Spring 5-2021

Metacognitive Function in Moderate to Severe Traumatic Brain Injury

Grace Amadon
University of Nebraska - Lincoln

METACOGNITIVE FUNCTION IN MODERATE TO SEVERE TRAUMATIC BRAIN INJURY

An Undergraduate Honors Thesis

Submitted in Partial fulfillment of

University Honors Program Requirements

University of Nebraska – Lincoln

by

Grace K. Amadon, BA

Psychology

College of Arts and Sciences

May 2021

Faculty Mentors:

Kathy Chiou, Ph.D., Department of Psychology

Calvin P Garbin, Ph.D., Department of Psychology

Table of Contents

Abstract

Traumatic brain injury (TBI) is an injury to the brain caused by a bump, blow, jolt to the head. Individuals with TBI demonstrate decreased awareness of their own potential deficits and functional abilities. These deficits have critical implications for recovery as self-awareness is important for those recovering from TBI in the implementation and engagement of rehabilitative processes after TBI. The following study analyzed 18 individuals with TBI approximately 11 years post injury to document metacognitive functioning after injury. Participants completed a metacognitive working-memory paradigm where they made judgements of their future and past performance on identifying a target shape and location. Task accuracy, subjective confidence, and metacognitive ratings were recorded through this paradigm. Task accuracy and metacognitive ratings were used in calculating the area under the receiver operating characteristic curve, as well as over- and under- confidence errors, both of which were used to measure metacognitive accuracy. Results indicate that individuals with TBI select the correct target stimulus less than half of the time. In the same manner, these individuals were somewhat unconfident in their responses based on a response considering a Likert scale of 1-4; however, participants were overconfident in their responses. Finally, there was a high degree of discrepancy between an individual's confidence and accuracy, exhibiting a low level of metacognitive sensitivity. These findings suggest the need to implement rehabilitative strategies that target self-awareness in order to promote successful return to work, life, and subjective normalcy following TBI.

Keywords: Metacognition, Self-awareness, Brain injury

Dedication

This thesis is dedicated to my family and the group of individuals who have supported me throughout my undergraduate studies. I could not have done this without the mentorship of Dr. Calvin Garbin, Dr. Kathy Chiou, Dr. Cary Savage, and their respective graduate students, including Rachael Snyder, Jeremy Feiger, Julia Laing, and Heather Bouchard.

METACOGNITIVE FUNCTION IN MODERATE TO SEVERE TRAUMATIC BRAIN INJURY

1.1 Traumatic Brain Injury

Traumatic Brain Injury (TBI) is an injury to the brain that is caused by a hit or jolt to the head that can result in physical, psychological, and/or cognitive deficits. These injuries account for more than 1.1 million emergency department visits, 235,000 hospitalizations, and 50,000 deaths annually (Langlois, Rutland-Brown & Wald, 2006; Robertson & Schmitter-Edgecombe, 2014). While these statistics are substantive, TBI is largely underestimated due to a variety of circumstances including missed diagnoses, refusal to seek care, among others. According to Langlois & Rutland-Brown, males are two times as likely as females to experience a TBI (2004). Most frequently, TBIs occur due to falls, motor vehicle accidents, domestic violence, and assaults (Langlois & Rutland-Brown, 2004). The effects of TBI can be detrimental to lifelong physical, cognitive, behavioral, and/or emotional attributes, specifically under the cognitive domains of attention, learning and memory, perception, and executive functioning (Chiou, Carlson, Arnett, Cosentino & Hillary, 2011) in which this research will explore.

1.2 Self-Awareness and Metacognition

Following the impact of a TBI, many individuals face challenges of being aware of their cognitive, behavioral, and emotional impairments (Port, Willmott & Charlton, 2001). This inability to recognize deficits resulting from a neurological injury can be classified as a lack of self-awareness (Robertson, Schmitter-Edgecombe, 2014). Anosognosia, deficits in self-awareness, are frequent following a brain injury (Bogod, Mateer & Macdonald, 2002) and may lead to difficulties in fully understanding the impact to which certain deficits have on the ability to perform activities of daily living (Port, Willmott & Charlton, 2001). In turn, rehabilitative

strategies may be underutilized due to the individual's inability to distinguish what has changed following a TBI, further preventing the successful return to work, school, or other occupation. Additionally, lack of self-awareness may inhibit an individual's ability to participate in rehabilitation, treatment programs, and more (Bogod, Mateer & Macdonald, 2002).

One specific facet of self-awareness is metacognition; the ability to recognize personal thought processes (Fleming & Lau, 2014). Metacognition appears differently from person to person, reflecting altered metacognitive abilities among individuals (Kelemen, Frost & Weaver, 2000). These differences may be more severe in individuals with impaired cognitive functioning, including those who have experienced TBI. Metacognition can be further broken down into two domains: metacognitive knowledge and metacognitive experience. Metacognitive knowledge is one's general knowledge of their ability to perform a task and can be explored through statements such as "I am good at spelling." Metacognitive experience is an individual's ability to monitor and evaluate their current, ongoing performance on a task (Flavell, 1979). This may appear in situations where someone is able to catch a mistake in the midst of spelling a word out loud. This metacognitive experience can be measured by collecting judgements of learning (JOL) and identifying feeling of knowing judgments (FOK), where individuals make predictions of their future performance, and through retrospective confidence judgements (RCJ), where individual's rate their confidence in the accuracy of their own performance (Kelemen, Frost & Weaver, 2000). In this regard, metacognitive accuracy is determined through the comparison of subjective self-report to objective performance on tasks. This determination can be done through measuring metacognitive bias and metacognitive sensitivity.

1.3 Measurements of Metacognitive Accuracy: Bias & Sensitivity

Metacognitive bias recognizes a difference in subjective confidence when task performance is constant, measuring if an individual is over or under confident (Fleming & Lau, 2014). Further, metacognitive sensitivity displays how good an individual is in differentiating between subjective correct and incorrect judgements. For the purpose of this study, participants' metacognitive measures were based on responses to a metacognitive working memory paradigm. With this information, the effects of a traumatic brain injury on metacognition are not fully understood in the literature. Therefore, the purpose of this study was to better understand metacognitive functioning in individuals with moderate to severe TBI.

One approach to quantifying metacognitive sensitivity is to calculate the area under the receiver operating characteristic curve (AUC). In general, this allows researchers to determine the diagnostic ability of a particular classifier. Applied to the study of metacognition, the individual's metacognitive judgments are viewed as the classifier, and thus the AUC represents how well these judgments align with actual performance. AUC values range from 0 to 1, where 0 indicates inaccurate test reflections and 1 indicates full accuracy (Mandrekar, 2015). Further, AUC values above 0.5 demonstrate moderate ability to diagnose differences. Values less than 0.5 indicate no difference between the groups being measured.

1.5 Study Goals

Comprehensive literature reviews indicate the need for further research understanding metacognition after TBI. Specifically, there are few reports of metacognitive functioning tested in individuals with TBI using judgements of learning and/or retrospective confidence judgements. In contrast, previous literature examines cognition in individuals with TBI through self-report questionnaires and/or reports given by caregivers such as the Patient Competency

Rating Scale (PCRS), Awareness Questionnaire (AQ), Self Awareness of Deficits Interview (SADI), Functional Self-Assessment Scale (FSAS), Dysexecutive Questionnaire (DEX), Cognitive Failures Questionnaire (CFQ), and more (Bivona, Ciurli, Barba, Onder, Azicnuda, Silvestro, Mangano, Rigon & Formisano, 2008; Ciurli, Bivona, Barba, Onder, Silvestro, Azicnuda, Rigon & Formisano, 2010; Fleming, Strong, & Ashton, 2009; Garmoe, Newman & O'Connell, 2005; Hart, Whyte, Kim, & Vaccaro, 2005). These measures provide generalized knowledge in metacognition following TBI, however, they fail to acknowledge a precise depiction of accuracy during a metacognitively challenging task in this population. In measuring metacognition through judgements of learning and retrospective confidence judgments, researchers gain an understanding of objective measures specific to one task at a given time. This method eliminates bias between raters (self, caregiver, etc.) and establishes greater sensitivity to the measure of metacognition. Overall, the purpose of this study was to understand metacognition in individuals with TBI, specifically in observing in-the-moment task performance to better view metacognitive accuracy. It was hypothesized that individuals with TBI would present poor metacognitive accuracy, as evidenced by low values of metacognitive sensitivity. Further, this study aimed to utilize subsequent findings to conduce rehabilitative strategies better targeting successful return to daily living following the impact of TBI.

Methods

2.1 Participants

In this study, 18 adults with moderate to severe TBI were recruited from the community. 7 participants were excluded from analyses due to errors in the administration of the research paradigm. On average, participants were around 45 years old, each with about 14 years of education. At the time of the study, TBI had occurred about 11 years prior. The sample primarily

consisted of Caucasian males; however, 9% of the sample were Hispanic, 27% were African American, and 9% were female.

2.2 Metacognitive Working Memory Paradigm

Each participant completed three runs of a metacognitive working memory paradigm with 16 trials per run. The metacognitive working memory paradigm was presented on a computer using a series of slides. For each trial, participants were shown a target stimulus with shapes in various locations. Participants were instructed to remember the shapes and their locations. Following an interstimulus fixation period, participants were asked to assess their future performance, providing a judgement of learning (JoL). JoL was assessed through the statement, "I am ____ that I will know the answer" with the choices of 1) unconfident, 2) somewhat unconfident, 3) somewhat confident, 4) confident. Following the answer of a target response, participants were asked to identify a retrospective confidence judgement (RCJ) through the question "I am _____ that my answer is correct." Choices in this response were 1) unconfident, 2) somewhat unconfident, 3) somewhat confident, 4) confident. An example of this trial sequence is presented in figure 1 below. For more information on the trial sequence, please see Appendix A. Task performance, confidence rating, and reaction times were recorded for each participant. Of the 16 trials, 12 were true trials that collected metacognitive judgements and 4 were foil trials. Foil trials were used intermittently as a distraction to avoid response bias and increase response reliability. Questions in foil trials asked participants to rather their level of fatigue and whether they were engaged in the task "how tired are you" and "are you paying attention."

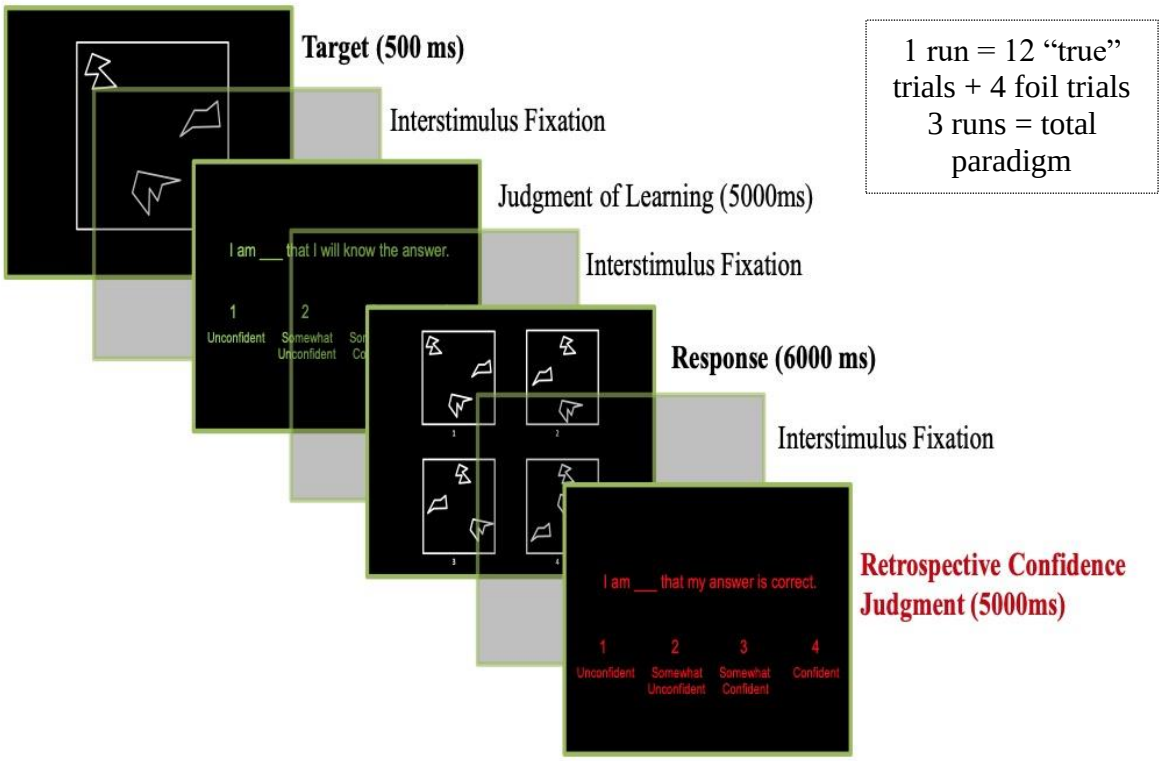

Figure 1: Metacognitive working memory paradigm. Participants were shown a target stimulus comprised of shapes in different locations. After an interstimulus fixation period, participants were asked to make a judgement of learning that assessed how confident they would be in selecting the correct response. Following an additional interstimulus fixation period, participants selected the box in which they believed identified the original target stimulus. A final fixation period occurred, and participants were asked to make a retrospective confidence judgement, assessing how confident they were in the answer they selected.

2.3 Measurements of Metacognitive Accuracy: Bias & Sensitivity

Two measures of metacognitive accuracy were calculated for each individual. For the purpose of this study, the researchers focused on the RCJ responses to examine metacognitive monitoring processes. Metacognitive bias measured the directionality and magnitude of monitoring errors. In other words, metacognitive bias measured whether participants were prone to errors of overconfidence or underconfidence on the task as a whole. To measure this, RCJ scores were converted from their Likert value between 1-4 to a percentage. Then, bias was

calculated by subtracting the percent correct on the target stimulus recognition task from their retrospective confidence rating. A value of 0 after these calculations demonstrated no bias. A positive value expressed overconfidence; their rating was high than their actual accuracy. A negative value demonstrates under confidence; their confidence rating was lower than their actual accuracy.

Metacognitive sensitivity refers to the accuracy of participants' RCJs, that is, the degree to which their level of reported confidence matched their objective performance. This was measured by calculating the area under the receiver operating characteristic curve (AUC). AUC values ranged from 0 to 1. Values closer to 0.5 suggest a low level of metacognitive sensitivity (discrepancies between confidence judgments and objective performance). Values closer to 1 represented a high level of metacognitive sensitivity (agreement between reported confidence and objective performance).

Results

Average accuracy of working memory performance in the participants with TBI was 48.53% (*sd* = 0.131). The average confidence rating (on a Likert scale of 1-4) reported by participants with TBI was 2.24. This can be translated into an average percentage of 56.7% . In measuring metacognitive bias, differences in accuracy and RCJ responses were observed. There was an over/under confidence value of .08 (*sd* = 0.150), showing that participants with TBI were overconfident in their responses. AUC values were found to be 0.65 (*sd* = 0.123), indicating an apparent discrepancy between participant's confidence and accuracy rating.

One sample t-tests were employed to understand how confidence and accuracy compared to their respective probability of being equivalent to chance. When comparing accuracy to chance using a nominal base rate of 25%, given that participants had a 1 in 4 chance of selecting

the correct target stimulus. It was found that individuals with TBI perform significantly better than chance (M = 47.7%, sd = 19.2%, p<.001). Likewise, in comparing confidence to chance using a nominal base rate of 50%, it was found that individuals with TBI are significantly more confident than would be expected if performing at chance (M = 58.9%, sd = 12.4%, p = .009).

A scatter plot between accuracy and confidence revealed outliers; one high in both accuracy and confidence, one low in both accuracy and confidence. These make the data appear to represent a linear relationship. Additionally, there are three individuals with relatively elevated confidence. Two correlations were completed to capture the relationship shown in the scatterplot. First, there is a marginally significant effect when everyone is included in the analysis (r = .463, p = .06). When excluding those with relatively elevated confidence ratings, there is a strong linear relationship (r = .675, p = .008); however, it is largely driven by the individuals holding high confidence and accuracy and the individual holding low confidence and accuracy. Further examination on these three cases shows that they are not homogeneous on age, education, gender, or time since injury.

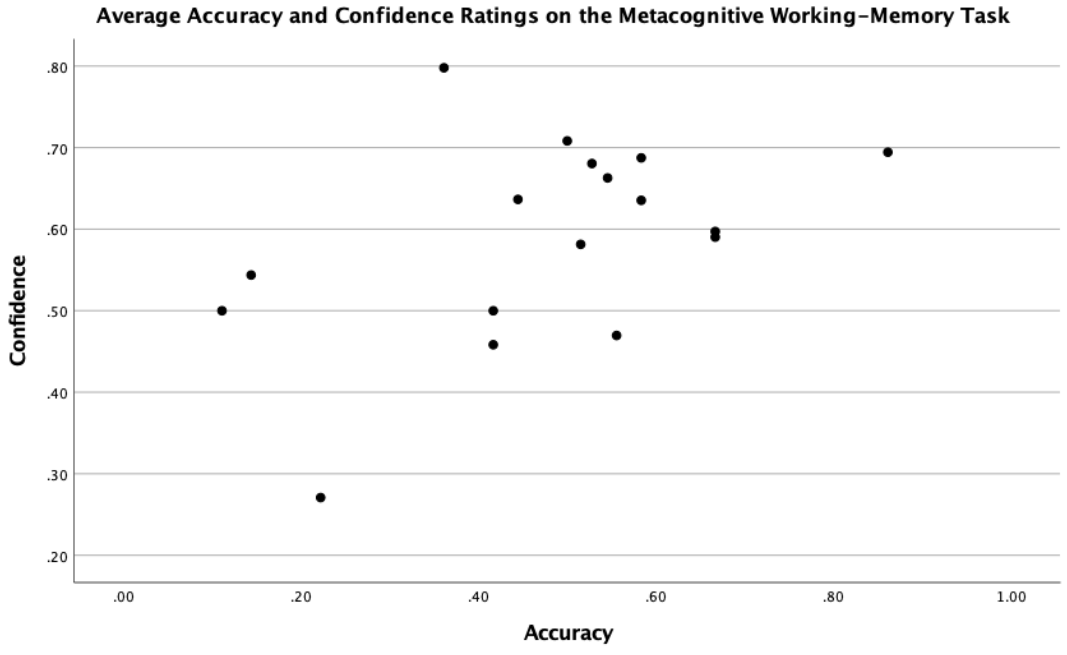

Figure 2: Average accuracy and confidence ratings on the metacognitive working-memory task

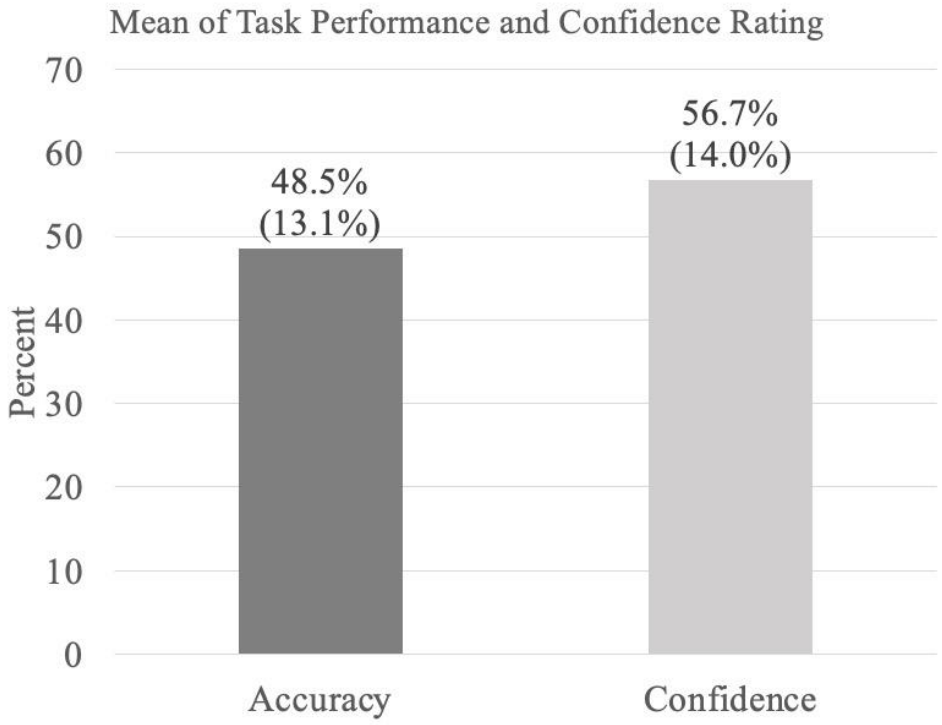

Figure 3: Mean (sd) of Task Performance and Confidence Ratings

Discussion

3.1 Conclusions

This study overall suggests that individuals with TBI demonstrate metacognitive abilities that need further interpretation following the impact of their injury. It is clear that performance on the working-memory paradigm is not perfect, however, without a comparison group, this study cannot determine the exact level of metacognitive ability in this sample. When shown a shape in a specific location as part of a working-memory paradigm, individuals with TBI had difficulties recognizing the correct target stimulus. Likewise, these individuals did not report high levels of confidence in their choices when asked to provide a judgement of their learning.

Further, when retrospectively judging their confidence, participants were overconfident in their responses; thereby assuming they chose the correct shape/location combination when results showed they were incorrect. Finally, there was a discrepancy between participants' confidence ratings and accuracy results, showing that individuals held low sensitivity to metacognitive tasks. Again, it is difficult to confirm the exact level of sensitivity without a comparison group, however, it is clear that the quantitative AUC values represent low sensitivity. In this regard, as it applies to community integration, rehabilitation engagement, and functional outcomes, those with low metacognitive sensitivity display decreased abilities to differentiate between their own correct and incorrect classifications (Maniscalco, B., & Lau, H., 2011). The combination of accuracy in selecting the correct target stimulus, confidence in the task, appearance of over- or under- confidence in relevant responses, as well as the sensitivities to confidence judgements and objective performance result in varying implications for rehabilitation and will be addressed below.

3.1.1 Accuracy

The findings within this sample demonstrate that individuals with TBI perform poorly on a working memory task. With a 48.5% accuracy rating, it is apparent that individuals with TBI answer less than half of the working-memory paradigm correctly, however, their performance is significantly better than chance given the 1 in 4 probability of selecting the correct target stimulus. Preliminary pilot data examining healthy controls (n = 10) that were not matched in age or education show that healthy controls performed the same metacognitive working-memory task with 79% accuracy, showing noticeable differences between the populations. This minimized accuracy is consistent with literature examining deficits in working memory following a TBI

(Hanten, G., Bartha, M., & Levin, H., 2010; Fleming, S., & Lau, H., 2014); however, further research is needed with a larger, matched sample in order to confirm.

After examination of individual's accurate responses against a nominal base rate of 25% (with the correct response being a 1 in 4 chance), it is apparent that individuals with TBI are able to maintain and manipulate information to make correct selections. This is important when targeting the completion of activities of daily living and other daily routines following TBI; if an individual is unable to maintain information to decipher stimuli such as which bus to get on, or which turn to take when using directions, they likely will not successfully complete what they desire or need to in order to carry out normal activities of daily living. In addressing difficulties with the ability to maintain and manipulate incoming information following the impact of TBI, researchers and clinicians can better improve interventions for those impacted by TBI.

3.1.2 Confidence

Within this sample, it was found that participants with TBI were somewhat unconfident in their responses when asked to choose a target stimulus. This was determined based on the Likert scale values (1-4), where the observed value of 2.24 reflected the rating of "somewhat unconfident" in selected responses. Interestingly, participants' confidence scores were significantly greater than chance when compared to a nominal base rate of 50% confident, demonstrating that individuals with TBI present with greater confidence, despite the impairments that follow a TBI that impede working memory and self-awareness (Barman, A., Chatterjee, A., & Bhide, R., 2016).

In acknowledging working-memory, it is known that strong working-memory abilities are necessary to have the memory capacity to confidently recognize a previously shown stimulus (Kasahara, M., Menon, D., Salmond, C., Outtrim, J., Taylor Tavares, J., Carpenter, T. A.,

Pickard, J., Sahakian, B., & Stamatakis, E., 2011). Working-memory abilities may be diminished in individuals with TBI at varying levels dependent on the severity of injury, which in turn may impede an individual's ability to confidently respond to stimuli (Kasahara et al., 2011). With this in mind, addressing an individual's confidence through the completion of working-memory tasks is necessary to inform rehabilitation surrounding confidence in completing activities of daily living. By implementing retrospective confidence judgements, individuals are asked to reflect on their experiences and engage in self-awareness, therefore processing their involvement in the task at hand.

3.1.3 Over-Confidence and Under-Confidence

While examining over and under-confidence in this context, errors of over confidence occur when participants report being confident in their response to a target stimulus despite answering incorrectly. In contrast, errors of under-confidence occur when participants report minimal confidence in their response to a target stimulus, even when answering correctly. These metrics allow for a more detailed examination of the direction of the metacognitive errors that are made. In this sample, participants with TBI tended to make errors of overconfidence, where they were more confident in their answers than they were correct. This is important for rehabilitation, especially in regard to self-awareness of the impairments which follow a TBI. Individuals who remain overconfident in their abilities face difficulties with the utilization of compensatory strategies (Barman, A., Chatterjee, A., & Bhide, R., 2016) and that difficulty is often addressed in rehabilitation. Compensatory strategies aimed to target over-confidence may include things like keeping a journal to have a consistent reminder source, limiting involvement in demanding activities when physically or emotionally tired, and having a planner to keep tasks organized. All of the aforementioned strategies may assist in preventing the likelihood of

becoming over-confident in daily responsibilities and tasks. By acknowledging issues of overconfidence in rehabilitation, research can target improving the accuracy of metacognitive confidence by accurately assessing one's own knowledge and skill level in order to promote correct judgements in daily life. Those with TBI face challenges in carrying out activities of daily living, motor skills, decision making, memory recall, and attentional/organizational deficits (Choy, N., Kuys, S., Richards, M., & Isles, R., 2002), so by addressing issues of over-confidence, and therefore acknowledging difficulties in compensatory strategies, individuals lessen their likelihood of experiencing deficits because of improper preparedness for a given situation.

3.1.4 Area Under the Receiver Operating Characteristic (AUC) Curve

In the context of the current sample, AUC values closer to 0.5 than 1 demonstrated that individuals with TBI have a low level of metacognitive sensitivity. In this case, an AUC of 0.65 shows that our sample had low sensitivity, however, the magnitude of this insensitivity is unclear because there was no control group for comparison. Regardless, understanding metacognitive sensitivity in individuals with TBI is important for addressing implications for rehabilitation. With low levels of metacognitive sensitivity, individuals face consequences in self-reflection of their cognitive and working-memory processes, therefore experiencing difficulties with regulating behavior, learning, memory, and performance (Koriat, 2007). In terms of daily life, challenges in the above areas present a potential for consequences when completing tasks successfully, recognizing correct versus incorrect stimuli in real-life activities (i.e., selecting the right bus route, entering the correct household when returning home, etc.), and more. Understanding these similar findings within the literature, future research should target factors

such as working memory and self-awareness throughout rehabilitation following TBI in order to promote awareness of behavior and reciprocal consequences

3.2 Limitations

The current study had a limited sample size of 18 individuals with traumatic brain injury due to errors in administration of the research paradigm. Consequently, data from 7 participants had to be excluded from analyses for these reasons, leaving just 11 participants. Additionally, this study was 91% male and 9% female, which makes it difficult to ascertain gender differences as the demographic is likely not representative of a full population. Further, without a control group to compare to, these results cannot be fully attributed to the effects of TBI alone. There may be outside factors including environmental and genetic characteristics that contribute to the diminished metacognitive sensitivity as seen in this study.

3.3 Future Directions

The current project was part of a larger research study understanding a multitude of variables in individuals with TBI. Other than the measures of metacognition; accuracy, confidence, over/under confidence, and metacognitive sensitivity, the paradigm collected reaction times based on target stimulus selection. Future research might examine differences in reaction times throughout each trial of the working memory paradigm to determine if individuals with TBI exhibit a capacity for change in metacognitive responses overtime, specifically when examining correct responses and subsequent response times. Demographically, future projects should analyze findings according to age in order to understand age differences that may occur following TBI. An area this study did not analyze is a control group without traumatic brain injury. With the comparison of a control group, any deficits found can be better attributed to the TBI, rather than individual differences and tendencies among the TBI population. Further,

researchers did not analyze structural imaging data that was collected as part of the larger study; however, a beneficial next step in this research would be to utilize neuroimaging data to understand neural mechanisms involved in metacognition, especially in regard to metacognitive judgments of working memory.

This sample consisted of individuals who were approximately 134.64 months, or 11.22 years post injury (*sd* = 123.43). It would be beneficial to assess metacognition in individuals with more acute injuries. In collecting these metrics immediately following injury, researchers would be able to understand aspects that can be attributed to immediate effects of the injury. Further, collecting these data in the first 12 months of injury would allow researchers to examine results prior to suggested full recovery. If, at 11 years post-TBI, individuals are facing such severe deficits in metacognition, we must aim to understand the severity of the deficits in the early stages of recovery.

In terms of participation in rehabilitation following TBI, the ability to see an individual's progress over time on these metacognitive working memory tasks would allow researchers to understand changes throughout recovery. This would be possible by developing the ability to test research participants utilizing the same working-memory paradigm used in the current study prior to entering rehabilitation, again at a controlled set-point in their intervention program, as well as exit from the program. In turn, insight would be provided that understands where individuals are at upon entrance of a rehabilitation program, mid-way through, as well as following their exit from the program. With this in mind, novel intervention programs may be developed which focus on improving areas of metacognition following TBI including metacognitive accuracy, confidence, over- and under- confidence, as well as metacognitive sensitivity.

Appendix

Appendix A

Metacognitive Working Memory Paradigm: Target Stimulus

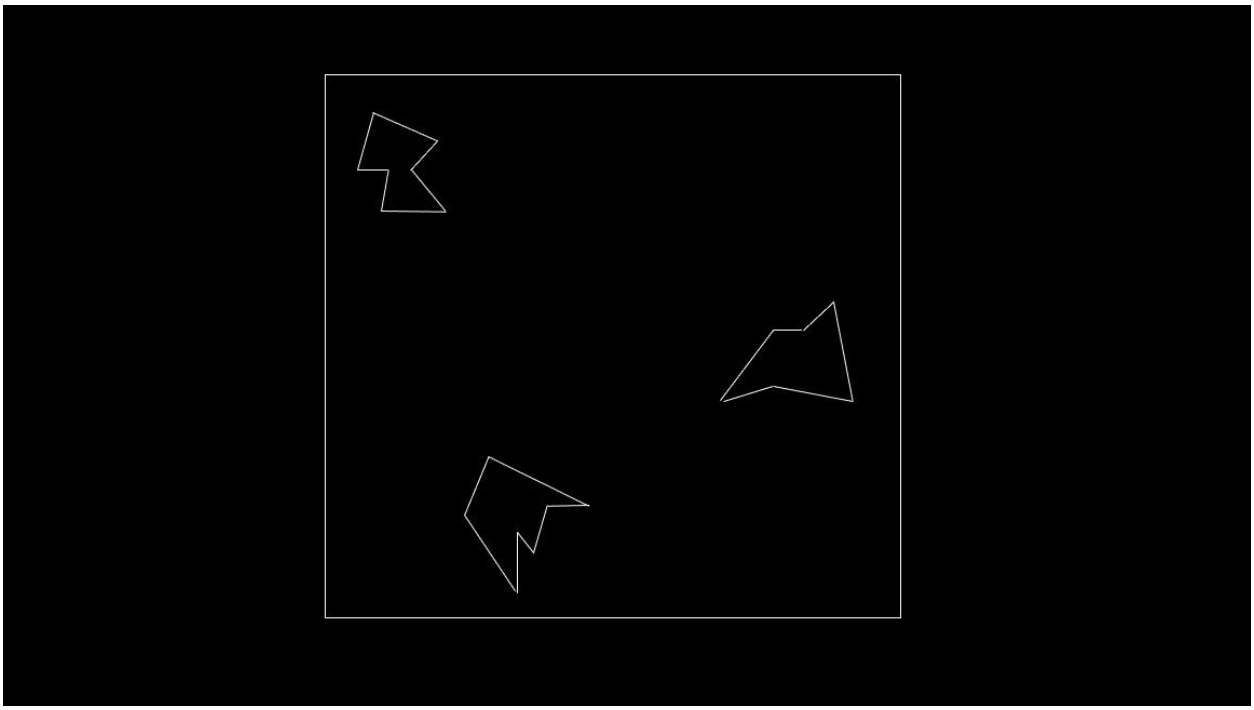

Figure 4: An example of the target stimulus to be identified by the participant. Participants were asked to identify the correct target shapes and locations.

Appendix B

Metacognitive Working Memory Paradigm: Judgement of Learning

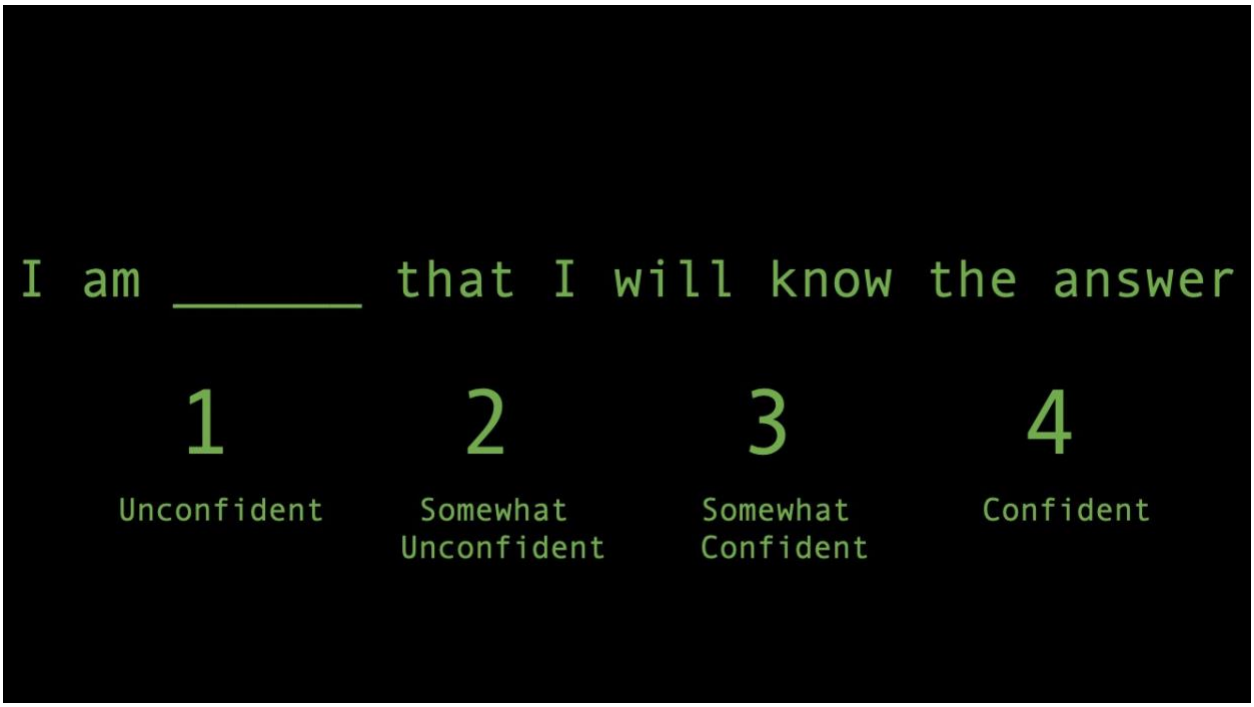

Figure 5: Judgement of Learning. Participants were asked to make a judgment of their future performance on identifying the target stimulus. Choices included (1) unconfident, (2) somewhat unconfident, (3) somewhat confident, (4) confident.

Appendix C

Metacognitive Working Memory Paradigm: Selection of Correct Target Stimulus

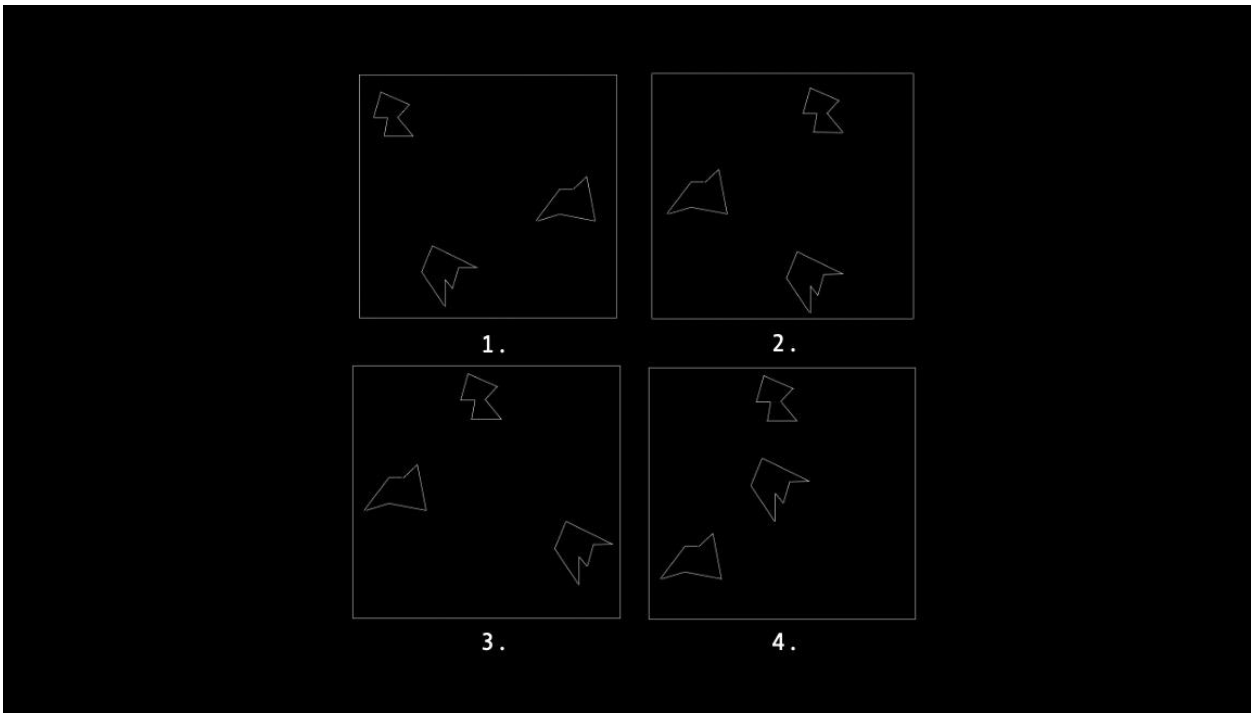

Figure 6: Identification of target stimulus. Participants identified the correct shapes and locations from the original target stimulus.

Appendix D

Metacognitive Working Memory Paradigm: Retrospective Confidence Judgement

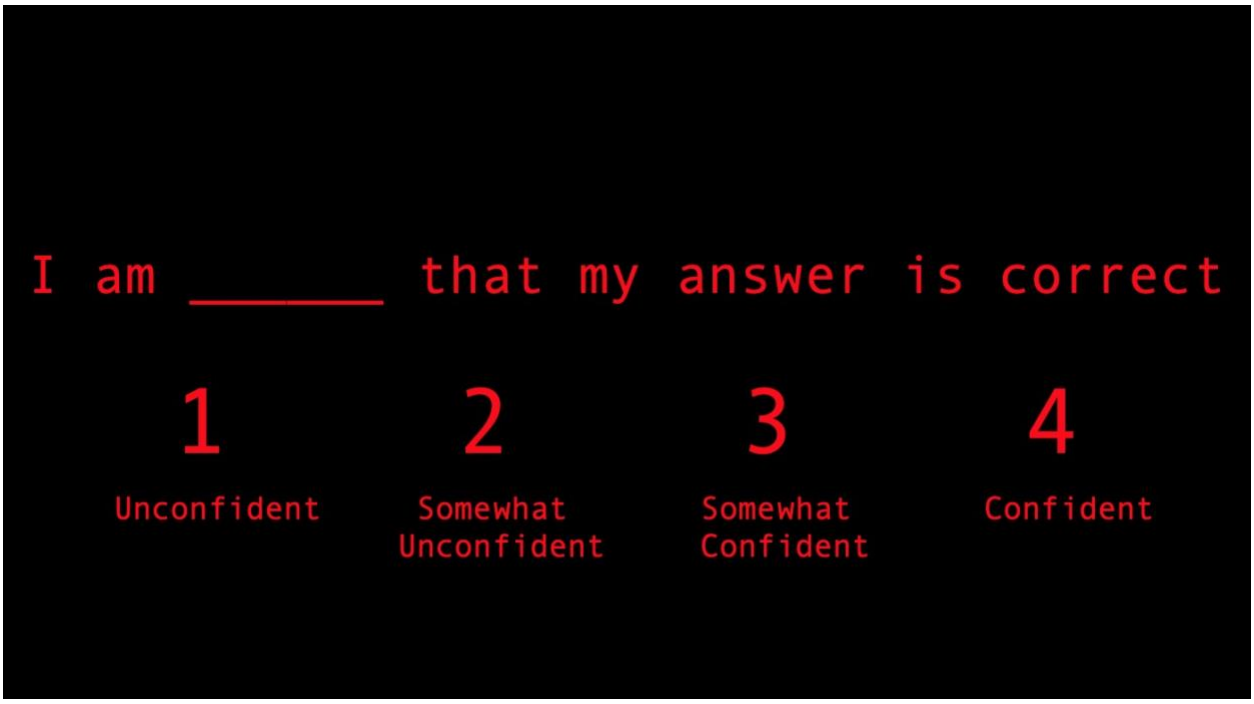

Figure 7: Retrospective Confidence Judgement. Participants were asked to rate how confident they were in the answer they selected from the previous slide. Choices included (1) unconfident, (2) somewhat unconfident, (3) somewhat confident, (4) confident.

Acknowledgements

This research was originally sponsored by a research grant from the New Jersey Commission on Brain Injury Research awarded to Kathy Chiou. Thank you to Andrew Cwiek, Ekaternia Dobryakova, Holly Klecha, James Morecraft, Erica Weber and Kathy Chiou for the assistance in this research. In addition, thank you to the Undergraduate Creative Activities and Research Experience board at the University of Nebraska – Lincoln for funding the exploration of these data.

References

Barman, A., Chatterjee, A., and Bhide, R. (2016). Cognitive impairment and rehabilitation strategies after traumatic brain injury. *Indian Journal of Psychological Medicine, 38* (3), 172-181. doi: 10.4103/0253-7176.183086

Ben-Yishay, Y., and Diller, L. (1993). Cognitive remediation in traumatic brain injury: Update and issues. *Archives of Physical Medicine and Rehabilitation, 74.* 204-213.

Bivona, U., Ciurli, P., Barba, C., Onder, G., Azicnuda, E, Silvestro, D., Mangano, R., Rigon, J. and Formisano, R. (2008). Executive function and metacognitive self-awareness after severe traumatic brain injury. *Journal of the International Neuropsychological Society, 14* (5), 862-868. doi: 10.1017/S1355617708081125

Bogod, N. M., Mateer, C. A., and Macdonald, S. W. S. (2002). Self-awareness after traumatic brain injury: A comparison of measures and their relationship to executive functions. *Journal of the International Neuropsychological Society, 9,* 450-458. doi: 10.10170S1355617703930104

Chiou, K. S., Carlson, R. A., Arnett, P. A., Cosentino, S. A., and Hillary, F. G. (2011). Metacognitive monitoring in moderate and severe traumatic brain injury. *Journal of the International Neuropsychological Society, 17,* 720-731. doi: 10.1017/S1355617711000658

Choy, N. L., Kuys, S., Richards, M., and Isles, R. (2002). Measurement of functional ability following traumatic brain injury using the Clinical Outcomes Variable Scale: A reliability study. *Australian Journal of Physiotherapy, 48* (1), 35-39.

Ciruli, P., Bivona, U., Barba, C., Onder, G., Silvestro, D., Azicnuda, E., Rigon, J., and 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. doi: 10.1017/S135561770999141X

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist, 34*(10), 906–911. doi: 10.1037/0003-066X.34.10.906

Fleming, S. M., & Lau, H. C. (2014). How to measure metacognition. *Frontiers in human neuroscience*, *8*, 443.

Fleming, J. M., Strong, J., and Ashton, R. (2009). Self-awareness of deficits in adults with traumatic brain injury: How best to measure? *Brain Injury, 10* (1), 1-16. doi: 10.1080/026990596124674.

Garmoe, W., Newman, A., and 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). *Journal of Head Trauma Rehabilitation, 20* (4), 348-358.

Hanten, G., Bartha, M., and Levin, H. (2010). Metacognition following pediatric traumatic brain injury: A preliminary study. *Developmental Neuropsychology, 18* (3), 383-398. doi: 10.1207/S1532694206.

Hart, T., Whyte, J., Kim, J., and 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. doi: 10.1097/00001199-200507000-00005.

Kasahara, M., Menon, D., Salmond, C., Outtrim, J., Taylor Tavares, J., Carpenter, T. A., Pickard, J., Sahakian, B., and Stamatakis, E. (2011). Traumatic brain injury alters the functional

brain network mediating working memory. *Brain Injury, 25* (12), 1170-1187. doi: 10.3109/02699052.2011.608210

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.

Koriat, A. (2007). "Metacognition and consciousness," in The Cambridge Handbook of Consciousness, eds P. D. Zelazo, M. Moscovitch, and E. Davies (New York, NY: Cambridge University Press), 289–326.

Langlois JA, Rutland-Brown W, Thomas KE. *Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations, and Deaths.* Atlanta: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2004.

Langlois, J. A., Rutland-Brown, W., and Wald, M. M. (2006). The epidemiology and impact of traumatic brain injury: A brief overview. *Journal of Head Trauma Rehabilitation, 21* (5), 375-378.

Mandrekar, J. N. (2010). Receiver operating characteristic curve in diagnostic test assessment. *Journal of Thoracic Oncology, 5* (9), 1315-1316. doi: 10.1097/JTO.0b013e3181ec173d

Maniscalco, B., and Lau, H. (2012). A signal detection theoretic approach for estimating metacognitive sensitivity from confidence ratings. *Consciousness and Cognition, 21* (1), 422-430. doi: 10.1016/j.concog.2011.09.021

Maniscalco, B., Peters, M., and Lau, H. (2016). Heuristic use of perceptual evidence leads to dissociation between performance and metacognitive sensitivity. *Attention, Perception, & Psychophysics, 78,* 923-937. doi: 10.3758/s13414-016-1059-x

Port, A., Willmott, C., and Charlton, J. (2009). Self-awareness following traumatic brain injury and implications for rehabilitation. *Brain Injury, 16* (4), 277-289. doi: 10.1080/02699050110103274

Rausch, M., Muller, H. J., and Zehetleitner, M. (2015). Metacognitive sensitivity of subjective reports of decisional confidence and visual experience. *Consciousness and Cognition, 35,* 192-205. doi: 10.1016/j.concog.2015.02.011

Robertson, K., and Schmitter-Edgecombe, M. (2015). Self-awareness and traumatic brain injury outcome. *Brain Injury, 29* (7-8), 848-858. doi: 10.3109/02699052.2015.1005135