obtained from these tests. The participants with TBI were found to perform worse on the VSAT ($t(32)= -3.432$, $p=0.002$).

Discussion

Between-group Differences on Tasks of Executive Functioning and Metacognition

This study aimed to investigate the relationship between executive functioning performance and metacognitive abilities in adults with TBI. It was anticipated that indiviudals with TBI would demonstrate deficits in awareness of their own cognitive ability and that these deficits could be traced to difficulties on tests of executive functioning. Consistent with a large literature examining cognitive deficits in TBI, the participants with TBI in this study demonstrated cognitive impairments in the area of executive functioning, specifically, on the DKEFS(EF) and Trailmaking B(EF) tasks. Despite these between-group differences in executive functioning, statistical analyses did not yield any significant between-group differences for either measure of metacognitive functioning (i.e., gamma coefficient or AM value).

Unique between- and within- group findings for the Matrix-O(M) task. The results of the t-test performed on the between group metacognitive scores did not yield any significant findings at the *p*=0.05 level when using a two-tailed comparison. However, for discussion here, the between-group differences in the Matrix-O(M) scores are interpreted as potentially meaningful (gamma coefficient: *p*=.045; AM value: *p*=.054, one-tailed comparison, no correction). The higher average gamma coefficient for the Matrix-O in the group of healthy adults indicates that they maintained relatively greater agreement between their confidence ratings and the response scores (incorrect or correct). When considering the higher AM values in the healthy adults, it appears that items that they were answering correctly were also receiving relatively higher confidence ratings.

This between-group difference found using a one-tailed comparison on only the Matrix-O(M) task is of interest because the difference in scores seemed to depend upon how the stimuli were presented. The Matrix Reasoning subtest of the WAIS-III was divided into two tests: Matrix-R(M) and Matrix-O(M). These two tests were identical in stimuli, the only difference between the two was the order of item difficulty, with the items in the Matrix-O(M) increasing incrementally in difficulty and Matrix-R(M) containing items where relative difficulty was randomized. These data suggest that when the items are ordered, the healthy adults benefit in terms of having more accurate relative agreement (gamma coefficient); however, the TBI group was more accurate in terms of rating magnitude, or confidence (AM value; see Figs 1 and 2). Interestingly, the data also demonstrate that within samples, both groups had significantly higher gamma coefficients on the Matrix-O(M) items compared to the Matrix-R(M) items (also presented visually in Figures 1 and 2). The ANOVA revealed that the order of item difficulty indeed had a statistically significant main effect on gamma coefficient scores, meaning that order of item difficulty as an independent variable influenced the outcome of the gamma coefficient. In other words, there was a statistically significant difference between gamma coefficients from the ordered task and the gamma coefficients from the task with item difficulty presented randomly. These findings suggest that the participants perhaps had some sort of implicit recognition when the items were ordered to increase in difficulty and were using that to inform the ratings of their performance. Interestingly, when examining the AM values, the ordered task was beneficial only to the group with TBI; the healthy adults continued to rate themselves overconfidently.

Trend of "discrepancy" suggests two separate measures of metacognition. An observation made from the data was that AM values were found to be elevated even when there were high gamma coefficients present. These results may appear to be "discrepant" findings (i.e., intuitively, one would expect high gamma coefficients to coincide with AM values close to 0, instead of having both a high gamma coefficient and a high AM value). However, these discrepancies are not unexpected given that these are two distinct measures of metacognition. The gamma coefficient is a relative measure, and only describes the agreement that exists between one's confidence ratings and his/her item response. However, the AM value is a measure of the "degree" or magnitude of confidence one has in relation to their item responses; for a correct response, one might be "completely certain" (a maximum score of 6) or expressed less confidently (a score of 4, "somewhat certain"). Each of these responses could achieve identical gamma coefficients but discrepant AM values. For example, two participants might both accurately identify when they were answering items correctly; however, one participant consistently rated him/herself the highest confidence score, while the other rated him/herself more conservatively. The participant reporting high confidence will end up with a higher AM score than the other participant, but as long as both had a high surplus of concordant dyads, their gamma coefficients will both be high and potentially even identical. This "discrepancy" of scores has also been found in other studies of metacognition; Kennedy's (2001) investigation of metamemory demonstrated that healthy adults and adults with TBI performed comparably on scores of gamma coefficients, however, in Kennedy (2001), the healthy adults tended to underestimate themselves, while participants with TBI overestimated their abilities.

The tendency for adults with TBI to be more conservative with their AM values may be attributed to more frequent exposure to limitations in daily life due to their injury. Adults with TBI most likely have more experiences that reveal the extent of their deficits (e.g. having to go through rehabilitation programs, inability to continue a previously held job) than healthy adults; thus increasing their awareness. An interesting extension of this study would be to gather information regarding psychosocial histories to identify variables that may effect the participant's experience and quality of life (e.g. job status before and after injury, amount and quality of caregiver support received, time spent in rehabilitative program) and examine how that contributes to their metacognitive abilities. Alternatively, it might also be informative to examine metacognitive abilities immediately following injury, before individuals receive exposure to experiences that may cue them to their deficits. This may be telling of whether awareness is immediately intact after injury, if it can be learned, and if there is a subset of subjects that do not reacquire this cognitive skill.

The Relationship Between Executive Functioning and Metacognition

An important aim of this study (Hypothesis 2) was to investigate if a relationship exists between executive functioning and metacognitive abilities. Based upon correlational analyses, problem-solving was found to be positively correlated with the Metamemory values, and with both indices of Meta-mental flexibility. As anticipated, these findings suggest that executive functioning is related to metacognition; furthermore, the finding that problem-solving alone was significantly correlated with metacognition suggests that the problem-solving component of executive functioning is integral to predicting metacognitive ability. The significance of the problem-solving component in metacognitive ability is further supported by the finding that out of the 3 executive functioning tests that the adults with TBI performed well on, 2 of them were problem-solving tasks. This suggests that it was the preservation of their problem solving skills that might have enabled them to perform well on tasks of metacognition,

In contemplating why problem-solving, out of the three identified components used in this study, might have been correlated with the metacognitive tasks, one might consider the nature of these problem-solving tasks. Both the Shipley's(EF) and the Matrix reasoning(EF) require the cognitive flexibility to recognize and complete patterns and sequences, but both tasks also require the individual to "figure out the rule" behind the patterns in order to complete a puzzle. During tasks that require one to problem-solve or decipher a logical pattern such as these, accurate and successful completion appears to be somewhat dependent upon the participant's ability to think in a different mindset and determine how the test designer intended on the puzzle to be solved. Potentially, it is this ability to problem solve by flexibly thinking "outside" of oneself that allows for more accurate assessment of one's own cognitive performance.

Different Domains of Metacognition: Metamemory versus Meta-mental flexibility

Different neuropsychological tests from distinct cognitive domains were modified to create separate metacognitive indices; this manipulation was performed in order to examine the potential for separate subtypes of metacognitive ability. Exploratory correlation analyses between the tasks of Metamemory and Meta-mental flexibility yielded no significant relationships for both the AM values and the gamma coefficients. These findings would suggest that the domains of metamemory and meta-mental flexibility are different from each other. A repeated measures ANOVA confirmed that the domains were significantly different from each other when using gamma coefficients; however, this was not the case when using AM values.

Potential differences between Metamemory and Meta-mental flexibility. The finding that the domains of metacognition did not correlate with each other and thus may be different from each other is qualitatively supported by the finding that all participants were overconfident on Meta-mental flexibility tasks and, relative to these scores, all participants were underconfident on memory tasks. Additionally, Metamemory gamma coefficients were the lowest out of all 4 metacognition tests for both groups.

One reason for this dissociation between Metamemory and Meta-mental flexibility is that people are normally more “exposed” to identifying memory problems and experiencing the consequence of such errors. Regular feedback is received when an error in memory has been made (e.g., forgetting car keys, deadlines). However, it could be proposed that errors in problem solving do not provide such explicit feedback, resulting in more subjective ambiguity as to whether or not an error as been made.

Another possibility for differences in performance between Metamemory and Meta-mental flexibility is that for the Meta-mental flexibility tasks, the participants had no previous exposure to the answers, thus they may not have as much reason to doubt themselves; whereas on the Metamemory task, they have been exposed to the answer during the learning trial and they may experience more ambiguity in confidence when forced to choose between a correct answer and one that may be semantically related.

Potential unidirectional use of the AM value across domains. Although the correlation of AM values between Metamemory and Meta-mental flexibility was not statistically significant, there is reason to believe that with a larger sample size, the effect may be real (r=0.30, p=0.068). For the sake of discussion, the direction of these findings is consistent with the repeated measures ANOVA finding that there were no significant differences between the means of the domains; suggesting that there is indeed a relationship between the AM values of Metamemory and Meta-mental flexibility. This finding would suggest that perhaps the use of AM values are in a unidirectional manner, that is, individuals are likely to consistently make judgments in the same direction, regardless of domain (e.g. if one overestimates on Metamemory tasks, s/he will also overestimate on Meta-mental flexibility tasks). This may reflect a consistency in response style held by individuals.

The Effect of Depression on Metacognitive Performance

Depressive symptoms have been recognized in the literature to be influential on cognitive functioning. One of the aims of this study was to investigate if depressive symptoms would also affect metacognitive abilities. A correlation analysis of the scores from the BDI and the metacognitive scores (both AM values and gamma coefficients) revealed that depression was positively correlated to the Metamemory AM value. When the correlation was carried out between groups, only the group with TBI demonstrated the positive correlation. This finding was surprising, as it suggests that for adults with TBI experience, the experience of increased depressive symptoms is related to an increase in overconfident reports. This raises the question whether depression is experienced differently after injury than depression without injury. It is possible that the overconfidence reflects a coping style of denial; although individuals with depression are aware of their relative accuracy, they underestimate how severe their impairment is; in other words, they know they are doing badly, but they may not be able to report objectively the severity of the impairment. Further participant recruitment and data collection will be needed in order to confirm such an effect.

Limitations of the Current Study

Although this study yielded many interesting findings, it is not without its limitations and there are areas that could be expanded on for a comprehensive understanding of metacognitive monitoring and awareness of deficit in adults with TBI. First, the number of subjects recruited for this study is limited (17 with TBI and 20 healthy individuals). Due to further nuances in participant responses (e.g. participant skipping items, noticeable poor participant effort), some additional data points needed to be omitted. This may have reduced the power and robustness of the statistical analyses that were used. It should also be noted that one healthy participant disclosed that he had a history of post traumatic stress disorder after testing. This participant's data was included at this point because his test scores did not indicate any severe impairment in cognitive functioning, but it is not known if his symptoms of anxiety would have affected his scores. The data from this participant will be removed when a suitable replacement is recruited.

Secondly, with regard to test/stimulus selection, some of the tests selected may not have provided enough variance for metacognitive processes to be measured; it is not possible to calculate a gamma coefficient if there is not enough variance in reported confident judgments or in the item responses (i.e., participants were getting the answers all correct or all incorrect). This was the case for at least one of the tests initially selected: the verbal paired associates subtest of the WMS-III. Both healthy adults and adults with TBI performed so well on the recognition task that gamma coefficients could not be calculated, and the data from this test ended up not being used in any analyses. It is not known to what degree the other tests offered opportunity for variance in response. Another issue with test/stimulus selection is that the type of feedback provided by the test may affect metacognitive performance. For example participants may have received higher gamma coefficients on the Shipley's (M) because one receives more explicit feedback the item is answered incorrectly (i.e., they do not know how to fill in the blank), as opposed to the Matrix reasoning (M) tests, when they are given choices to choose from, the feedback that the question was answered incorrectly is not explicit. .

Lastly, this study faced a problem encountered by other metacognitive studies—that is, the use of an ordinal scale to rate a subjective experience. The use of a Likert scale forces responses to be categorized in a way that may not be most accurate. There is also some subjectivity involved in using Likert scales, and it is not known if all participants use the scale in the same way (e.g. one participant's "completely certain" may be another participant's "somewhat certain"). Furthermore, the ordinal data then had to be converted into interval data in order to be compared; assumptions are made in this study that these continuous, subjective feelings of confidence can be accurately described and measured in a discrete way. There is a possibility that this method of measurement is insensitive to the full spectrum of confidence judgments. Also, there are some limitations in the measurements used (gamma coefficients and AM values). In attempts to avoid Type I errors, the gamma coefficient eliminates all tied dyads; however, this may eliminate a significant number of data points. Other analyses (e.g. Somer's d, Kim's d) may be conducted that do not eliminate dyads, but they run the risk of a false positive finding. In regard to the AM value, although 0 is thought to be a "perfect" score, it may represent an unlikely "standard". That is, the cutoff for "over" or "underconfidence" is uncertain without a larger standardization sample. For example, it is difficult to know if overestimation (as seen in the sample of healthy adults in this study) is normative and that adults with TBI are just "more pessimistic" about their abilities. It seems then, that the AM value would be most helpful when there is a reference group to which relative comparisons can be made.

Conclusion

This study represents a novel investigation of metacognitive skills in adults with moderate to severe TBI. In this sample of adults with TBI, metacognitive abilities appeared to be intact and were comparable to a group of age and education matched healthy individuals. Interestingly, differences in metacognitive abilities (regardless of sample group membership) do appear when the structure of the task is manipulated. Participants' knowledge of the structure of the task influenced metacognitive ability. Participants appeared to be aware of when the difficulty of items in a task progressed from easy to more difficult, and used it to their advantage in making confidence judgments. The results of this study also suggest that performance on executive functioning tasks is related to metacognitive abilities. Specifically, the problem-solving facet of executive functioning was found to be positively correlated with metacognitive accuracy.

The results of this study also allowed for a closer inspection of the construct of metacognition and the potential existence of separate metacognitive domains. Interestingly, performance differences in different domains of metacognition occurred depending on what measurement of metacognition was used (i.e. gamma coefficient or AM value). The gamma coefficients were found to be different between tasks of metamemory and meta-mental flexibility; the statistically significant differences between the gamma coefficients from the different tasks suggest that metacognition is not a unitary construct but may be composed of different domians. However, no differences between domains were found when measuring the magnitude of accuracy of the confidence judgments (AM values). Due to the fact that AM values measure the magnitude of response and may be less sensitive to actual accuracy in item response and confidence judgment, this finding may be an indication of trends in report tendencies.

Metacognitive processes may potentially influence the ability to appropriately regulate emotions, which ultimately has implications for successful recovery, rehabilitation, and treatment. This study investigated such a potential relationship between metacognitive monitoring processes and depressive symptoms. Surprisingly, a positive correlation was found between participants' magnitudes of confidence on metamemory tasks and levels of depression. The overconfident reports suggest some inaccuracy in metacognitive responses, implying that deficits in metacognitive accuracy are associated with depression; what is surprising about this finding is that the inaccuracy leans toward a "positive" attitude of overconfidence, where participants who believe they are more capable than objectively determined suffer more depressive symptoms.

This study provides a preliminary, objective investigation of metacognitive monitoring processes and executive functioning in a sample of adults with moderate to severe TBI. The results of this study may be indirectly applicable to understanding more about the recovery of cognitive processes following brain injury. The finding that executive functioning and metacognition are related supports the theory of a unified or associated cognitive network; this can be potentially useful to clinicians in their prognosis of cognitive outcome after injury to one part of the network. Additionally, the study of metacognitive processes and their relationship and influence on cognitive and psychological functioning can yield implications for ways to improve treatment and rehabilitation efforts in a clinical population (e.g. attempts to improve metacognitive abilities in order to improve participation in therapy).

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APPENDIX

TABLES AND FIGURES

Table 1

Demographics of Sample Groups

Sample group	Age		Years of education		Years since injury	
	Mean	SD	Mean	SD	Mean	SD
TBI	33.8	14.0	13.8	2.6	5.6	5.3
Healthy	38.2	15.4	14.8	2.3	--	--

Table 2

Mean Scores on Executive Functioning Tasks (z-scores)

Task	TBI Mean (*SD*)	Healthy Mean (*SD*)
Stroop	-0.42 *(2.2)*	0.40 *(1.6)*
Trailmaking B	-0.63 *(1.4)*	0.29 *(0.80)*
Matrix Reasoning	0.47 *(0.64)*	0.77 *(0.54)*
Shipley’s	0.17 *(0.64)*	0.85 *(0.74)*
DKEFS	-0.33 *(1.3)*	0.90 *(0.69)*

Table 3

Executive Functioning Performance: TBI vs. HC

Executive functioning test	t(df error) = t (obtained)	Signficance (*p*)
Stroop	t(34) = -1.30	0.202
Trailmaking B test	t(19) = -2.21	0.039
Matrix reasoning	t(35) = -1.53	0.133
Shipley's abstraction	t(35) = -1.80	0.080
Verbal fluency (average DKEFS)	t(24) = -3.61	0.001

Table 4

Mean Gamma Coefficients for Metacognitive Tests

Metacognitive test	TBI		Healthy adults	
	Mean	SD	Mean	SD
mShipley's	0.815	0.166	0.814	0.440
Matrix-O	0.686	0.273	0.837	0.240
Matrix-R	0.356	0.499	0.342	0.495
mHVLT	0.141	0.554	0.252	0.525

Table 5

Metacognitive Performance (GammaCoefficients): TBI vs. HC

Metacognitive test	t(df error) = t (obtained)	Signficance (*p*)
mShipley's abstraction	t(35) = 0.007	0.995
Matrix-O	t(33) = -1.736	0.092
Matrix-R	t(35) = 0.087	0.931
mHVLT	t(31) = -0.590	0.559

Table 6

Averages of AM values from Metacognitive Tests

Metacognitive test	TBI		Healthy adults	
	Mean	SD	Mean	SD
mShipley's	2.41	14.52	5.200	11.45
Matrix-O	1.00	11.81	11.15	22.88
Matrix-R	15.5	17.09	10.70	18.58
mHVLT	-2.471	11.63	-3.550	14.07

Table 7

Metacognitive Performance (AM values): TBI vs. HC

Metacognitive test	t(df error) = t (obtained)	Signficance (*p*)
mShipley's abstraction	t(35) = -0.653	0.518
Matrix-O	t(35) = -1.649	0.108
Matrix-R	t(35) = 0.817	0.419
mHVLT	t(35) = 0.251	0.803

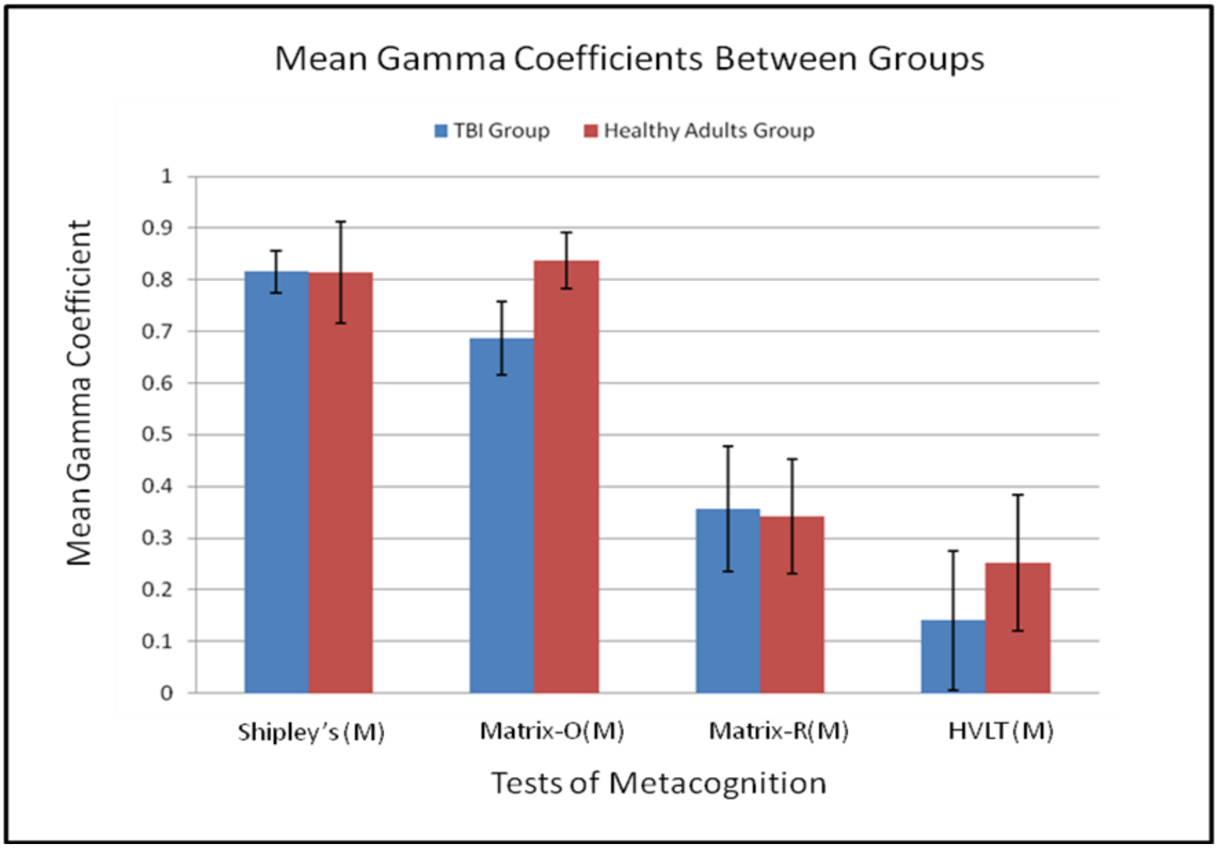

Figure 1. Chart of gamma coefficients from the metacognition tests for both groups.

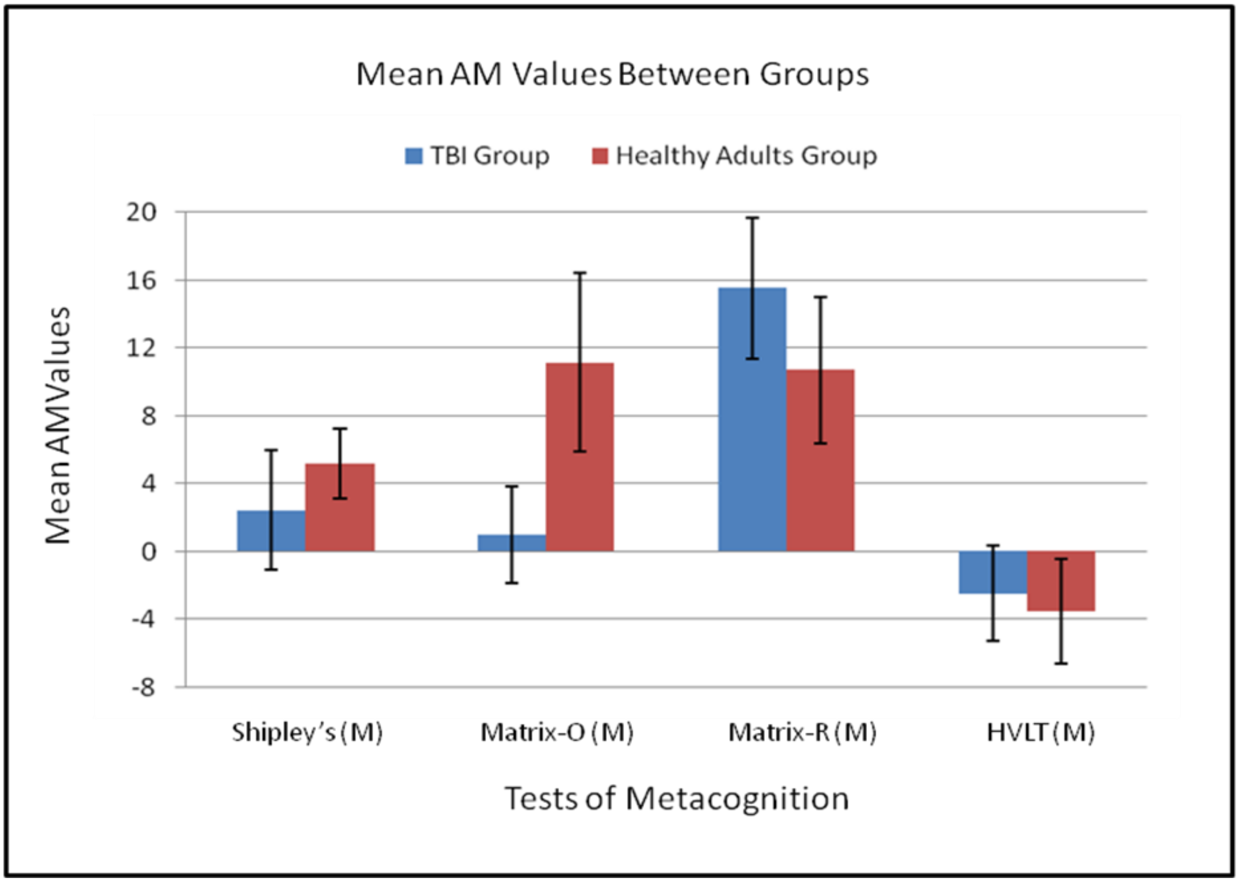

Figure 2. Chart of the mean AM values from the metacognition tests for each group.