Metacognition in Individuals Aging with Traumatic Brain Injury

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Abstract

OBJECTIVE: To measure metacognition in adults aging with moderate-severe traumatic brain injury (TBI) through objective (task-based) and subjective (self-report) measures to determine association between measures, and ability to predict executive functioning (EF), emotional functioning, and functional outcome.

METHOD: 130 individuals (TBI $n = 102$; healthy controls (HC) $n = 28$) were included. Participants completed objective tasks of metacognition and EF, and self-reported measures of metacognition (MCQ-30), psychiatric symptoms (BSI-18), and community participation (PART-O). The objective metacognitive task and MCQ-30 subscales were used as predictors of EF, anxiety, and community participation. Post-hoc analyses examined the association between objective and subjective metacognitive measures in TBI subgroups (overconfident, metacognitively accurate).

RESULTS: The objective metacognitive task and one self-report subscale predicted EF [$F(2) = 9.69, p < 0.001, R^2 = 0.17$]. Two self-report subscales predicted anxiety [$F(2) = 19.15, p < 0.001, R^2 = 0.28$]. No variables predicted community participation. There was a significant interaction between the metacognitive groups (overconfident, accurate) and MCQ-30 on objective metacognitive performance [$R^2 = 0.23, p = 0.037$].

CONCLUSION: Individuals aging with TBI demonstrated metacognitive deficit 45% of the time and when they did, ~90% over-estimated their ability. Both objective and subjective metacognitive measures predicted aspects of functional outcomes. However, self-report and objective metacognitive measures are related only when objective metacognitive performance is high, confirming long-standing concerns that self-report may be unreliable when awareness of deficit is present. These findings challenge the predictive validity of self-report measures of metacognition.

Keywords: traumatic brain injury (TBI); metacognition; executive functioning; functional outcome

Impact Statement**Key Points –**

Question: How do objective (i.e., task-based) and subjective (i.e., self-report) measures of metacognition predict functional outcomes in a population of individuals aging with TBI?

Findings: While both objective and subjective measures have different predictive value for understanding aspects of functional outcome, self-report measures may be limited to understanding patients' perceptions of their own metacognitive awareness and have less value in predicting "in-the-moment" metacognitive performance, in particular when deficit is present.

Importance: Metacognitive deficits continue into late adulthood in individuals with chronic TBI, and these deficits have implications for executive functioning evident during testing and day-to-day functioning. There is little use of objective metacognitive assessment clinically, yet there are well-known limitations of self-report measures when assessing metacognition.

Next Steps: With longstanding concern about the role of TBI in exacerbating the normal aging process, with critical focus on frontal systems (Moretti et al., 2012), there is need for empirical measurement of metacognitive function and awareness of deficit more generally.

Metacognition is the ability to reflect on one's own cognitive processes (Flavell, 1979) and has important implications for everyday functioning, such as perceptions of quality of life, adherence to rehabilitation, and ability for independent living (Chiou, Carlson, Arnett, Consentino, & Hillary, 2011; Evans, Sherer, Nakase-Richardson, & Yablon, 2005; Flashman & McAllister, 2002; Ownsworth & Fleming, 2005). Deficits in metacognition are well-documented in various psychiatric and neurologic populations, including traumatic brain injury (TBI) (Ben-Yishay et al., 1985; Bivona et al., 2008; Prigatano, 1986; Sherer, Bergloff, Boake, High Jr., & Levin, 1998), as well as in healthy and abnormal aging populations (Calsco, Besnard, & Allain, 2019; Mograbi, Ferri, et al., 2012; Morris & Hannesdottir, 2004). Metacognitive deficit in both TBI and aging populations is unsurprising given that both brain injury and cognitive aging processes frequently result in damage to and degeneration of the frontal lobe, a region commonly associated with executive functions and evaluative processes (Dempster, 1992; Moscovitch & Winocur, 1992; Ownsworth & Fleming, 2005; West, 1996).

While the metacognitive literature in TBI has not been linked to it as of yet, there is growing concern that TBI adversely influences the aging process with several studies pointing to disproportionately greater decline in frontally-mediated functioning (Moretti, Cristofori, Weaver, Chau, Portelli, & Grafman, 2012; Raymont, Greathouse, Reding, Lipsky, Salazar, & Grafman, 2008). However, little is known about what happens to metacognition in a population aging with TBI. Given that metacognition and self-monitoring strategies have demonstrated utility in helping healthy older adults compensate for age-related cognitive decline (Hertzog & Dunlosky, 2011), understanding the nature of this deficit in this population could prove particularly useful for assisting older individuals aging with TBI with strategies to improve overall functioning.

Multiple methods have been used to quantify metacognitive ability. Questionnaires have historically been the most commonly used method to describe and measure metacognitive processes. This method is relatively cost-effective and easy to use, but may be problematic and biased due to self-report measures requiring individuals to report on their own internal experience. It has been documented that people may not be accurate reporters of their own cognitions and internal thought processes (Akturk & Sahin, 2011) and these natural “blind spots” in human cognition are exacerbated after TBI, where awareness of performance may be impaired. There are several commonly used questionnaires to assess metacognition in aging individuals, as well as individuals sustaining TBI, including the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982), the Dysexecutive Questionnaire (Burgess, Alderman, Evans, Emslie, & Wilson, 1998), the Thought Control Questionnaire (Wells & Davies, 1994), and the Metacognitions Questionnaire (Cartwright-Hatton & Wells, 1997). These measures pose questions about an individual’s ability to handle negative thoughts, their perceptions of their own worries, and perceived confidence in their memory and past judgments (Wells & Cartwright-Hatton, 2004). Using brief questionnaires for metacognitive ability can be helpful when examining metacognitive skills in relation to psychological disorders, as they can generally screen for distortions in thought processes and deficits in cognitive monitoring (Wells & Cartwright-Hatton, 2004).

While these screeners are useful tools, they may not be as accurate or as sensitive as other quantifiable methods of measuring metacognition (Schellings et al., 2013; Veenman, 2005). To provide convergent validity, studies frequently have both participants and a caregiver informant complete a questionnaire reporting on the participant’s level of awareness. For example, measures such as the Frontal Behavior Inventory (FBI; Kertesz, Davidson, & Fox, 1997) and the

Frontal Systems Behavior Scale (FrSBe; Grace, Stout, & Malloy, 1999) have been used to calculate a discrepancy score for reports of frontal lobe related behaviors in both TBI and aging populations (Mallow & Grace, 2005). The goal of this discrepancy score is to bring greater objectivity to the report of functioning above and beyond what can be gained from an individual's self-reported level of functioning (Bivona et al., 2008; Ciurli et al., 2010).

Experimental manipulations offer an alternative method for measuring metacognitive ability that overcome some of the methodological limitations of self-report. Metacognition has been assessed through objective tasks, such as perceptual judgment and decision-making procedures (Fleming, Huijgen, & Dolan, 2012) or motor inhibition paradigms (Murphy, Robertson, Harty, & O'Connell, 2015) that assess confidence judgments in relation to task performance. Error-monitoring tasks have also been used to determine an individual's "online awareness" of their ability to detect an error in the moment (Ham et al., 2013), demonstrating reflective monitoring processes occurring in the moment. Similarly, in the study of meta-memory, participants are required to provide in-the-moment responses regarding how well they think they will remember the words as a measure of prospective metacognitive accuracy (Flavell, 1979). These experimental procedures measure metacognitive ability objectively and avoid the potential bias of self-report measures, but the question remains as to whether the construct measured by self-report questionnaires and objective metacognitive tasks are the same.

To further complicate the assessment of metacognition, the conceptualization of metacognitive ability as a single construct has been challenged, with some investigators arguing that there is less evidence for a global metacognitive ability but rather distinct components comprising metacognition (Kelemen, Frost, & Weaver, 2000; Vandergrift, Goh, Mareschal, & Tafaghodtari, 2006). Overall assessment of metacognitive ability may not be as sensitive to the

differences in domain-specific metacognitive skills, and distinct metacognitive domains are not necessarily highly correlated with one another and demonstrate weak associations with overall metacognitive accuracy (Nelson & Narens, 1994; Kelemen et al., 2000). Similarly, a review examining self-awareness deficits in moderate-severe TBI concluded that multiple measures of metacognitive awareness are not highly correlated with each other (Dromer, Kheloufi, & Azouvi, 2020). Depending on the measurement and conceptualization of metacognitive ability, metacognition has been shown to be associated with executive functioning skills (Bivona et al., 2008; Ciurli et al., 2010; Follmer & Sperling, 2016), anxiety (Irak & Tusan, 2008; Ryum et al., 2017), and reintegration into the community following brain injury (Robertson & Schmitter-Edgecombe, 2015). These findings suggest that metacognition is better conceptualized as a set of distinct skills rather than one overarching ability, and that metacognitive ability may also be related to multiple areas of cognitive, emotional, and psychosocial functioning, which are particularly important to understand within the context of recovery from brain injury.

While it has been established that both individuals sustaining TBI and older adults commonly experience metacognitive deficit, it remains unclear how to best capture the type of metacognitive deficit experienced by individuals aging with TBI, and how deficits in metacognitive ability impact functional outcome. While metacognition is known to wane with aging and is directly impacted by neurotrauma, there is virtually no work examining the confluence of these effects, which is an important gap in the literature given the known risk of TBI for cognitive decline in senescence (Moretti et al., 2012).

Study Goals:

There is longstanding use of subjective measures to assess metacognition in neurological populations but with the common concern that metacognitive deficits are not ideally identified

using self-report (Akturk & Sahin, 2011; Veenman, 2011) and may not show strong convergence with objective measures of performance (Jacobse & Harskamp, 2012). The primary aim of this paper is to first demonstrate metacognitive deficit in a population of individuals aging with TBI, and then assess metacognition through both objective (task-based) and subjective (self-report) measures in order to determine their points of overlap as well as incremental validity for predicting outcomes after brain injury that relate to metacognitive ability. To do so, we will first examine differences in an objective and subjective measure of metacognition between a group of individuals aging with TBI and healthy control group. Then, we use both the objective and subjective measures of metacognitive ability to predict three outcome domains of functioning that are sensitive to TBI-related impairments: 1) executive functioning, a cognitive domain that comprises metacognition, 2) self-reported levels of anxiety, which have been shown to hold overlapping relationships with metacognition, and 3) societal participation and community integration, which are ecologically valid indicators of functional recovery and quality of life. The present paper seeks to evaluate the relationship between metacognition and these outcomes of interest in older adults with moderate-severe TBI, comparing the predictive value of self-report and objective metacognitive measures. We hypothesize that performance-based metacognition will be a stronger predictor of outcome than self-reported metacognitive ability, and this distinction will be more pronounced in participants with TBI who may have injury-related deficits in self-awareness.

Methods

Participants

Participants included 102 older individuals (age > 55 years) with history of moderate or severe TBI (msTBI) and 28 uninjured older adult participants. Participants must have sustained a

TBI of at least moderate severity as evidenced by at least one of the following: Glasgow Coma Scale score < 13 (not due to intoxication/sedation) on admission to emergency care, documented loss of consciousness of at least one hour, documented posttraumatic amnesia of at least 24 hours, or positive findings on neuroimaging, as these injuries have been demonstrated to produce similar deficits to moderate-severe injuries (Kashluba, Hanks, Casey, & Millis, 2008; Tayim, Flashman, Wright, Roth, & McAllister, 2016). Individuals were excluded if they had a history of TBI separate from the index injury, other neurologic disorder, or serious psychiatric illness such as schizophrenia or bipolar disorder. See Table 1 for participant demographics.

Participants were recruited through Penn State Hershey Medical Center in Hershey, Pennsylvania and Moss Rehabilitation Research Institute Einstein Healthcare Network in Philadelphia, Pennsylvania. All participants were phone screened to determine eligibility. Participants underwent an informed consent process prior to the conduct of any research activities. They were provided compensation for their participation and travel expenses. All components of the study were approved by both The Pennsylvania State University and Moss Rehabilitation Research Institute institutional review boards.

Measures

Participants were administered a comprehensive neuropsychological test battery measuring several cognitive domains, including neuropsychological tests, self-report questionnaires of mood, behavior, quality of life, and overall involvement and functioning in life (defined as societal involvement and community integration).

Objective Metacognitive Task

Objective metacognitive performance evaluation was assessed using a modified Matrix Reasoning task adapted from Wechsler Adult Intelligence Scale – Third Edition (Wechsler, 1997) with retrospective confidence judgments served as the objective measure of metacognition (see Chiou et al., 2011; Chiou & Hillary, 2012; Grossner, Bernier, Brenner, Chiou, & Hillary, 2018; Grossner, Bernier, Brenner, Chiou, Hong, & Hillary, 2019). This perceptual reasoning task required participants to complete an abstract puzzle from one of five presented choices. The metacognitive portion of this task required participants to report their level of confidence in their choice on a six-point Likert scale ranging from “completely certain” to “completely uncertain.” This task is thought to represent the performance evaluation aspect of metacognitive ability.

Quantifying Metacognitive Accuracy from Objective Task

Metacognitive accuracy values were calculated from the performance scores and retrospective confidence judgment ratings from the objective metacognitive task. This accuracy value was quantified using a Type II area under the receiver operating characteristic (ROC) curve. This method measures metacognitive sensitivity by incorporating both the participant’s correct and incorrect responses, as well as the reported confidence level for each trial. It also accounts for the participant’s overall tendency to respond confidently or unconfidently, addressing the issue of metacognitive bias. This methodology is documented in Maniscalco and Lau’s paper (2012) and has been used in previous studies from our laboratory (Grossner et al., 2018; Grossner et al., 2019). The MATLAB code is available in supplemental materials.

Metacognitions Questionnaire (MCQ-30)

The MCQ-30 is a multidimensional self-report measure of metacognition (Wells & Cartwright-Hatton, 2004). It is a short-form assessment of the original Metacognitions Questionnaire (Cartwright-Hatton & Wells, 1997). There are five subscales of the MCQ-30, with

six items comprising each subscale. The subscales represent the following domains: cognitive confidence, positive beliefs, cognitive self-consciousness, uncontrollability and danger, and need to control thoughts. Higher scores represent more self-reported metacognitive concerns.

Executive Functioning Composite

The executive functioning composite was created from two measures of executive functioning: Trail Making Test – B (Army Individual Test Battery, 1944) and the Delis-Kaplan Executive Function System (D-KEFS) Color-Word Interference – Inhibition condition (Delis, Kaplan, & Kramer, 2001). Trail Making Test – B requires cognitive abilities such as visual search and scanning, processing speed, mental flexibility, and executive functioning while alternating between connecting numbers in ascending order and letters in alphabetical order (Tombaugh, 2004). The score on this task is the completion time in seconds (Reitan, 1958). The Color-Word Interference – Inhibition condition task from the D-KEFS similarly measures processing speed, mental flexibility, and inhibitory control (Lippa & Davis, 2010). This task, which is based on the Stroop (1935) task, is the third condition of a four-part task, requiring the participant to name the color of ink in which the words (red, blue, and green) are printed as quickly as possible while inhibiting the prepotent response to read aloud the color word names. The score on this task is the completion time in seconds (Delis, Kaplan, & Kramer, 2001). The raw scores for each were transformed into Z-scores and averaged to create a composite score.

Brief Symptom Inventory-18 (BSI-18)

The Brief Symptom Inventory-18 (BSI-18; Derogatis, 2000) is a short-form assessment of the Brief Symptom Inventory (BSI; Derogatis, 1993). Both of these measures were created from the Symptom Checklist-90-Revised (SCL-90-R; Derogatis, 1994), which assesses nine dimensions of psychiatric symptoms. The BSI-18 was developed as a shorter self-report screener

to specifically assess somatization, anxiety, and depression, as well as a global severity index of these psychiatric domains (Derogatis, 2000).

Participation Assessment with Recombined Tools – Objective (PART-O)

The Participation Assessment with Recombined Tools – Objective (PART-O; Whiteneck et al., 2011) is an objective measure of community participation created from items from three instruments: the Community Integration Questionnaire, the Participation Objective, Participation Subjective, and the Craig Handicap Assessment and Reporting Technique. This measure asks individuals about the frequency with which they participate in various events during a typical week or month, including questions about social and romantic relationships. It includes three subscales of Productivity, Social Relations, and Out and About, and asks individuals about the frequency with which they participate in various events during a typical week or month, including questions about social and romantic relationships. It assumes that more participation in life activities is better, thereby higher scores reflects higher levels of functioning (Bogner, Bellon, Kolakowky-Hayner, & Whiteneck, 2013).

Procedure

All participants in both the TBI and healthy control groups received the same protocol. The data used in this study was taken from a parent study that collected neuroimaging, genetics, and blood pressure protocols, but the neuropsychological testing battery from the parent study was the only portion used for subsequent analyses.

Participants were administered a comprehensive neuropsychological battery, including the measures detailed above. These six measures from the battery were used in analyses: 1. Objective metacognitive task, 2. Trail Making Test - B, 3. D-KEFS Color-Word Interference – Inhibition condition, 4. MCQ-30, 5. BSI-18, and 6. PART-O. Metacognitive accuracy values

were obtained using the area under the ROC curve (described above). An executive functioning (EF) composite was used as the objective measure of executive functioning. The EF composite was created using performance on Trail Making Test – B and D-KEFS Color-Word Interference – Inhibition condition. Z-scores for each task were calculated based on the mean and standard deviation of the whole sample and then averaged to create the composite. The MCQ-30 derives a total score, as well as subscale scores of “cognitive confidence,” “positive beliefs,” cognitive self-consciousness,” “uncontrollability and danger,” and “need to control thoughts.” The BSI-18 derives three subscale scores of somatization, anxiety, and depression, as well as a global severity index. Only the anxiety subscale was used in subsequent analyses. Lastly, the PART-O has a total score and three subscales of “out and about,” “productivity,” and “social relations.” See Table 2 for details on each of the predictor and outcome variables.

Data Analysis Plan

We conducted independent samples t-tests to determine differences in objective and subjective measures of metacognition between the TBI and healthy control groups. To determine the association between metacognitive measures, we used Pearson’s R correlations between the objective measure of metacognition and the total and subscale scores of the subjective measure of metacognition. To examine the relationship between metacognition and the three outcome variables (EF, anxiety, and societal involvement), we used three separate stepwise linear regression models with the objective and subjective metacognitive measures as predictors and 1) EF composite, 2) anxiety subscale of BSI-18 and 3) PART-O as the dependent variables. As part of post-hoc analyses, we sought to explore the relationship between measures of metacognition in subgroups of participants who were metacognitively accurate or inaccurate. To do so, we first

computed a “confidence to accuracy” ratio by subtracting the average number of trials answered correctly on the objective metacognitive task from the average confidence rating on each trial. We then examined the relationships between objective and subjective measures of metacognition within each of the subgroups (accurate; inaccurate) using linear regression.

Results

Determining Metacognitive Deficit in TBI

An independent samples t-test revealed poorer metacognitive performance on the objective measure of metacognition in the TBI sample compared to the healthy control group [TBI: $M(SD) = 0.64(0.10)$, HC: $M(SD) = 0.70(0.09)$], $t(128) = -2.56$, $p = 0.012$, $d = 0.55$. Similarly, the TBI group also reported greater metacognitive complaints on the MCQ-30 total score than the healthy control group [TBI: $M(SD) = 59.81(13.69)$, HC: $M = 53.67(13.28)$], $t(127) = 2.09$, $p = 0.039$, $d = 0.45$. The objective metacognitive task was negatively related to MCQ-30 total score, $r = -0.17$, $p = 0.052$. In terms of the subscales of the MCQ-30, the objective metacognitive task was associated with cognitive self-consciousness, but there were no significant associations between the objective metacognitive task and any of the other subscales. See Table 3 for the correlation coefficients between objective metacognitive task and MCQ-30 subscales.

Due to the differences in education in the original sample, we conducted independent samples t-tests for the objective and subjective metacognitive variables in a subset of the TBI group compared to the healthy control group. We randomly eliminated individuals in the TBI group with the lowest level of education (12 years) until there was no longer a significant difference in education between the TBI and HC groups, [TBI: $M(SD) = 14.54(2.49)$, HC:

$M(SD) = 15.64(2.82)$], $t(106) = -1.96, p = 0.053, d = 0.43$. 22 individuals in the TBI group were excluded, yielding 80 individuals in the TBI group and 28 in the healthy control group. The results remained the same, with a significant difference on the objective metacognitive task, [TBI: $M(SD) = 0.65(0.10)$, HC: $M(SD) = 0.70(0.09)$], $t(106) = -2.14, p = 0.035, d = 0.47$, as well as the subjective self-report measure, [TBI: $M(SD) = 60.30(14.44)$, HC: $M(SD) = 53.67(13.28)$], $t(105) = 2.11, p = 0.038, d = 0.47$.

Metacognition as a Predictor of Executive Functioning Following TBI

The subsequent analyses were conducted within the TBI sample only in order to focus on how self-report and objective measures of metacognition predict cognitive, emotional and functional outcomes for patients with TBI. A stepwise linear regression was conducted with the EF composite as the dependent variable and objective metacognitive performance and the five MCQ-30 subscales as the predictors. The objective measure of metacognition alone accounted for 11% of the variance in EF performance, $R^2 = 0.11$. A model including both the objective measure and the MCQ-30 subscale Positive Beliefs best predicted executive functioning, explaining a total of 17% of the variance in EF performance, $F(2) = 9.69, p < 0.001, R^2 = 0.17$. All other predictors were excluded from the model with $p > 0.133$.

Metacognition as a Predictor of Emotional Functioning Following TBI

A stepwise linear regression was conducted with BSI – Anxiety subscale as the dependent variable and objective metacognitive performance and the five MCQ-30 subscales as the predictors. A model with only the Uncontrollability and Danger subscale of the MCQ-30 explained 25% of the variance in self-reported anxiety, $R^2 = 0.53$, and model including the Uncontrollability and Danger and Cognitive Confidence subscales of the MCQ-30 best predicted

self-reported anxiety and explained 28% of the variance in reported anxiety, $F(2) = 19.15$, $p < 0.001$, $R^2 = 0.28$. All other predictors were excluded from the model with $p > 0.344$.

Metacognition as a Predictor of Life Participation and Everyday Functioning Following TBI

A stepwise linear regression was conducted with PART-O as the dependent variable and objective metacognitive performance and the five MCQ-30 subscales as the predictors. There were no significant variables entered into the model, with predictors excluded from the model with $p > 0.05$. MCQ-30 subscales of Cognitive Confidence and Positive Beliefs were most highly correlated with PART-O objective life functioning [PART-O and Cognitive Confidence: $r = -0.140$, $p = 0.081$; PART-O and Positive Beliefs: $r = -0.152$, $p = 0.064$], but were excluded from the model.

Examining Awareness Deficit and Validity of Subjective Measures

We conducted post-hoc analyses to determine whether the relationship between subjective and objective metacognitive measures was dependent upon objective metacognitive ability. We hypothesized a stronger relationship between objective and subjective measures of metacognition for individuals who were accurate on the objective task of metacognition. To do this, a “confidence to accuracy” ratio was calculated by subtracting the average number of trials answered correctly on the objective metacognitive task from the average confidence rating on each trial. The resulting ratio was either positive, denoting the participant was more confident than they were accurate on the task, or negative, denoting they were less confident than accurate on the task. This ratio was used to determine subgroups of individuals with TBI who were either metacognitively accurate (defined as <20% over or under confident in relation to performance accuracy), metacognitively inaccurate and overconfident (defined as >20% overconfident in relation to performance accuracy), or metacognitively inaccurate and underconfident (defined

as >20% underconfident in relation to performance accuracy). See Figure 1 and Table 4 for the breakdown of participants in each group.

Only the overconfident and metacognitively accurate TBI groups were used for subsequent analyses due to sample size limitations in the inaccurate-underconfident group. There were no differences between these groups on MCQ-30 total score [$t(95) = -0.65, p = 0.517$], self-reported anxiety on the BSI-18 [$t(95) = 0.25, p = 0.807$], the PART-O total score [$t(94) = -0.66, p = 0.510$]. There was a difference in EF, in that the overconfident group performed worse ($M = -0.39, SD = 0.84$) on the EF tasks than the metacognitively accurate group ($M = 0.12, SD = 0.98$), $t(94) = -2.69, p = 0.008, d = 0.55$. These results indicate that individuals with TBI who are more accurate in their metacognitive ability also show more preserved EF abilities.

There was a significant interaction between the metacognitive groups (accurate and overconfident) and the self-report total score on the objective measure of metacognition, $R^2 = 0.23, p = 0.037$. Figure 2 depicts the absence of relationship found between self-report and objective measures of metacognition in the group of individuals with TBI who are overconfident reporters of their own performance, and a strong correlation between objective and subjective measures in the metacognitively accurate group. This pattern suggests that when individuals are more metacognitively accurate (i.e., confident and correct) on the objective measure of metacognition, they report less difficulty with worry and self-monitoring thoughts overall on the self-report measure.

Within the metacognitively accurate group, there were significant associations between the objective measure of metacognition and the MCQ-30 total score and 3 subscales of Cognitive Confidence, Cognitive Self-consciousness, and Uncontrollability and Danger. This indicates that when participants are more accurate on the objective task, they report fewer concerns about their

confidence in their thoughts (Cognitive Confidence) and their ability to monitor their thoughts (Cognitive Self-consciousness), as well as less concern about worried thoughts being dangerous (Uncontrollability and Danger). See Table 5 for the correlation coefficients between the objective metacognitive task and MCQ-30 subscales in the metacognitively accurate group.

In the overconfident group, there were no significant associations between the objective measure of metacognition and the MCQ-30 total score or subscales. See Table 6 for the correlation coefficients between the objective metacognitive task and MCQ-30 subscales in the overconfident group.

Discussion

The goal of this study was to advance our understanding of metacognitive deficit in individuals *aging with* moderate to severe TBI. To do so, we used both objective and subjective measures of metacognition as predictors of executive functioning, psychiatric functioning, and societal and community involvement. Compared to the healthy control group, older individuals with a history of TBI demonstrated deficits in empirical measurements of metacognition and also reported greater concerns about worried thoughts, monitoring thoughts, and confidence in memory and cognition on subjective measures of metacognition. This finding was not universal, with the TBI sample being roughly split with 56 of 102 individuals (54.9%) showing intact evaluation of their objective metacognitive ability and 46 of 102 participants (45.1%) demonstrating metacognitive deficit. This is consistent with a previous review of the literature, determining that 30% to 50% of patients with moderate to severe TBI exhibit impairments in self-awareness (Dromer et al., 2020). Further examination of the metacognitively impaired group

indicated that 41 of 46 individuals with deficit (89.1%) were overconfident in their ability, whereas only 5 of 46 (10.9%) underrated their metacognitive performance.

When examining the TBI group as a whole, a combination of objective and subjective measures of metacognition best predicted executive functioning, two subscales measuring “uncontrollability and danger” and “cognitive confidence” best predicted anxiety, and neither measure was a strong predictor of overall societal involvement following TBI. When examining metacognitive subgroups of individuals with TBI, the association between the objective and subjective measure of metacognition that was apparent in the metacognitively intact group disappeared within the group of individuals with TBI who were metacognitive inaccurate and over-confident. This has important implications for assessing metacognition solely through the use of self-report questionnaires in populations with objective deficits in metacognition. This finding, while perhaps unsurprising, remains a central problem to the assessment of metacognitive ability where the majority of instruments rely on self-report.

It was our expectation that the objective measure of metacognition would be a better predictor of EF due to the inflated inaccuracy of a self-report measure in this population. This hypothesis was only partially supported in that the objective measure in conjunction with the Positive Beliefs about Worry subscale of the MCQ-30 together best predicted EF. The items in this subscale of the MCQ-30 included questions such as, “Worrying helps me to solve problems,” “Worrying helps me to get things sorted out in my mind,” and “I need to worry in order to work well.” It is possible that the awareness of how worrying is used to problem solve is predictive of actual problem solving and EF ability following TBI. The relationship between EF ability, self-awareness, and problem-focused coping styles has been documented in the TBI literature (Ownsworth, McFarland, & Young, 2000), with better EF performance associated with

better problem solving and problem-focused coping one-year post TBI (Krpan, Levine, Stuss, & Dawson, 2007). Problem-focused coping requires the use of executive functions, such as foresight and planning, as well as generating alternative solutions and weighing alternatives (Lazarus & Folkman, 1984). It is possible that individuals sustaining TBI who are more likely to use problem-focused strategies are better at EF tasks, indicating why this measure of metacognitive ability predicted EF.

There are additional considerations for the differences in predictive ability of the objective and subjective measures of metacognition. At least some of the differences observed between objective and subjective measures in the current sample can likely also be attributed to distinct task demands required from an objective task and the self-report questionnaire. Additionally, the MCQ-30 examines different aspects of metacognitive ability including metacognitive beliefs, metacognitive monitoring, and one's own confidence in their cognitive abilities (Wells & Cartwright-Hatton, 2004), whereas the objective task represents on-line and "in the moment" performance evaluation of a specific cognitive task. In order to assess both the overall subjective experience of metacognitive ability as well as objective in-the-moment metacognitive ability, both objective tasks and self-report measures should be used to capture more of the global metacognitive construct.

In examining objective participation and functioning in daily life as measured through the PART-O, no metacognitive variables were found to be significant predictors. There may be other significant factors that were not measured in this study that would predict someone's willingness to participate in meaningful life activities following brain injury. Disability is one factor that has demonstrated moderate to strong association ($r = 0.59 - 0.70$) with scores on the PART-O (Bogner et al., 2013) and was not measured in this study. Additionally, findings are mixed as to

whether metacognition and self-awareness are significant predictors of community participation and reintegration after TBI. Some have demonstrated that self-awareness, and in particular error monitoring ability, is predictive of community reintegration following TBI (Robertson & Schmitter-Edgecombe, 2015). Others have found no association between self-awareness and community integration (Fleming, Strong, & Ashton, 1998; Goverover, Johnston, Togli, & DeLuca, 2007). Findings are also mixed as to whether metacognitive awareness is predictive of successful return to work outcomes following TBI (see Manoli, Delecroix, Daveluy, & Moroni, 2019; Ownsworth & McKenna, 2004 for review).

The discrepancies seen here may be at least partially attributable to how metacognition is defined and measured differently throughout the literature. Future research should continue to measure metacognition through multiple methods, including basic and objective metacognitive capacities such as error monitoring as well as retrospective confidence judgements, to determine the components of metacognition that are most vital for day-to-day functioning. Additionally,

Limitations

There are several limitations to this study. While many of the hypotheses focused on the TBI sample, we did include a small comparison group of healthy control individuals to provide some context for measures of metacognition. Additionally, the TBI and HC groups did significantly differ on levels of education, with the TBI group completing on average 13.99 years of education and the healthy control group completing 15.64 years. It should be noted that the between-group differences in metacognitive ability remained observable when examining a subset of individuals with TBI who were equivalent to the healthy control group on education.

Additionally, we acknowledge that our sample is primarily comprised of individuals identifying as White, and while 22% of the sample identified as Black, we have much smaller

representation from individuals who identify as Hispanic or Latinx, and no individuals who identify as Asian. This limits the generalizability of our results to a less racially diverse group.

Lastly, while our measures of metacognition assess several facets of metacognitive ability, they do not represent error monitoring ability, which has been documented in the literature as a predictor of participation in meaningful community activities (Robertson & Schmitter-Edgecombe, 2015). Future research can examine an additional objective task of error monitoring to determine whether this objective task is more predictive of participation in daily life than the task used in this study that investigates the metacognitive facet of performance evaluation.

Conclusion

In summary, metacognitive deficit was apparent in approximately 45% of the sample of individuals aging with moderate-severe TBI as measured through objective testing. Both objective and subjective measures of metacognition were sensitive to deficits following moderate to severe TBI in an older adult population and both contributed to predicting functional outcomes, but the utility of these measures may rely on level of metacognitive ability. This caveat is of critical importance for our understanding of metacognition, as well as in its clinical assessment. There is strong evidence that metacognition is not a unitary construct (any more than EF is, for example), yet this issue is often not considered with respect to *which dimension* of metacognition is being measured. We argue that there may be situations where self-report indicators of metacognitive deficit may offer insight into one's experience, but they may not provide insight into one's in-the-moment evaluation of their own task performance. This latter ability is vital to consider, as the patient's ability to incorporate feedback is critical to intervention and rehabilitation (Chiou, Klecha, Jones, & Dobryakova, 2021). These results

provide context for the recommendation of the use of multiple measures of metacognition (i.e., objective tasks and subjective self-report measures) when assessing individuals at risk for metacognitive deficit due to aging and brain injury. With increased understanding of metacognitive deficit in an aging population with TBI, novel points of intervention can be developed to improve this ability and increase quality of life.

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Table 1. Participant demographics.

	Age M (SD)	Gender	Education M (SD)	Race	Ethnicity	TPI (years) M (SD)	GCS M (SD)
TBI	64.02 (8.07)	70 M, 32 F	13.99 (2.44)*	79 W, 23 B	5 Hispanic, 76 non-Hispanic, 19 not reported	9.60 (6.90)	11.55 (4.24)
HC	64.00 (7.90)	12 M, 16 F	15.64 (2.82)*	21 W, 7 B	28 non- Hispanic	--	--

* indicates significant difference between groups at $p < 0.05$.

Note: W = White, B = Black, M = male, F = female, TBI = traumatic brain injury, HC = healthy control, TPI = time post injury, GCS = Glasgow Coma Scale score

Table 2. Tasks used as predictor and outcome variables for analyses.

Predictor Variables		Outcome Variables		
Objective MC Predictor	Subjective MC Predictor	Executive Functioning Outcome	Anxiety Outcome	Life Functioning Outcome
<ul style="list-style-type: none"> Modified Matrix Reasoning task with retrospective confidence judgments 	MCQ-30: <ul style="list-style-type: none"> Cognitive confidence Positive beliefs about worry Cognitive self-consciousness Uncontrollability and danger Need to control thoughts Total score 	EF Composite: <ul style="list-style-type: none"> Trail Making Test – B D-KEFS Color-Word Interference – Inhibition condition 	BSI-18: <ul style="list-style-type: none"> Anxiety Subscale 	PART-O: <ul style="list-style-type: none"> Productivity Social Relations Out and About Total Score

Note: EF = executive functioning, MC = metacognition, MCQ-30 = Metacognitions Questionnaire-30, BSI-18 = Brief Symptom Inventory-18; PART-O = Participation Assessment with Recombined Tools – Objective

Table 3. Correlation coefficients between objective metacognitive task and MCQ-30 subscales.

	MCQ total	Cog. Conf.	Pos. Beliefs	Cog. Self-con.	Uncontrol.	Need Control
Obj.	-0.172*	-0.124	-0.048	-0.186*	-0.140	-0.018

Abbrvs. "Obj." = objective metacognitive task, "MCQ total" = total on MCQ-30, "Cog. Conf." = MCQ-30 cognitive confidence, "Pos. Beliefs" = MCQ-30 positive beliefs about worry, "Cog. Self-con." = MCQ-30 cognitive self-consciousness, "Uncontrol." = MCQ-30 uncontrollability and danger, "Need Control" = MCQ-30 need to control thoughts.

* = correlation is significant at the 0.05 level (two-tailed)

Table 4. Breakdown of participants in the TBI and HC groups who were overconfident, accurate, or underconfident in their metacognitive performance evaluations.

	TBI N (%)	HC N (%)	Total N (%)
Overconfident	41 (40.2%)	8 (28.6%)	49 (37.7%)
Accurate confidence	56 (54.9%)	18 (64.3%)	74 (56.9%)
Underconfident	5 (4.9%)	2 (7.1%)	7 (5.4%)

Note: TBI = traumatic brain injury, HC = healthy control, N = number of participants, % = percentage of group sample

Table 5. Correlation coefficients between objective metacognitive task and MCQ-30 subscales in the metacognitively accurate group.

	Obj.	MCQ total	Cog. Conf.	Pos. Beliefs	Cog. Self-con.	Uncontrol.	Need Control
Obj.	1	-0.405**	-0.360	-0.192	-0.290*	-0.363**	-0.211

Abbrvs. "Obj." = objective metacognitive task, "MCQ total" = total on MCQ-30, "Cog. Conf." = MCQ-30 cognitive confidence, "Pos. Beliefs" = MCQ-30 positive beliefs about worry, "Cog. Self-con." = MCQ-30 cognitive self-consciousness, "Uncontrol." = MCQ-30 uncontrollability and danger, "Need Control" = MCQ-30 need to control thoughts.

* = correlation is significant at the 0.05 level (two-tailed)

** = correlation is significant at the 0.001 level (two-tailed)

Table 6. Correlation coefficients between objective metacognitive task and MCQ-30 subscales in the overconfident group.

	Obj.	MCQ total	Cog. Conf.	Pos. Beliefs	Cog. Self-con.	Uncontrol.	Need Control
Obj.	1	-0.043	-0.047	-0.032	-0.148	0.061	-0.007

Abbrevs. "Obj." = objective metacognitive task, "MCQ total" = total on MCQ-30, "Cog. Conf." = MCQ-30 cognitive confidence, "Pos. Beliefs" = MCQ-30 positive beliefs about worry, "Cog. Self-con." = MCQ-30 cognitive self-consciousness, "Uncontrol." = MCQ-30 uncontrollability and danger, "Need Control" = MCQ-30 need to control thoughts.

Figure 1. Distribution of participants' metacognitive confidence ratings from percentage underconfident to percentage overconfident in performance on objective metacognitive task.

Figure 2. Interaction examining relationship between subjective and objective measures of metacognition for the overconfident and accurate metacognitive TBI groups.

Abbrevs: Overconf. = overconfident and inaccurate group, Acc. = accurate group