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Metacognitive Monitoring in Moderate and Severe Traumatic Brain Injury

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Abstract

The ability to engage in self-reflective processes is a capacity that may be disrupted after neurological compromise; research to date has demonstrated that patients with traumatic brain injury (TBI) show reduced awareness of their deficits and functional ability compared to caretaker or clinician reports. Assessment of awareness of deficit, however, has been limited by the use of subjective measures (without comparison to actual performance) that are susceptible to report bias. This study used concurrent measurements from cognitive testing and confidence judgments about performance to investigate in-the-moment metacognitive experiences after moderate and severe traumatic brain injury. Deficits in metacognitive accuracy were found in adults with TBI for some but not all indices, suggesting that metacognition may not be a unitary construct. Findings also revealed that not all indices of executive functioning reliably predict metacognitive ability. (*JINS*, 2011, *17*, 720–731)

Keywords: Awareness, Brain injury, Metacognition, Confidence judgments, Self-monitoring, Executive functioning

INTRODUCTION

TBI and Deficits in Awareness

Traumatic brain injury (TBI) is sustained by approximately 1.7 million Americans yearly, and leaves an estimated 5.3 million people living with disabilities (Faul, Xu, Wald, & Coronado, 2010). Individuals with TBI often experience persisting cognitive impairments in the domains of attention, learning and memory, perception, and executive functioning that are largely resistant to rehabilitation efforts (Prigatano & Fordyce, 1986; Whyte & Rosenthal, 1993).

One additional consequence following TBI can be reduced awareness, or the capacity to reflect upon one's own condition. The level of awareness maintained by individuals who have sustained TBI has important consequences for patient outcome and may influence the development of psychopathology, perceived quality of life, feelings of subjective well-being, vocational potential, adherence to rehabilitation efforts (e.g., medication compliance), and return to independent living (Evans, Sherer, Nick, Nakase-Richardson, & Yablon, 2005; Flashman & McAllister, 2002; Godfrey, Partridge, Knight, & Bishara, 1993; Kervick & Kaemingk, 2005; Ownsworth & Fleming, 2005; Prigatano, 1997; Sherer et al., 2003; Trahan, Pépin, & Hopps, 2006). For these reasons, understanding self-appraisal following TBI has important clinical implications.

Anosognosia is a term coined by Babinski to reflect diminished self-awareness and, in particular, failure to recognize personal disability (Babinski, 1914); it has since received widespread application in clinical populations to describe unawareness of illness (Barrett, Eslinger, Ballentine, & Heilman, 2005; Goldenberg, Müllbacher, & Nowak, 1995; Heilman, Barrett, & Adair, 1998; Lebrun, 1987; Leritz, Loftis, Crucian, Friedman, & Bowers, 2004; McGlynn & Schacter, 1997; Pia & Tamietto, 2006; Rickelman, 2004; Wagner, Spangenberg, Bachman, & O'Connell, 1997). Implicit to this literature is that awareness is multi-faceted; Amador et al. (1993) found patients to have variability in the level of insight held about different aspects of illness (awareness of mental disorder, effects of medication, and social consequences of mental disorder). Specific to TBI, Fleming and Strong (1995) proposed three levels or areas in which impairments of self-awareness can manifest: awareness of injury related deficits (which can include cognitive impairments), awareness of functional implications of deficits, and awareness to set realistic goals or predict prognosis. The current study focuses on awareness of cognitive performance after TBI, specifically, decrements in metacognition.

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Metacognition

As defined early on by Flavell, the term "metacognition" describes one's ability to track their cognitive processing and includes both knowledge and experience (Flavell, 1979). Metacognitive knowledge refers to cumulative beliefs that can guide cognitive pursuits; while metacognitive experiences pertain to monitoring and control processes that occur in the moment of cognitive engagement (Flavell, 1979). For the purpose of this study, we focus on the latter, that is, the ability to monitor one's performance and the recognition of on-line performance during information processing.

One well established theoretical model of metacognition maintains that this higher order cognition includes a "meta" level that monitors and controls processes that are occurring at an "object" level (Nelson & Narens, 1990). Metacognitive experience can be measured objectively by making comparisons between actual performance and the individual's judgments of performance collected before (prospective monitoring) or after performing (retrospective monitoring) a task (for a review of these methods, see Dunlosky & Metcalfe, 2009). Typically, these judgments include ease of learning (EOL), judgment of learning (JOL), feeling of knowing (FOK), and retrospective confidence judgments (RCJ) (Nelson, 1992; Nelson & Narens, 1990). These approaches have been used to examine metacognitive ability in several cognitive domains, including control of action (Augustyn & Rosenbaum, 2005), comprehension of text (Dunloskly, Baker, Rawson, & Hertzog, 2006; Griffin, Jee, & Wiley, 2009; Griffin, Wiley, & Thiede, 2008; Lefèvre & Lories, 2004; Maki & Berry, 1984; Rawson, Dunlosky, & Thiede, 2000; Thiede, Wiley, & Griffin, 2010), and a great number of studies have investigated memory (i.e., metamemory) (Hager & Hasselhorn, 1992; Hertzog, Dixon, & Hultsch, 1990; Kaszniak & Zak, 1996; Leonesio & Nelson, 1990; McDonald-Miszczak, Hertzog, & Hultsch, 1995; Pannu & Kaszniak, 2005; Tiede, Derksen, & Leboe, 2009).

Little is known about metacognitive experiences after TBI as tested by using reports of judgment on an item by item basis (such as EOLs, JOLs, and RCJs). Instead, the majority of studies that examine awareness of cognitive ability after TBI rely on inventories based upon patient and/or other report [e.g., Self Awareness of Deficits Interview (SADI), Scale of Unawareness of Mental Disorders (SUM-D), Patient Competency Rating Scale (PCRS) (Ciurli, et al., 2010; Fleming, Strong, & Ashton, 1996; Garmoe, Newman, O'Connell, 2005; Hart, Whyte, Kim, & Vaccaro, 2005; McAvinue, O'Keeffe, McMackin, & Robertson, 2005; Ownsworth & Fleming, 2005; Ownsworth, McFarland, & Young, 2002; Prigatano & Klonoff, 1998; Roche, Fleming, & Shum, 2002; Satz et al., 1998; Sawchyn, Mateer, & Suffield, 2005; Sherer et al., 2003; Trahan et al., 2006)]. While such measures offer clinically relevant information, they are subjective and biased by perceptual differences in raters; there is often limited reliability between raters and an inherent difficulty in establishing a "gold standard" for distinct sets of ratings. Moreover, the items in these inventories can be broad in nature (i.e, items query how one might feel about his/her memory in general) and address only the individual's overall ability in a domain; while this method provides information regarding more general metacognitive knowledge, it has limited ability to directly assess accuracy of awareness in the moment. In contrast, item-by-item reports of judgments were developed to allow for confidence to be directly tied to cognitive decision making, thus providing a more sensitive and accurate measure of metacognitive experience. Although these types of judgments were initially developed for study of healthy individuals, more recently, investigators have successfully used these measurements to study clinical populations as well (Cosentino & Stern, 2005).

In the limited literature that does exist of objectively measured metacognitive experiences after TBI, impairments have been documented in the domain of metamemory; individuals with TBI make less accurate judgments of learning than healthy adults (Kennedy, Carney, & Peters, 2003; Kennedy & Yorkston, 2000). However, these findings were challenged by Anderson and Schmitter-Edgecombe (2009), who found that despite performing poorly on memory tasks, adults with TBI were still able to accurately predict their performance. It has also been documented that the accuracy of RCJs made by individuals with TBI were comparable to those of healthy adults; however, qualitative differences emerged such that when errors were made, they tended to be more overconfident, while healthy adults were under-confident (Kennedy, 2001). The limited number of studies investigating metacognition after TBI and the focus on metamemory reflects a need for research in this population examining distinct cognitive domains.

Metacognition and Executive Functioning

"Executive functioning" is a term that captures several higher order cognitive processes that are responsible for complex behaviors such as planning, organization, and problem-solving. In the model posed by Norman and Shallice (1986), executive functioning acts in a supervisory manner by monitoring and manipulating more basic schemas, which ultimately affects the outcome. Of interest, this model holds important similarities to Nelson and Narens's (1990) model of metacognition; both models include a higher order level that monitors and controls "lower," more basic information processing. The similarity between metacognition and executive functioning to act as regulatory systems has convinced some that the two processes may be related (Fernandez-Duque, Baird, & Posner, 2000; Shimamura, 2000). One hypothesis is that the complex attentional control afforded by executive functions is necessary for self-reflective processes, such as metacognition (Hart et al., 2005). Another stance asserts that metacognitive judgments are influential in the exertion of executive control over behaviors; studies in healthy individuals have found that adjustments in behavior are linked to their judgments of performance (Karpicke, 2009; Metcalfe, 2009; Redford, 2010). Finally, results from neuroimaging studies have identified an association between frontal networks and executive functioning (Chen, Wei, & Zhou, 2006; Collette, Hogge, Salmon, & Van Der Linden, 2006; Markela-Larenc et al., 2004); similar networks have also been found to be associated with metacognition (Chua, Schacter, Rand-Giovannetti, & Sperling, 2006; Chua, Schacter, & Sperling, 2009; Kikyo, Ohki, & Miyashita, 2002). The allocation of similar neural resources further supports the notion that executive functioning and metacognition are related.

Indeed, age related differences in metamemory appear to track with differences in executive abilities (Perrotin, Belleville, & Isingrini, 2007; Perrotin, Isingrini, Souchay, Clarys, & Taconnat, 2006; Perrotin, Tournelle, & Isingrini, 2008; Souchay, Isingrini, & Espagnet, 2000). However, it also appears that metamemory performance is captured by a unique component of processing self-relevant information that is independent of executive functioning in older adults (Cosentino, Metcalfe, Holmes, Steffener, & Stern, in press), and in individuals with schizophrenia (Koren et al., 2004). Furthermore, the relationship between executive functioning and metacognition is questionable in light of evidence from studies of animals that demonstrate higher order functioning but do not show self-awareness (Gallup & Suarez, 1991). Similar observations of retained executive functioning abilities despite impairment in self-awareness have also been documented in humans (Stuss & Alexander, 2000; Stuss & Levine, 2002). Thus, while metacognitive processes and executive functioning seem to share a common neural substrate and serve similar regulatory functions, the degree to which they overlap is uncertain; in particular, it remains unknown whether deficits in the abilities reflected in these constructs are dissociable following neurological disruption.

The evidence thus far for a relationship between executive functioning and metacognition after TBI remains inconclusive; using self-report inventories, some studies have found that deficits in executive functioning are related to poor metacognitive knowledge (Allen & Ruff, 1990; Bogod, Mateer, & MacDonald, 2003; Ciurli et al., 2010; Hart et al., 2005), while others have found no relationship (Bach & David, 2006). The literature examining the relationship between in-the-moment metacognitive experiences and executive functioning following TBI is much more limited, and findings here are also mixed. One study of metacognition in a heterogeneous sample (including stroke and TBI) found mixed results when comparing feeling of knowing judgments with measurements of frontal lobe dysfunction; statistical analyses using a gamma coefficient suggested a significant correlation, but the use of Hamann's coefficient did not confirm those findings (Schneyer et al., 2004). Another study of metamemory failed to find a relationship between prospective monitoring judgments and tasks of executive functioning, suggesting that these may be two distinct processes (Anderson & Schmitter-Edgecombe, 2009). Thus, the relationship between executive dysfunction (and its subcomponents) and metacognitive experience remains unclear and the current study aims to directly examine these two supervisory systems.

Study Goals

A review of the literature has identified gaps in the understanding of metacognitive experiences objectively after TBI (especially in domains other than metamemory). Thus, the primary goal of the current study was to investigate metacognition (defined here as beliefs, perceptions, and thoughts about one's own cognitive performance) by using objective measures. In particular, in-the-moment metacognitive accuracy in participants with TBI and healthy adults was examined using item-by-item confidence judgments of performance. Through the use of these confidence judgments, it was an important goal of this study to document the relationship between metacogntive accuracy and performance on executive functioning tasks. The literature in metacognition following TBI to this point has focused almost exclusively on metamemory; and it was a goal of this study to also examine metacognition in TBI in a task requiring abstract reasoning.

METHODS

Subjects

Participants consisted of 21 individuals between the ages of 18 and 65 with moderate to severe TBI and 21 healthy adults (HCs) matched for age and education. Injury severity was determined by Glasgow Coma Scale (GCS) score reported in medical charts at the time of admission to hospital; moderate and severe injuries were defined by GCS scores between 3 and 12, or were substantiated as positive findings on neuroimaging scans as noted in patient medical charts. One participant had a GCS score of 14; however, the results from her imaging scans revealed significant injury, including verifiable subdural hematoma. A detailed description of imaging findings, GCS scores, and time post injury are presented in Table 1; demographic and clinical descriptive variables for the individuals with TBI and HCs are summarized in Table 2. There was no significant difference in age or years of education between the two groups. Exclusion criteria for both the TBI sample and HCs included history of: psychiatric illness, colorblindness, and substance abuse that required hospitalization or rehabilitation. All participants received and agreed to the informed consent approved by the Institutional Review Board at the institution.

Procedure and Measures

An identical battery of paper and pencil neuropsychological tests was administered to all participants. The neuropsychological tests used to examine executive functioning were administered as published; for tests of metacognition, modifications were made to existing tests to capture retrospective confidence judgments (RCJs). To collect RCJs, participants used a 6-point Likert scale to rank how certain they answered the item correctly immediately after responding to each item in a task. All metacognitive tasks (described in further detail below) in the battery followed this format for reporting RCJs. Before metacognitive testing, a practice task was given to familiarize participants with making RCJs. During the practice task, participants completed 20 multiple choice trivia questions (e.g., "Buenos Aires is the capital of which

Table 1. Clinical descriptors for participants with TBI

Subject	Time post injury (years)	GCS score	Imaging findings
1	9	3	Right frontal HEM; subcortical right cerebral and temporal lobe contusions
2	2	3	SAH; right frontal focal HEM; DAI right frontal and parietal
3	1	3	Bilateral frontal DAI; posterior left frontal SAH; right posterior paraflaciform SDH
4	8	7	Frontal lobe and cerebellum DAI
5	19	3	Right frontal HEM; focal parenchymal HEM in bilateral frontoparietal region, inferior right frontal, left basal ganglia and left posterior pons
6	2	3	White matter lesion in left motor strip; focal lesion in left frontal
7	3	3	Small bilateral SDH; midline shift; IPH in left frontoparietal lobe with edema
8	12	3	Acute left parietal SDH; right frontal and parietal epidural hematoma; diffuse SAH
9	2	5	Bilateral SAH; DAI
10	1	11	Left temporal contusion
11	15	3	Increased signal at right peduncle, posterior corpus callosum, and left thalamus; shear injuries
12	7 months	8	Bilateral frontal contusion; DAI in frontal lobes
13	3	3	Frontal petechial HEM; DAI
14	7	7	Left temporoparietal parenchymal HEM; IPH in left posteroparietal region, SDH bilaterally
15	2	14	Left frontal contusion
16	5	3	Bilateral IVH and IPH throughout parietal and frontal lobes
17	5	**	Right parieto-occipital SDH
18	3 months	8	Right frontal SAH
19	21	3	HEM in lateral, third and fourth ventricles; hemorrhagic contusion in left thalamus area
20	4 months	3	DAI
21	3 months	3	DAI; right occipital IVH

Note. HEM = hemorrhage; SAH = subarachnoid hematoma; DAI = diffuse axonal injury; SDH = subdural hematoma; IPH = intraperitoneal hemorrhage; IVH = intraventricular hemorrhage.
**GCS score not available; injury severity was based upon imaging findings and reported loss of consciousness of 1 day.

country?"), each followed immediately with an inquiry of confidence.

Tests of Executive Functioning

There is existing evidence that executive functioning is not a unitary construct; rather, it includes components of set shifting, inhibition, monitoring, productive fluency, and cognitive flexibility (Busch, McBride, Curtiss, & Vanderploeg, 2005; Miyake et al., 2000). Tests of executive functioning were chosen based on their ability to assess these components; the tests included: the Trailmaking Tests (Army Individual Test Battery, 1944; Reitan & Wolfson, 1985), Verbal fluency subtest from the Delis-Kaplan Executive Functioning System (DKEFS) (Delis, Kaplan, & Kramer, 2001), and the Stroop Color Word Test (Trenerry, Crosson, Deboe, & Leber, 1989). Additionally, modified administrations (modifications described below) of the Matrix Reasoning subtest from the Wechsler Adult Intelligence Scale-III (WAIS-III) (Wechsler, 1997) and the Abstraction subtest from the Shipley's Institute of Living Scale (Shipley, 1946) were included as measures of executive functioning (refer to Figure 1). Consideration was warranted to the complexity of executive functioning as a construct that may involve other basic cognitive processes; thus, to control for these more basic processes and provide a "purer" measure of executive functioning, the Digit Span subtest from the WAIS-III (Wechsler, 1997) was also included in the battery as a measure of simple attention/working memory. With the exception of the modified Matrix Reasoning and Shipley's Abstraction subtests, standard administration was followed on these tests, thus *Z*-scores were calculated using normative data provided by the test publishers.

Table 2. Participant demographic information: mean(standard deviation)

	Gender	Age (years)	Years of education	Mean GCS	Time post injury (years)
Participants with TBI	9 female 12 male	33.1 (13.5)	13.9 (2.5)	5.0 (3.2)	5.6 (6.3)
Range		18–63	11–20	3–14	3 months –19 years
Healthy Adults	11 female 10 male	30.8 (13.6)	14.7 (2.2)	—	—
Range		18–59	12–20	—	—

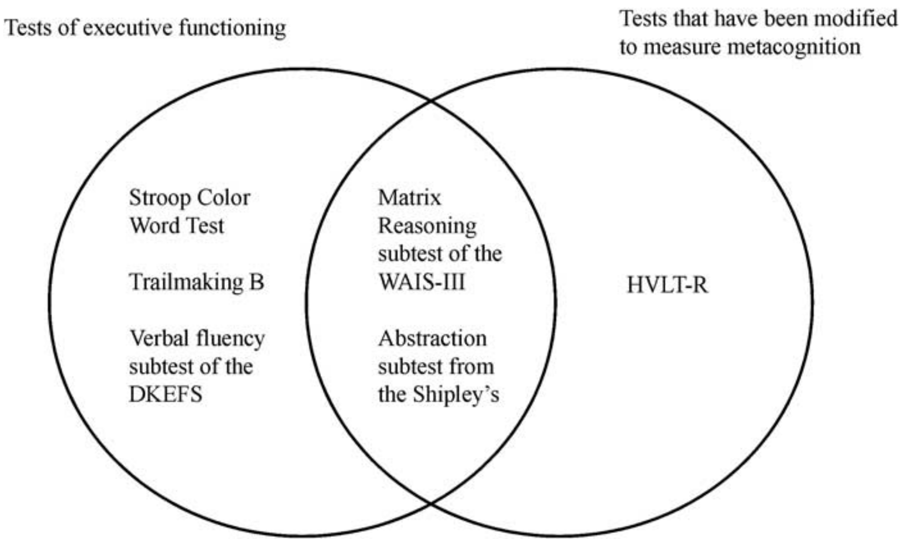

Fig. 1. Organization of neuropsychological tests used to measure executive functioning and metacognition.

In-the-Moment Metacognitive Confidence Judgments

As noted, to measure metacognitive ability, standard neuropsychological tests were modified so that immediately after answering each item of a task, participants were required to make a RCJ. After providing a response for each item, participants were asked to complete the sentence: "I am _______that my answer is correct." Participants reported their answer by selecting one of six options: completely certain, certain, somewhat certain, somewhat uncertain, uncertain and completely uncertain. These item-by-item confidence judgments were completed on the following tests: the Matrix Reasoning subtest from the WAIS-III (Wechsler, 1997), the Abstraction subtest from the Shipley's Institute of Living Scale (Shipley, 1946), and the recognition portion of the Hopkins Verbal Learning Test-R (HVLT-R) (Benedict, Schretlen, Groninger, & Brandt, 1998). These measures were chosen for modification as these tasks are non-timed, and consist of individual items that are amenable to confidence judgments. RCJs from the modified Matrix Reasoning and Shipley's Abstraction subtests were used to reflect the domain of meta-abstract reasoning, while the judgments from the modified HVLT-R served as measurements of metamemory. Of note, during the administration of the HVLT-R, participants were exposed only once to the word list instead of the standard three learning trials to reduce ceiling effects during the recognition trial. Due to the deviation from test standardization for these measures, the means and standard deviations of the HC sample from this study were used to gauge performance in the sample with TBI.

Performance and confidence judgment of the metacognitive items were coded so that a Goodman and Kruskal gamma coefficient, a measure of resolution, could be calculated (Goodman & Kruskal, 1954). These rank-order coefficients, ranging between -1 and 1, describe the concordance between pairs of performance and confidence data in a given task; that is, the extent to which confidence judgments are high when performance is high, and judgments are low when performance is low. Gamma coefficients with values closer to 1 suggest a more accurate match between confidence and performance (more accurate awareness). A gamma coefficient was calculated for each test of metacognition, for each participant (for details of the computation and use of the gamma coefficient, please refer to: Gonzalez & Nelson, 1996; Goodman & Kruskal, 1954; Nelson, 1984). The gamma coefficients were then converted into Z scores using a Fisher's r to z transform to improve the properties of the distribution (Howell, 1987) and to enable comparison against scores from the executive functioning tasks.

Executive Functioning Indices and Metacognition Indices

To more easily examine the different components of executive functioning, the scores from the different tests were combined to create indices reflecting the components noted earlier of set shifting/switching and inhibition, abstract reasoning and mental flexibility, and production fluency. Results from a factor analysis demonstrated a common organizing factor underlying the trailmaking tests and the Stroop (de Frias, Dixon, & Strauss, 2006); thus, in this study the scores were grouped together in a Switching/Inhibition index. The averaged scores from the Matrix Reasoning and Abstraction subtests were grouped into an Abstract Reasoning index based upon evidence of a high correlation and relationship between the two types of tasks (Pringle & Haanstad, 1971). Scores from the DKEFS Verbal Fluency test made up the Verbal Fluency index. The dimensionality of metacognition was examined by dividing the scores from the metacognition tests into two groups based upon domain membership. The gamma coefficients from the Matrix reasoning and Abstraction subtests were averaged and grouped into a Meta-Abstract Reasoning (meta-AR) score, while the coefficient from the HVLT-R task formed the Metamemory (metaMEM) score.

Table 3. Performance on executive functioning (indices and separate tasks): Mean Z scores (standard deviation)

	Participants with TBI	Healthy adults	*t* values
Abstract Reasoning Index	−1.0 (1.3)	0.0 (—)*	*t* (29.6) = −3.2, *p* = .004
Matrix Reasoning	−0.7 (1.2)	0.0 (—)*	
Shipley's Abstraction	−1.5 (1.7)	0.0 (—)*	
Switching/Inhibition Index	−0.7 (1.7)	0.5 (1.1)	*t* (25.1) = −2.5, *p* = .01
Trailmaking B	−1.0 (1.4)	0.3 (0.7)	
Stroop	−0.7 (2.1)	0.7 (1.7)	
Verbal Fluency Index	−0.4 (1.2)	0.9 (0.7)	*t* (32.7) = −4.3, *p* = .001
Letter fluency	−0.6 (1.3)	0.7 (0.8)	
Category fluency	−0.2 (1.3)	0.8 (1.0)	
Total Switches	−0.6 (1.4)	0.8 (0.9)	
Switching accuracy	−0.2 (1.3)	1.1 (0.9)	

*Normative data do not apply here; HC sample represents normative data.

Data Analyses and Results

All data analyses (including calculation of the gamma coefficients) were performed using Statistical Package for the Social Sciences (SPSS) Version 17.0.

Group Differences in Executive Functioning Performance and Metacognitive Accuracy

Differences in executive functioning performance between the participants with TBI and HCs were determined by using an independent samples *t*-test to compare the *Z*-scores obtained on the three executive functioning indices described earlier. Participants with TBI showed significantly worse performance compared to HCs on all three executive functioning indices (data including performance on the indices as well as on each task of executive functioning are summarized in Table 3).

Differences in metacognitive accuracy between the HCs and participants with TBI were determined by comparing gamma coefficients using an independent samples *t*-test. Participants with TBI had significantly lower gamma coefficients in the metaMEM domain compared to HCs; meaning they were less accurate in judgments of their memory performance. In contrast, there was no significant difference between gamma coefficients in the meta-AR domain across participants with TBI and HCs (data are summarized in Table 4). Of note, for individuals with TBI, the number of years post injury did not predict metacognitive accuracy.

Relationship Between Executive Functioning and Metacognition

The relationship between executive functioning and metacognitive accuracy was investigated using correlation analyses. Analyses were conducted using the *Z*-scores from each of the executive functioning indices and the *Z*-scores converted from gamma coefficients. In an effort to work with relatively "pure" measures of executive functioning, initial analyses were conducted to determine the contribution of basic attention and working memory processes to each executive index. In this group of participants with TBI, attention/working memory, as measured by the Digit Span subtest of the WAIS-III (Wechsler, 1997), was significantly correlated to all three indices of executive functioning (Verbal Fluency $r = 0.55$; $p = .01$; Abstract Reasoning $r = 0.65$; $p = .00$; and Switching/Inhibition $r = 0.54$; $p = .02$), but not related to any of the metacognitive indices. To account for this covariance, a partial correlation analysis was performed between executive function performance and metacognitive accuracy while controlling for attention/working memory performance. Using this "purer" measure of executive functioning, no significant relationships between executive functioning and metacognition were found in the sample of HCs. For the participants with TBI, the only significant correlation found was between Abstract Reasoning and meta-AR; that is, only performance on abstract reasoning tasks was related to accuracy of metacognitive judgments. A summary of these correlational results are found in Table 5.

Table 4. Differences in gamma coefficients: Mean (standard deviation)

	Participants with TBI	Healthy adults	*t* values
Metamemory	0.2 (0.5)	0.5 (0.4)	*t* (40) = −2.3*
Meta-Abstract Reasoning (Composite of Matrix Reasoning and Shipley's Abstraction subtests)	0.6 (0.2)	0.7 (0.2)	*t* (40) = −0.3
Matrix Reasoning Subtest	0.5 (0.2)	0.6 (0.3)	*t* (40) = −1.4
Shipley's Abstraction Subtest	0.8 (0.2)	0.8 (0.4)	*t* (39) = −0.1

*Denotes statistical significance at $p < .05$.

Table 5. Correlation between executive functioning indices and metacognition domains (Pearson's r values)

	Participants with TBI		Healthy Adults	
	Metamemory	Meta-abstract Reasoning	Metamemory	Meta-abstract Reasoning
Zero Order Correlations				
Abstract Reasoning Index	$r = 0.42$	$r = 0.43$	$r = 0.12$	$r = 0.02$
Switching/Inhibition Index	$r = -0.11$	$r = 0.41$	$r = 0.20$	$r = 0.11$
Verbal Fluency Index	$r = 0.04$	$r = 0.19$	$r = 0.02$	$r = 0.20$
Partial Correlations†				
Abstract Reasoning Index	$r = 0.30$	$r = 0.46$*	$r = 0.13$	$r = 0.02$
Switching/Inhibition Index	$r = -0.37$	$r = 0.42$	$r = 0.18$	$r = 0.10$
Verbal Fluency Index	$r = -0.16$	$r = 0.15$	$r = 0.04$	$r = 0.22$

*Indicates significance at $p = .05$.
†Controlling for working memory.

Differences in Metacognitive Domains

The overlap in the two metacognitive domains studied here was examined by conducting both a first order correlation analysis and a repeated-measures analysis of variance (ANOVA); these analyses were chosen to test both the magnitude to which metacognition in the domains were related to one another (correlation) and the significance of any differences (repeated-measures ANOVA). A repeated-measures ANOVA was used because the same participants were engaged in two different conditions that were to be compared; that is, each participant provided a measure of metaMEM as well as a measure of meta-AR. For each group, no significant relationships were found between the metacognitive domains (results in Table 6). The repeated-measures ANOVA revealed a statistically significant difference in gamma coefficients between the two metacognitive domains ($F(1,40) = 14.98$; $p = .000$) and demonstrated that all participants showed better metacognitive accuracy (higher gamma coefficients) on the tasks of meta-AR (mean = 0.65; $SD = 0.22$) compared to metaMEM (mean = 0.36; $SD = 0.50$). A significant interaction (depicted in Figure 2) was also found between metacognitive domain and group (TBI or HC) membership ($F(1,40) = 4.66$; $p = .04$). The findings from these analyses suggest a difference in metacognitive appraisal between the domains of memory and abstract reasoning.

The meta-AR domain was constructed from the combination of two tasks (Shipley's Abstraction and Matrix Reasoning); thus, it was necessary to also examine if there were differences based on which measurement of meta-AR was used. The separate gamma coefficients for each of the meta-AR tasks were computed and the values are provided in Table 4. A correlation analysis conducted between the metaMEM gamma coefficients and each separate subtest of the meta-AR index found no significant relationships (results presented in Table 6). These confirm the earlier finding that metacognitive abilities differ between domains.

Of interest, when comparing the gamma coefficients from different tasks within the same meta-AR domain (gamma coefficients from Matrix Reasoning and coefficients from Shipley's Abstraction) no significant relationship was found between the individual meta-AR gamma coefficients either (results shown in Table 6), suggesting differing metacognitive abilities within a domain as well.

DISCUSSION

This study is the first to use item-by-item judgments to objectively examine the relationship between the processes of executive functioning and metacognition in a sample of participants with moderate and severe TBI.

Metacognition and Executive Functioning

Importantly, the data here demonstrate that impairment in various aspects of executive functioning does not uniformly predict impairment in metacognitive ability. The failure to find a relationship between metacognitive accuracy and independent tasks of executive functioning reveals dissociable components to these processes and is at least partially attributable to the known multi-dimensionality of "executive functions." The findings

Table 6. Correlations of gamma coefficients between and within metacognitive domains

	Participants with TBI	Healthy adults
Between domains		
MetaMEM and Meta-AR	$r = 0.32$, $p = .16$	$r = 0.10$, $p = .67$
MetaMEM and Shipley's (Meta-AR)	$r = 0.41$, $p = .07$	$r = 0.01$, $p = 1.00$
MetaMEM and Matrix Reasoning (Meta-AR)	$r = 0.13$, $p = .58$	$r = -0.10$, $p = .83$
Within domain (Meta-AR)		
Shipley's and Matrix Reasoning	$r = 0.12$, $p = .62$	$r = -0.22$, $p = .34$

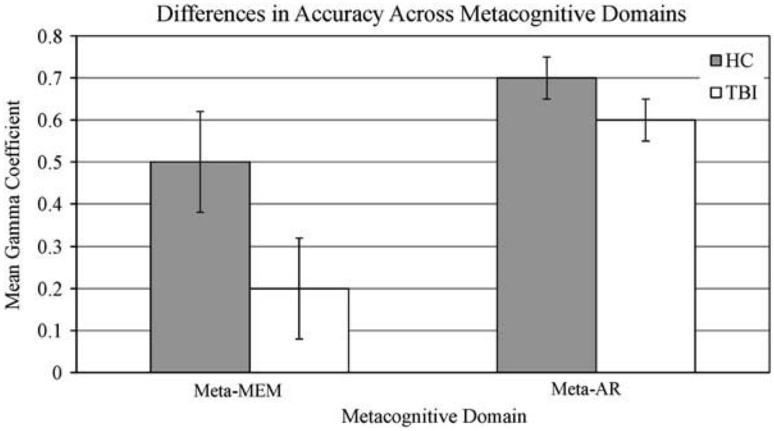

Fig. 2. Graph of differences in metacognitive accuracy across domains of MetaMEM and Meta-AR.

in TBI are similar to what has been observed in other samples; examinations of metamemory in the aging and schizophrenia literature corroborate the observation that executive functioning and aspects of metacognitive accuracy are dissociable (Cosentino et al., in press; Koren et al., 2004; Souchay, Isingrini, Clarys, Taconnat, & Eustache, 2004). The contribution of this study's findings to the understanding of the relationship between executive functioning and metacognition has significant implications for clinical application. As evidence that metacognitive processes are distinct from executive functioning mounts, clinical tools need to be developed that ensure independent and accurate assessment of these constructs.

In considering why the Abstract Reasoning index in particular was found to be related to metacognitive abilities, it is possible that the nature of the abstract reasoning task used in this study places demand on self-monitoring processes that are also inherent to metacognition. Successful completion of the Matrix Reasoning subtest, for example, involves search of a pattern or "rule" that can be applied to complete each sequence. Abstract reasoning tasks such as this require evaluation of one's own thought processes and some degree of "perspective taking" to determine how the problem was intended to be solved. The ability to engage in abstract reasoning may be linked to metacognitive accuracy due to similar evaluative processes required for each. If this were the primary basis of the association between abstract reasoning and metacognitive processes, an association between abstract reasoning and the metaMEM measure may be expected as well. Such an association was not found in this study, thus, we cannot rule out the possibility that the observed association reflects the tendency for performance on a measure to be correlated with metacognitive accuracy for that measure (Koriat & Helstrup, 2007), as RCJs for the Abstract Reasoning index comprise the meta-AR score. However, evidence elsewhere in the metamemory literature indicates that such a correlation is not a consistent and necessary phenomenon (Hager & Hasselhorn, 1992; Leonesio & Nelson, 1990), thereby suggesting that the association found in this study between the abstract reasoning component of executive functioning and metacogntive accuracy may indeed be due to shared evaluative processes.

The absence of a significant relationship between the executive functioning and metacognition in the sample of HCs may be due to a threshold effect whereby some degree of impairment is required, or due to increased observable variance measured in the TBI sample. That is, the intact Abstract Reasoning skills in the HC group could have left little variance to be examined during correlational analysis; or there was an all-or-none phenomenon, where above some threshold, intact abstract reasoning skills have little relationship to intact metacognitive accuracy.

Support for Dimensions to Metacognition

The co-existence of high accuracy in one metacognitive task and low accuracy in another for individuals with TBI indicates that metaMEM and meta-AR may be distinct. Similarly, the failure to find a relationship between the metacognitive accuracy on metaMEM and meta-AR tasks in either groups supports the notion that these metacognitive capacities may represent distinct domains. Importantly, this dissociation indicates that preserved ability in one domain may not predict similar skills in another. This has important implications for how deficits in metacognition are conceptualized after neurological injury; such deficits may not be universally observed across cognitive areas and require independent assessment.

Differences in metacognitive accuracy within domains were found as well, as metacognitive accuracy on individual subtests from the meta-AR composite were not correlated. This difference in accuracy may be attributed to a dissociation in task demands; for example, Shipley's Abstraction requires the participant to produce the answer while Matrix Reasoning requires decision making between options provided. These distinct task demands are also associated with differential feedback received—less ambiguity may be experienced when an item requires a self-generated response, ultimately affecting the reported metacognitive judgment. This hypothesis is supported by the observation that all participants in this study had better metacognitive accuracy on the Shipley's Abstraction subtest compared to the Matrix Reasoning subtest and participants with TBI were seen to benefit the most (i.e., have greatest awareness) when completing tasks that require self-generated responses.

In the metaMEM domain, the impaired accuracy demonstrated by the individuals with TBI found in this study was inconsistent with findings in an earlier study of RCJs by Kennedy (2001), where adults with TBI did not demonstrate such deficits. One possible reason for this discrepancy has to do with how metamemory was measured; a free recall task was used in the Kennedy (2001) study, while this study used a recognition format. In another study, Kennedy (2004) documented differences in metacognitive accuracy during recall when using two different types of tasks (noun pair recall *vs.* recall of narrative information). Together, these observations raise the question of whether judgments of metacognition can be generalized across tasks within the same domain; there is certainly evidence that performance on judgments of learning (recall-based) and feeling of knowing (recognition-based) tasks are not correlated (Souchay et al., 2004), likely reflecting important differences in the task demands for metacognitive judgments about self-generated content (i.e., recall) *versus* those made regarding information generated by the experimenter (i.e., recognition).

The influence of how a construct is assessed is also relevant for the study of "dimensionality" in metacognition; research to date has not controlled for how metacognitive ability is assessed. It is possible that the difference in accuracy observed between metaMEM and meta-AR is attributable to subtle differences in assessment; that is, judgments may be influenced depending on the procedure used to assess metacognition in each domain. Similarly, a "task load" effect may also be possible whereby two tasks measuring the same construct differentially tap into metacognitive accuracy due to differences in overall task difficulty. Future work requires specific manipulations (e.g., use of identical task demands) within each cognitive domain to tease apart the potential influences of assessment and task load on the dimensionality of metacognition. Identifying the contribution of task characteristics effects will be important to determine if metacognition can be divided along cognitive dimensions. Even so, the current data minimally demonstrate that the approach to assessing metacognitive ability is crucial and certain formats may be more sensitive to deficit than others (e.g., recall *vs.* recognition formats).

The use of gamma coefficients in this study has resulted in important insights into metacognition after TBI; and although to date gamma coefficients have frequently been used in studies of metacognition, there remain limitations in using this measure. In particular, the gamma coefficient requires variance in the data to be calculated; coefficients cannot be generated if one or more variables is constant (e.g., items all answered correctly or report of identical confidence ratings). Test items must thus cover a breadth of difficulty; this may have been difficult to achieve for participants who performed at the floor or ceiling.

While the gamma coefficient provides a measure of relative accuracy, important supplemental information might be gained from examining judgment directionality. Kennedy (2001) created an "absolute value" (AV) measure which determined judgment directionality (under or overconfidence). AVs were computed for the data from this study (for detailed description of the procedure, please refer to Kennedy, 2001); and in *post hoc* analyses, a significant main effect of domain was found demonstrating consistent underconfidence in both groups on the task of metaMEM, but overconfidence on tasks of meta-AR ($F(1,40) = 19.9$; $p = .000$). These results again support the finding that evaluative processes differ across domains of metacognition. Additionally, the magnitude of confidence of participants with TBI did not differ significantly from HCs in either domain (metaMEM: $t(40) = 0.67$; $p = .50$; Meta-AR(Shipley's): $t(25.5) = 0.15$; $p = .88$; Meta-AR(Matrix): $t(40) = 0.55$; $p = .58$), suggesting that the magnitude and direction of judgments made by participants with TBI were similar to the HCs. Taken together with the data from the gamma coefficients, the correspondence of low coefficients and underconfident responses reported by the participants with TBI help to confirm that the deficits in metamemory reflect a genuine effect. The AV measure appears to capture important information about the quality of awareness that may be helpful in separating the effect of potential influencing factors (e.g., response bias) and is deserving of further examination in future studies.

Future studies can expand in several other areas to increase the understanding of metacognitive experience after TBI. While this study focused on a retrospective monitoring process, there is evidence that prospective monitoring processes in metamemory are compromised after TBI (Kennedy et al., 2003; Kennedy & Yorkston, 2000); however, these have yet to be tested in the domain of meta-AR, and their relationship to executive functioning remains uncertain. A longitudinal examination of metacognition through the different temporal stages of recovery would provide useful information regarding the course of change in metacognitive abilities after neurological insult. As interest of metacognitive processes in neurological populations grows, it will be important that future studies further evaluate and confirm the validity of these measures such that there can be appropriate application in clinical samples.

CONCLUSIONS

The capacity for self-awareness is critical in day-to-day functioning and often disrupted following TBI. While subjective questionnaires dominate the literature examining awareness of deficit and offer flexibility in assessment, such methods pose significant challenges for making determinations regarding awareness of on-task performance, and for investigating the nature of metacognitive deficits in clinical populations. In this study, the use of RCJs paired with cognitive testing permits direct examination of metacognitive accuracy and its relationship to other cognitive domains. The results of this study demonstrate that metacognition in TBI is task dependent and may not be a unitary construct; the deficit observed in metaMEM did not extend to meta-AR, which was preserved in this sample. Moreover, the results of this study failed to demonstrate a consistent relationship between executive functioning and metacognition, providing evidence that while related, these constructs seem to have unique characteristics and divergent demands.

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REFERENCES

Allen, C.C., & Ruff, R.M. (1990). Self-rating versus neuropsychological performance of moderate versus severe head-injured patients. *Brain Injury*, *4*, 7–17.

Amador, X.F., Strauss, D.H., Yale, S.A., Flaum, M.M., Endicott, J., & Gorman, J.M. (1993). Assessment of insight in psychosis. *The American Journal of Psychiatry*, *150*(6), 873–879.

Anderson, J.W., & Schmitter-Edgecombe, M. (2009). Predictions of episodic memory following moderate to severe traumatic brain injury during inpatient rehabilitation. *Journal of Clinical and Experimental Neuropsychology*, *31*(4), 425–438.

Army Individual Test Battery. (1944). *Manual of directions and scoring*. Washington, DC: War Department, Adjutant General's Office.

Augustyn, J.S., & Rosenbaum, D.A. (2005). Metacognitive control of action: Preparation for aiming reflects knowledge of Fitt's Law. *Psychonomic Bulletin & Review*, *12*(5), 911–916.

Babinski, J. (1914). Contribution a l'étude des troubles mentaux dans hémiplégie orgnique cérébrale (anosognosie). *Revue Neurologique*, *27*, 845–847.

Bach, L.J., & David, A.S. (2006). Self-awareness after acquired and traumatic brain injury. *Neuropsychological Rehabilitation*, *16*(4), 397–414.

Barrett, A.M., Eslinger, P.J., Ballentine, N.H., & Heilman, K.M. (2005). Unawareness of cognitive deficit (cognitive anosognosia) in probable AD and control subjects. *Neurology*, *64*, 693–699.

Benedict, R.H.B., Schretlen, D., Groninger, L., & Brandt, J. (1998). Hopkins Verbal Learning Test-Revised: Normative data and analysis of inter-form and test-retest reliability. *The Clinical Neuropsychologist*, *12*, 43–55.

Bogod, N., Mateer, C.A., & MacDonald, S.W. (2003). Self-awareness after traumatic brain injury: A comparison of measures and their relationship to executive function. *Journal of the International Neuropsychological Society*, *9*, 450–458.

Busch, R.M., McBride, A., Curtiss, G., & Vanderploeg, R.D. (2005). The components of executive functioning in traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*, *27*, 1022–1032.

Chen, Q., Wei, P., & Zhou, X. (2006). Distinct neural correlates for resolving stroop conflict at inhibited and noninhibited locations in inhibition of return. *Journal of Cognitive Neuroscience*, *18*(11), 1937–1946.

Chua, E.F., Schacter, D.L., Rand-Giovannetti, E., & Sperling, R.A. (2006). Understanding metamemory: Neural correlates of the cognitive process and subjective level of confidence in recognition memory. *Neuroimage*, *29*, 1150–1160.

Chua, E.F., Schacter, D.L., & Sperling, R.A. (2009). Neural correlates of metamemory: A comparison of feeling-of-knowing and retrospective confidence judgments. *Journal of Cognitive Neuroscience*, *21*(9), 1751–1765.

Ciurli, P., Bivona, U., Barba, C., Onder, G., Silvestro, D., Azicnuda, E., … Formisano, R. (2010). Metacognitive unawareness correlates with executive function impairment after severe traumatic brain injury. *Journal of the International Neuropsychological Society*, *16*(2), 360–368.

Collette, F., Hogge, M., Salmon, E., & Van Der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience*, *139*, 209–221.

Cosentino, S., Metcalfe, J., Holmes, B., Steffener, J., & Stern, J. (in press). Finding the self in metacognitive evaluations: A study of metamemory and agency in non-demented elders. *Neuropsychology*.

Cosentino, S., & Stern, Y. (2005). Metacognitive theory and assessment in dementia: Do we recognize our areas of weakness? *Journal of the International Neuropsychological Society*, *11*(7), 910–919.

de Frias, C.M., Dixon, R.A., & Strauss, E. (2006). Structure of four executive functioning tests in healthy older adults. *Neuropsychology*, *20*(2), 206–214.

Delis, D.C., Kaplan, E., & Kramer, J.H. (2001). *Delis Kaplan Executive Function Systems*. San Antonio, TX: The Psychological Corporation.

Dunloskly, J., Baker, J.M., Rawson, K.A., & Hertzog, C. (2006). Does aging influence people's metacomprehension? Effects of processing ease of judgments of text learning. *Psychology and Aging*, *21*(2), 390–400.

Dunlosky, J., & Metcalfe, J. (2009). *Metacognition*. Thousand Oaks, CA: Sage Publications, Inc.

Evans, C.C., Sherer, M., Nick, T.G., Nakase-Richardson, R., & Yablon, S.A. (2005). Early impaired self-awareness, depression, and subjective well-being following traumatic brain injury. *Journal of Head Trauma Rehabilitation*, *20*(6), 488–500.

Faul, M., Xu, L., Wald, M.M., & Coronado, V.G. (2010). *Traumatic brain injury in the United States: Emergency department visits, hospitalizations, and deaths 2002–2006*. Atlanta, GA: Centers for disease Control and Prevention, National Center for Injury Prevention and Control.

Fernandez-Duque, D., Baird, J.A., & Posner, M.I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition*, *9*, 288–307.

Flashman, L.A., & McAllister, T.W. (2002). Lack of awareness and its impact in traumatic brain injury. *Neurorehabilitation*, *17*, 285–296.

Flavell, J.H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, *34*(10), 906–911.

Fleming, J.M., & Strong, J. (1995). Self-awareness of deficits following acquired brain injury: Considerations for rehabilitation. *British Journal of Occupational Theory*, *58*, 55–58.

Fleming, J.M., Strong, J., & Ashton, R. (1996). Self-awareness of deficits in adults with traumatic brain injury: How best to measure? *Brain Injury*, *10*, 1–15.

Gallup, G.G., Jr., & Suarez, S.D. (1991). Social responding to mirrors in rhesus monkeys (*macaca mulatta*): Effects of temporary mirror removal. *Journal of Comparative Psychology*, *105*(4), 376–379.

Garmoe, W., Newman, A.C., & O'Connell, M. (2005). Early self-awareness following traumatic brain injury: Comparison of brain injury and orthopedic inpatients using the functional self-assessment scale (FSAS). *The Journal of Head Trauma Rehabilitation*, *20*(4), 348–358.

Godfrey, H.P., Partridge, F.M., Knight, R.G., & Bishara, S.N. (1993). Course of insight disorder and emotional dysfunction following closed head injury: A controlled cross-sectional follow up study. *Journal of Clinical and Experimental Neuropsychology*, *15*(4), 503–515.

Goldenberg, G., Müllbacher, W., & Nowak, A. (1995). Imagery without perception—A case study of anosognosia for cortical blindness. *Neuropsychologia*, *33*(11), 1373–1382.

Gonzalez, R., & Nelson, T.O. (1996). Measuring ordinal association in situations that contain tied scores. *Psychological Bulletin*, *119*(1), 159–165.

Goodman, L.A., & Kruskal, W.H. (1954). Measures of association for cross classifications. *Journal of the American Statistical Association*, *49*(268), 732–764.

Griffin, T.D., Jee, B.D., & Wiley, J. (2009). The effects of domain knowledge on metacomprehension accuracy. *Memory and Cognition*, *37*(7), 1001–1013.

Griffin, T.D., Wiley, J., & Thiede, K.W. (2008). Individual differences, rereading, and self-explanation: Concurrent processing and cue validity as constraints on metacomprehension accuracy. *Mem Cogni*, *36*(1), 93–103.

Hager, W., & Hasselhorn, M. (1992). Memory monitoring and memory performance: Linked closely or loosely? *Psychological Research*, *54*, 110–113.

Hart, T., Whyte, J., Kim, J., & Vaccaro, M. (2005). Executive function and self-awareness of "real-world" behavior and attention deficits following traumatic brain injury. *Journal of Head Trauma Rehabilitation*, *20*(4), 333–347.

Heilman, K.M., Barrett, A.M., & Adair, J.C. (1998). Possible mechanisms of anosognosia: A defect in self-awareness. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences*, *353*(1377), 1903–1909.

Hertzog, C., Dixon, R.A., & Hultsch, D.F. (1990). Relationships between metamemory, memory predictions, and memory task performance in adults. *Psychology of Aging*, *5*(2), 215–227.

Howell, D.C. (1987). *Statistical methods for psychology* (2nd ed.). Boston, MA: PWS Publishers.

Karpicke, J.D. (2009). Metacognitive control and strategy selection: Deciding to practice retrieval during learning. *Journal of Experimental Psychology: General*, *138*(4), 469–486.

Kaszniak, A.W., & Zak, M.G. (1996). On the neuropsychology of metamemory: Contributions from study of amnesia and dementia. *Learning & Individual Differences*, *8*(4), 355–381.

Kennedy, M.R.T. (2001). Retrospective confidence judgments made by adults with traumatic brain injury: Relative and absolute accuracy. *Brain Injury*, *15*(6), 469–487.

Kennedy, M.R.T. (2004). Self-monitoring recall during two tasks after traumatic brain injury: A preliminary study. *American Journal of Speech-Language Pathology*, *13*, 142–154.

Kennedy, M.R.T., Carney, E., & Peters, S.M. (2003). Predictions of recall and study strategy decisions after diffuse brain injury. *Brain Injury*, *17*(12), 1043–1064.

Kennedy, M.R.T., & Yorkston, K.M. (2000). Accuracy of metamemory after traumatic brain injury: Predictions during verbal learning. *Journal of Speech, Language, and Hearing Research*, *43*(5), 1072–1086.

Kervick, R.B., & Kaemingk, K.L. (2005). Cognitive appraisal accuracy moderates the relationship between injury severity and psychosocial outcomes in traumatic brain injury. *Brain Injury*, *19*(11), 881–889.

Kikyo, H., Ohki, K., & Miyashita, Y. (2002). Neural correlates for feeling-of-knowing: An fMRI parametric analysis. *Neuron*, *36*, 177–186.

Koren, D., Seidman, L.J., Poyurovsky, M., Goldsmith, M., Viksman, P., Zichel, S., & Klein, E. (2004). The neuropsychological basis of insight in first episode schizophrenia: A pilot metacognitive study. *Schizophrenia Research*, *70*(2), 195–202.

Koriat, A., & Helstrup, T. (2007). Metacognitive aspects of memory. In S. Magnussen & T. Helstrup (Eds.), *Everyday memory* (pp. 251–274). New York, NY: Psychology Press.

Lebrun, Y. (1987). Anosognoisa in aphasics. *Cortex*, *23*(2), 251–263.

Lefèvre, N., & Lories, G. (2004). Text cohesion and metacomprehension: Immediate and delayed judgments. *Memory and Cognition*, *32*(8), 1238–1254.

Leonesio, R.J., & Nelson, T.O. (1990). Do different metamemory judgments tap the same underlying aspects of memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(3), 464–467.

Leritz, E., Loftis, C., Crucian, G., Friedman, W., & Bowers, D. (2004). Self-awareness of deficits in Parkinson disease. *The Clinical Neuropsychologist*, *18*, 352–361.

Maki, R.H., & Berry, S.L. (1984). Metacomprehension of text material. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(4), 663–679.

Markela-Lerenc, J., Ille, N., Kaiser, S., Fiedler, P., Mundt, C., & Weisbrod, M. (2004). Prefrontal-cingulate activation during executive control: Which comes first? *Cognitive Brain Research*, *18*, 278–287.

McAvinue, L., O'Keeffe, F., McMackin, D., & Robertson, I.H. (2005). Impaired sustained attention and error awareness in traumatic brain injury: Implications for insight. *Neuropsychological Rehabilitation*, *15*(5), 569–597.

McDonald-Miszczak, L., Hertzog, C., & Hultsch, D.F. (1995). Stability and accuracy of metamemory in adult and aging: A longitudinal analysis. *Psychology of Aging*, *10*(4), 553–564.

McGlynn, S.M., & Schacter, D.L. (1997). The neuropsychology of insight: Impaired awareness of deficits in a psychiatric context. *Psychiatric Annals*, *27*(12), 806–811.

Metcalfe, J. (2009). Metacognitive judgments and control of study. *Current Directions in Psychological Science*, *18*(3), 159–163.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wagner, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Nelson, T.O. (1984). A comparison of current measures of the accuracy of feeling-of-knowing predictions. *Psychological Bulletin*, *95*(1), 109–133.

Nelson, T.O. (1992). *Metacognition: Core readings*. Boston: Allyn & Bacon.

Nelson, T.O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. *The Psychology of Learning and Motivation*, *26*, 125–173.

Norman, D.A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R.J. Davidson, G.E. Schwartz, & D. Sapiro (Eds.), *Consciousness and self regulation* (pp. 1–17). New York: Plenum.

Ownsworth, T., & Fleming, J. (2005). The relative importance of metacognitive skills, emotional status, and executive function in psychosocial adjustment following acquired brain injury. *Journal of Head Trauma Rehabilitation*, *20*(4), 315–332.

Ownsworth, T.L., McFarland, K., & Young, R.M. (2002). The investigation of factors underlying deficits in self-awareness and self-regulation. *Brain Injury*, *16*(4), 291–309.

Pannu, J.K., & Kaszniak, A.W. (2005). Metamemory experiments in neurological populations: A review. *Neuropsychology Review*, *15*(3), 105–130.

Perrotin, A., Belleville, S., & Isingrini, M. (2007). Metamemory monitoring in mild cognitive impairment: Evidence of a less accurate episodic feeling-of-knowing. *Neuropsychologia*, *45*(2), 2811–2826.

Perrotin, A., Isingrini, M., Souchay, C., Clarys, D., & Taconnat, L. (2006). Episodic feeling-of-knowing accuracy and cued recall in the elderly: Evidence for double dissociation involving executive functioning and processing speed. *Acta Psychologica*, *122*(1), 58–73.

Perrotin, A., Tournelle, L., & Isingrini, M. (2008). Executive functioning and memory as potential mediators of the episodic feeling-of-knowing accuracy. *Brain and Cognition*, *67*(1), 76–87.

Pia, L., & Tamietto, M. (2006). Unawareness in schizophrenia: Neuropsychological and neuranatomical findings. *Psychiatry and Clinical Neurosciences*, *60*, 531–537.

Prigatano, G.P. (1997). The problem of impaired self-awareness in neuropsychological rehabilitation. In J. Leon-Carrion (Ed.), *Neuropsychological rehabilitation: Fundamentals, innovations and directions*. Florida: GR/St. Lucie Press.

Prigatano, G.P., & Fordyce, D.J. (1986). Cognitive dysfunction and social adjustment after brain Injury. In G.P. Prigatano, D.J. Fordyce, H.K. Zeiner, J.R. Roueche, M. Pepping, & B.C. Wood (Eds.), *Neuropsychological rehabilitation after brain injury*. Baltimore, MD: Johns Hopkins University Press.

Prigatano, G.P., & Klonoff, P.S. (1998). A clinician's rating scale for evaluating impaired self-awareness and denial of disability after brain injury. *The Clinical Neuropsychologist*, *12*(1), 56–67.

Pringle, R.K., & Haanstad, M. (1971). Estimating WAIS IQs from progressive matrices and Shipley-Hartford scores. *Journal of Clinical Psychology*, *27*(4), 479–481.

Rawson, K.A., Dunlosky, J., & Thiede, K.W. (2000). The rereading effect: Metacomprehension accuracy improves across reading trials. *Memory and Cognition*, *28*(6), 1004–1010.

Redford, J.S. (2010). Evidence of metacognitive control by humans and monkeys in a perceptual categorization task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(1), 248–254.

Reitan, R.M., & Wolfson, D. (1985). *The Halstead-Reitan Neuropsychological Test Battery: Therapy and clinical interpretation*. Tucson, AZ: Neuropsychological Press.

Rickelman, B.L. (2004). Anosognosia in individuals with schizophrenia: Toward recovery of insight. *Issues in Mental Health Nursing*, *25*, 227–242.

Roche, N.L., Fleming, J.M., & Shum, D.H. (2002). Self-awareness of prospective memory failure in adults with traumatic brain injury. *Brain Injury*, *16*(11), 931–945.

Satz, P., Forney, D.L., Zaucha, K., Asarnow, R.R., Light, R., McCleary, C., … Becker, D. (1998). Depression, cognition, and functional correlates of recovery outcome after traumatic brain injury. *Brain Injury*, *12*(7), 537–553.

Sawchyn, J.M., Mateer, C.A., & Suffield, J.B. (2005). Awareness, emotional adjustment, and injury severity in postacute brain injury. *Journal of Head Trauma Rehabilitation*, *20*(4), 301–314.

Schneyer, D.M., Verfaellie, M., Alexander, M.P., LaFleche, G., Nicholls, L., & Kaszniak, A.W. (2004). A role of right medial prefrontal cortex in accurate feeling-of-knowing judgments: Evidence from patients with lesions to frontal cortex. *Neuropsychologia*, *42*, 957–966.

Sherer, M., Hart, T., Nick, T.G., Whyte, J., Thompson, R.N., & Yablon, S.A. (2003). Early impaired self-awareness after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation*, *84*, 168–176.

Shimamura, A.P. (2000). Toward a cognitive neuroscience of metacognition. *Consciousness and Cognition*, *9*, 313–323.

Shipley, W.C. (1946). *Institute of Living Scale*. Los Angeles, CA: Western Psychological Services.

Souchay, C., Isingrini, M., Clarys, D., Taconnat, L., & Eustache, F. (2004). Executive functioning and judgment-of-learning versus feeling-of-knowing in older adults. *Experimental Aging Research*, *30*(1), 47–62.

Souchay, C., Isingrini, M., & Espagnet, L. (2000). Aging, episodic feeling-of-knowing, and frontal functioning. *Neuropsychology*, *14*(2), 229–309.

Stuss, D.T., & Alexander, M.P. (2000). Executive functions and the frontal lobes: A conceptual view. *Psychological Research*, *63*, 289–298.

Stuss, D.T., & Levine, B. (2002). Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology*, *53*, 401–433.

Thiede, K.W., Wiley, J., & Griffin, T.D. (2010). Test expectancy affects metacomprehension accuracy. *British Journal of Educational Psychology*. [Epub ahead of print].

Tiede, H.L., Derksen, C., & Leboe, J.P. (2009). An investigation of increases in metamemory confidence across multiple study trials. *Memory*, *17*(3), 288–300.

Trahan, E., Pépin, M., & Hopps, S. (2006). Impaired awareness of deficits and treatment adherence among people with traumatic brain injury or spinal cord injury. *The Journal of Head Trauma Rehabilitation*, *21*(3), 226–235.

Trenerry, M.R., Crosson, B., Deboe, J., & Leber, W.R. (1989). *Stroop Neuropsychological Screening Test*. Lutz, FL: Psychological Assessment Resources, Inc.

Wagner, M.T., Spangenberg, K.B., Bachman, D.L., & O'Connell, P. (1997). Unawareness of cognitive deficit in Alzheimer disease and related dementias. *Alzheimer Disease and Associated Disorders*, *11*(3), 125–131.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale-III*. San Antonio, TX: The Psychological Corporation.

Whyte, J., & Rosenthal, M. (1993). Rehabilitation of the patient with brain injury. In J.A. DeLisa (Ed.), *Rehabilitation medicine: Principles and practice* (2nd ed., pp. 825–860). Philadelphia: J.B. Lippincott Company.