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Emotion Perception Correlates In Moderate And Severe Traumatic Brain Injury

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EMOTION PERCEPTION CORRELATES
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DEDICATION

It is my pleasure to dedicate this project to my greatest husband, Daniel, and my close family and friends. Each professional milestone would not have been possible without your ongoing encouragement, support, and patience.

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CHAPTER 1: INTRODUCTION

Moderate and severe traumatic brain injury (TBI) is a potentially devastating life event that occurs among 1-1.25 million individuals each year (Corrigan, Selassie, & Orman, 2010; Jager, Weiss, Coben, & Pepe, 2000). Consequences to physical, cognitive, emotional, social, and behavioral functioning associated with TBI make it a leading cause of disability in which individuals often require rehabilitative or 24-hour care (Becker et al., 1977; Coronado et al., 2012; Corrigan et al., 2010; Ghajar, 2000; Hukkelhoven et al., 2003; Rosenfeld et al., 2012).

Impairments in interpersonal functioning are among many of the disruptive adverse consequences of TBI. The skill of reading facial emotions is critical to provide accurate information for effective understanding of interpersonal, emotional, and social cues (Blair, 2003; Bornhofen & McDonald, 2008). Individuals with TBI frequently have deficits in accurate facial emotion perception including problems with recognition, matching, labeling, and discriminating facial emotion expressions (Babbage et al., 2011; Biszak & Babbage, 2014; Croker & McDonald, 2005; McDonald & Flanagan, 2004; McDonald et al., 2011; McDonald & Saunders, 2005; Neumann et al., 2012; Radice-Neumann, Zupan, Babbage, & Willer, 2007; Spell & Frank, 2000; Williams & Wood, 2010). A meta-analysis by Babbage and colleagues (2011) estimated that, depending on the cutoffs used to classify impairment, up to 39 percent of individuals with TBI have difficulties accurately reading and classifying facial emotions compared to 7 percent of healthy adults. Although inefficiencies in emotion perception can occur in healthy adults, the level of impairment seen in TBI is more prominent than that seen in healthy adults (Croker & McDonald, 2005; Spell & Frank, 2000), with an estimated performance that places individuals with TBI approximately 1.1 standard deviations below their healthy counterparts (Babbage et al., 2011).

Studies have examined emotion perception across post-injury recovery and have found that emotion perception deficits often develop at the time of injury (e.g., Green, Turner, & Thompson, 2004) and may remain stable or chronic years after the injury (Babbage et al., 2014; Green, 2004; Green, Turner, & Thompson, 2004; Ietswaart, Milders, Crawford, Currie, & Scott, 2008). Functional weakness in emotion perception is particularly pertinent to patients with TBI, as family members of these patients often complain that their loved ones have personality changes, atypical social behaviors, and interpersonal problems following the injury (Milders, Fuchs, & Crawford, 2003; Milders, Ietswaart, Crawford, & Currie, 2008; Radice-Neumann et al., 2007; Spikman, Milders, et al., 2013). In fact, studies have found that such changes in behavior, including new onset disinhibition and inappropriate behavior are related to emotion perception difficulties following TBI (Jonker, Jonker, Scheltens, & Scherder, 2015).

Relatedly, the literature suggests that facial emotion perception social communication abilities explain more variance in social and occupational integration outcomes than do traditional cognitive measures in executive functioning abilities (Struchen et al., 2008). Furthermore, deficits in psychosocial functioning, including emotion perception, have been found to hinder adjustment and rehabilitation (Biszak & Babbage, 2014; Grattan & Ghahramanlou, 2002; Hoofien, Gilboa, Vakil, & Donovick, 2001; Yates, 2003).

Imaging Findings and Emotion Perception

Although evidence suggests that facial emotion perception is impaired in many patients with moderate or severe TBI (Babbage et al., 2011; Green, 2004; McDonald & Flanagan, 2004; McDonald et al., 2011; McDonald & Saunders, 2005; Neumann et al., 2012; Paradee et al., 2008; Radice-Neumann et al., 2007; Spell & Frank, 2000; Williams & Wood, 2010), it is not clear why or how this deficit occurs. Functional magnetic resonance imaging (MRI) studies reveal several areas in the cortical network that mediate facial emotion processing in healthy adults, including the fusiform gyrus for facial recognition or identification (Farah, 2000; Gauthier et al., 2000; Grill-Spector, Knouf, & Kanwisher, 2004; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999; Kanwisher, McDermott, & Chun, 1997; Kriegeskorte, Formisano, Sorger, & Goebel, 2007), the superior temporal sulcus for gaze direction processing (Hoffman & Haxby, 2000; Puce et al., 2003), and the amygdala and insula for processing of facial expressions (Adolphs, Tranel, Damasio, & Damasio, 1994; Breiter et al., 1996; Ishai, Pessoa, Bikle, & Ungerleider, 2004; Morris et al., 1996; Phillips et al., 1997). Other functional MRI studies have identified that emotion activity patterns are prevalent in the medial prefrontal cortex and left superior temporal sulcus (Peelen, Atkinson, & Vuilleumier, 2010).

Brain damage patterns associated with TBI are heterogeneous and often linked to the mechanism of injury (Roebuck-Spencer & Sherer, 2008); however, common sites of damage in TBI overlap with anatomical locations of many neural structures associated with emotion perception (e.g., Bornhofen & McDonald, 2008; Fontaine, Azouvi, Remy, Bussel, & Samson, 1999). Although mechanisms of injury in TBI can vary widely, the most common among them frequently produce damage to areas associated with emotion perception. For instance, poor facial emotion perception may result from multifocal lesions in emotion perception areas from diffuse axonal injury (e.g., on the orbital surface, within frontal and temporal lobes, etc.) following sudden impact from a motor vehicle collision (e.g., Adams, Graham, & Jennett, 2001; Bešenski, Broz, Jadro-Šantel, Pavić, & Mikulić, 1996; Bornhofen & McDonald, 2008; Gaetz, 2004; Kalsbeek, McLaurin, Harris, & Miller, 1980). Contusions observed in TBI may also involve the frontal and temporal poles and lateral and inferior aspects of the frontal and temporal lobes, which too are associated with emotion perception and processing (Levin, Williams, Eisenberg, High, & Guinto, 1992). Effects of TBI on white matter integrity (i.e., in the inferior longitudinal fasciculus and inferior fronto-occipital fasciculus) and the gray matter volume (i.e., in the lingual gyrus and parahippocampal gyrus) have been implicated in poor facial emotion perception performance (Genova et al., 2015). Brain damage to anatomical structures within *either* the ventral (i.e., amygdala, insula, and ventral areas of the anterior cingulate gyrus) or dorsal (i.e., dorsal regions of the prefrontal cortex, anterior cingulate gyrus, and hippocampus) systems of visual processing may contribute to impaired emotion perception and processing due to the interdependent nature of the systems (Phillips, Drevets, Rauch, & Lane, 2003). Furthermore, cortical connections allow for special neural mechanisms that are sensitive to quick and early detection and discrimination of emotional expressions (Morris, Öhman, & Dolan, 1998; Schupp, Junghöfer, Weike, & Hamm, 2004; Schupp, Öhman, et al., 2004; Schupp et al., 2007). In spite of the heterogeneous presentation of patients with TBI from diverse causes of injury, individuals post injury are continually at special risk for developing problems with emotion perception. Neumann and colleagues (2015) found that activation in varying neuroanatomical regions via functional MRI distinguish between a variety of neurocognitive processes (e.g., facial recognition, visuoperceptual processing, etc.) important to emotion perception. For instance, findings indicated that decreased activation in the fusiform gyrus signifies that persons with TBI have trouble processing faces globally, whereas decreased activation in the occipital cortex would suggest visuoperceptual processing difficulties (Neumann et al., 2015). Integration of neuroanatomical, neuropsychological, psychological, and emotional information is integral to understand emotion perception functioning.

Impaired Emotion Perception Accuracy and Other Functioning in TBI

In addition to anatomical brain mapping, a process approach may enhance appreciation of *why* and *how* individuals with TBI distinguish emotional material differently from their healthy adult counterparts.

Emotion Perception and Neuropsychological Functioning. Neuropsychological impairments among individuals with moderate and severe TBI is widely heterogeneous and individualized (e.g., Iverson & Lange, 2011; Roebuck-Spencer & Sherer, 2008). Despite varied presentations, research examining neurocognitive patterns in TBI most often reveals impairments in processing and psychomotor speed (Yim et al., 2013; Prigatano & Altman, 1990; Spikman, Timmerman, Milders, Veenstra, & van der Naalt, 2012), memory (Spikman et al., 2012; Sunderland, Harris, & Baddeley, 1984; Sunderland, Harris, & Baddeley, 1983; Yim et al., 2013) attention (Iverson & Lange, 2011; Lezak et al., 2004), and executive functioning domains (Bogod, Mateer, & Macdonald, 2003; Malex, Machulda, & Moessner, 1997; Rao et al., 2013; Yim et al., 2013; Spikman et al., 2012; Sunderland et al., 1983). Impairments are likely to become global and involve additional cognitive domains as injury severity increases (Dikmen et al., 1995). Research examining neuropsychological correlates of emotion perception is somewhat limited; however, increasing evidence indicates that tests of working memory, executive functioning, verbal reasoning, learning, and memory recall/recognition are correlated with accuracy of emotion perception performance in TBI samples (Allerdings & Alfano, 2006; Henry, Phillips, Crawford, Theodorou, & Summers, 2006; Rao et al., 2013; Spikman, Boelen, et al., 2013). Given that impaired processing speed is a hallmark symptom following TBI (e.g., Iverson & Lange, 2011, van de Naalt, 2012, etc.), the relationship between emotion perception accuracy and processing speed must be considered. Thus, the tradeoff between speed and power in assessing emotion perception was also of interest and explored via adjusting the presentation time of facial emotion tasks.

Emotion Perception: Error Patterns and Emotional Valence. With growing appreciation for the presence of emotion perception deficits following TBI, research has turned to examining patterns of individual emotion errors. Some findings have suggested that individuals with TBI make significantly more emotion perception errors than healthy adults for emotions with *negative* valence (i.e. anger, fear, sadness, disgust) than non-negative emotions (i.e., happy, joy, neutral, and surprise; Rosenberg, McDonald, Dethier, Kessels, & Westbrook, 2014; Spikman et al., 2013; Croker & McDonald, 2005; Hopkins, Dywan, & Segalowitz, 2002; Spell & Frank, 2000; Dethier, Blairy, Rosenberg, & McDonald, 2013; Rosenberg et al., 2015). However, mixed findings also have been reported (Zupan et al., 2014; Rosenberg et al., 2015). Studies have reported global impairments across positively and negatively valenced emotions (i.e., deficits including identification of happy faces) and also suggest that people with TBI may perceive affect in faces when none is being expressed (Zupan et al., 2014). Rosenberg et al. (2014) questioned the body of literature indicating deficits in specific emotions. Although they too observed that adults with TBI were less accurate in identifying negative valenced emotions as compared to positive, they suggested that the effect might be driven by relative item difficulty (i.e., measurement error): Given differences in intensity, some emotions (e.g., happy) are easier to identify than others (e.g., fear). Relative ease of identifying certain emotion expressions of others, such as happy, may facilitate ceiling effects. Accounting for *intensity* of emotion expression eliminated differences in accuracy for valence of specific emotions, instead indicating that a global deficit was driven broadly by injury severity (Rosenberg et al., 2015). Additionally, the number of response options available for *negative* compared to *positive* emotions may bias findings: Most emotion perception measures include up to four *negative* emotion response options and only one or two *positive/nonnegative* (including *neutral and surprise*) emotions.

Thus, rapid selection among several possible responses for *negatively* valenced emotions may produce relatively more errors compared to the selection of *positive* emotions*,* which have few response options and (theoretically) relatively lower cognitive demand complexity for the response.

Importantly, however, most prior research that has examined relative impairments in valence (i.e., negative, positive, neutral) or specific emotion categories has neglected to consider the specific types of misattributions when errors do occur (i.e., how incorrectly classified emotions are being categorized). For example, if errors occur most frequently in reading angry or fearful faces, a question of interest is which emotion (if any) is being mistaken for anger or fear. One study by Rosenberg and colleagues (2014) reported general patterns of each emotion misattribution, but did not examine neutral emotions or response omissions. Understanding of misattribution patterns among groups may provide insights about the emotional and relational difficulties observed in TBI so that education may be provided to patients and their loved ones. Additionally, knowledge could be utilized to identify targets for rehabilitation. Detailed examination of relative patterns of misattribution among people with TBI and the extent to which these patterns differ from healthy adults is sparse. Moreover, given support for the importance of emotion intensity in recognizing affect expressed by others (i.e., Rosenberg et al., 2014; Rosenberg et al., 2015), it is surprising that extant TBI research has not delved much into examining potential influences of intensity and content of *experienced* emotion in emotion perception accuracy.

Experienced Affect and Neurocognitive and Emotion Perception Performances.

Experienced Affect and Performance. Findings stating that intensity of *expressed* affect influences emotion perception (Rosenberg et al., 2014; Rosenberg et al., 2015; Zupan, Babbage, Neumann, & Willer, 2014) prompts the question of whether *experienced* affect exhibits a similar effect. Research suggests that individuals with TBI have increased rates of developing (e.g., Dikmen et al. 2004; Jorge et al. 2004) and maintaining (e.g., Hibbard et al. 2004, Koponen et al. 2002, etc.) depression following injury. Additionally, individuals with TBI often experience changes in personality that may be associated with an altered experience of emotion (e.g., increased apathy, impulsivity, and emotional lability, amotivation, and diminished empathy, etc.), which are likely related to brain damage and adjustments to impairments or functional loss (e.g., O'Shanick & O'Shanick, 2005; Lezak, Howieson, & Loring, 2004; Shoenberg & Scott, 2011; Milders et al., 2008; Iverson & Lange, 2011). Similar to neurocognitive presentations in TBI, manifestations of such changes vary from person to person. Given the increased incidence of depression and anxiety following TBI, investigations of the role of experienced affect on cognition and emotion perception performance is warranted. Whereas intensity of *expressed* affect has been examined by manipulating facial stimuli to explore whether this methodological adjustment alters perception of the presented emotions, examining intensity of *experienced* affect (e.g., emotion, prolonged mood, etc.) can enable exploration of extent to which internal experiences influence perception of emotion and cognition. Thus, the current study examined the role of *experienced* affect through proxies of content (i.e., self-reported mood states) and intensity (i.e., strength of internal experiences and reactions) endured by participants.

An example of the role of negatively experienced affect on neuropsychological functioning is most consistently observed in the depression literature, which reveals that individuals with major depression demonstrate more inefficiencies than healthy adults on tasks of complex attention/working memory, executive functioning, psychomotor and processing speed, and memory recall (Langenecker, Lee, & Bieliauskas, 2009). Research examining relationships between experienced affect and neuropsychological performance is limited in TBI samples. Available studies have found that individuals with comorbid TBI and major depression demonstrate significantly poorer performance than nondepressed individuals with TBI on measures of processing speed, working memory, executive functioning, and verbal memory (Rapoport, McCullagh, Shammi, & Feinstein, 2005; Chamelian & Feinstein, 2006; Rosenberg et al., 2015). These limited findings are suggestive that individuals with comorbid major depression and TBI demonstrate poorer neuropsychological functioning than individuals with depression or TBI alone. Given that TBI samples demonstrate neuropsychological and emotion perception deficits, the current study extended previous research to examine the extent to which emotion perception performance is affected by the combination of TBI and depressive symptoms.

Emotion Perception Performance and the Level and Content of Experienced Affect. Literature exploring the extent of the relationship between level of experienced affect and emotion perception abilities in TBI samples is limited. Available studies to date have examined low levels of affect via alexithymia, high levels of apathy, limited empathy, and low emotional reactivity. This literature demonstrates that low levels of experienced emotion in persons with TBI hinders accurate perception of emotion expressed by others (Allerdings & Alfano, 2001; McDonald, et al., 2011; de Sousa et al., 2010, 2011; Dethier et al., 2013; Henry et al., 2006; Hopkins, Dywan, & Segalowitz, 2002; McDonald, Li, et al., 2011; Sanchez-Navarro, Martinez-Selva, & Roman, 2005; Koponen et al., 2005; Saunders, McDonald, & Richardson, 2006; Soussignan, Ehrle, Henry, Schaal, & Bakchine, 2005). Studies have not examined the potential influence of high *experienced* affect intensity and emotion perception performance after TBI.

Although literature examining the relationship between emotion perception abilities and *high* levels of *experienced* affect intensity in TBI samples is sparse, findings from clinical samples other than TBI (i.e., ADHD) demonstrate that experience of high intensity affect hinders emotion perception performance in clinical samples but not in healthy adult samples (e.g., Rapport et al., 2002). Specifically, among adults with ADHD, intensity of experienced affect showed a nonlinear, Yerkes-Dodson curve such that affect intensity facilitated emotion perception accuracy at low to moderate levels but hindered emotion perception accuracy at high levels. Persons who were generally accurate at emotion perception showed the facilitative (positive) relation to experienced affect intensity, whereas persons with relatively poorer accuracy showed the adverse (inverse) relation to experienced affect intensity. Exploration of whether this pattern of performance applies to TBI samples is warranted, especially because changes to emotion experience, including intense, labile, overwhelming experience of emotion, is a common sequela of TBI (e.g., Dikmen et al. 2004; Jorge et al. 2004; Hibbard et al. 2004, Koponen et al. 2002).

Regarding the role of content of emotional experience on emotion perception, studies from psychiatric samples such as unipolar and bipolar depression reveal that depressive symptoms often hindered emotion perception performance (Bozikas et al., 2007; Langenecker et al., 2005; Summers, Papadopoulou, Bruno, Cipolotti, & Ron, 2006; Vederman et al., 2011; Murphy & Sahakian, 2001; Deldin et al., 2001). The extent to which depression affects emotion perception accuracy in TBI, and to what degree this relationship differs from healthy adults remains unclear; thus, the current study also aims to clarify the extent to which level of depression symptoms affects performance on emotion perception task.

Aims and Hypotheses of the Present Study

Specific Aim 1. The current study aimed to evaluate the extent to which adults with TBI differ from healthy adults on emotion perception and self-reported experienced affect (i.e., affect intensity and depression symptoms), and the extent to which these phenomena relate to specific neuropsychological impairments. In the context of this aim was a goal to explore emotion perception abilities across different modalities (visual and auditory) among adults with TBI as well as compared to healthy adult counterparts.

Given evidence that emotion perception is impaired in facial and auditory modalities among many persons with TBI (Babbage et al., 2011; Green et al., 2004; McDonald & Flanagan, 2004; McDonald et al., 2011; McDonald & Saunders, 2005l Neumann et al., 2013; Paradee et al., 2008; Radice-Neumann et al., 2007; Spell & Frank, 2000; Williams & Wood, 2010), it was expected that healthy adults would perform significantly better than adults in the TBI group on all tasks of emotion perception, with medium or larger effects. The literature examining the relative difficulty of auditory versus facial emotion perception tasks is growing; some studies demonstrate that persons with TBI exhibit stronger performance on tasks of facial than auditory emotion perception (i.e., Zupan et al., 2014). Others have examined the comparison of unimodal and multimodal emotion perception and found that, unsurprisingly, persons with TBI perform best when given multiple modalities simultaneously than either vocal or facial presentation alone (Zupan & Neumann, 2014). Speed versus power tradeoffs in accuracy are especially of interest after TBI. One method of exploring the relative contributions of processing speed and emotion-specific deficits is to manipulate processing speed demands. Given that slowed processing speed is a hallmark deficit of TBI (e.g., Iverson & Lange, 2011, van de Naalt, 2012, etc.), it was expected that participants would perform relatively more accurately following slowed presentations of emotions versus standard (fast) presentations. Another method of exploring the relative contributions of processing speed and emotion-specific deficits is to examine the relationship between processing speed and accuracy. It was expected that processing speed would be inversely related to accuracy, especially under conditions of high demand, but that processing speed would not wholly account for deficits in emotion perception.

In regards to experienced emotion, it was expected that individuals with TBI would report higher intensity of experienced emotion and more severe depressive symptoms than healthy adults. This hypothesis is consistent with previously described findings suggesting that individuals with TBI are at increased risk for developing personality and mood changes such as depression and emotional lability (e.g., Dikmen et al. 2004; Jorge et al. 2004; Hibbard et al. 2004, Koponen et al. 2002, etc.).

Specific Aim 2. This study also aimed to examine the extent to which neuropsychological functioning and self-reported experienced emotion (i.e., depression symptoms and intensity of experienced emotion) were related to facial and auditory emotion perception accuracy among people with TBI and healthy adults. In doing so, the current study aimed to determine the extent to which specific neuropsychological domains or global impairments underlie facial and auditory emotion perception difficulties.

From a cognitive perspective, increasing evidence indicates that executive functioning, processing speed, learning, and memory are related to accuracy of emotion perception after TBI (Yim et al., 2013; Allerdings & Alfano, 2006; Henry et al., 2006; Rao et al., 2013; Spikman, Boelen, et al., 2013). Thus, it was expected that poor emotion perception performance would be related most with impairments of executive functioning, as well as learning and memory. From a theoretical perspective, it was also expected that verbal attention and working memory performance would show a strong positive correlation with auditory emotion perception accuracy. It was expected that the pattern of relationships between cognitive domains of functioning and emotion perception would differ between adults with TBI and healthy adults.

Specifically, similar to prior research (Costa et al., 2015; Jonker et al., 2015), it was expected that a generally global pattern of cognitive deficits would be related to emotion perception difficulties among adults with TBI (i.e., driven largely by global impairments associated with injury severity) as compared to a pattern involving specific cognitive domains among healthy adults.

Given limitations in the TBI literature, hypotheses regarding experienced affect were derived by integrating theoretical and clinical perspective from the limited research on TBI as well as in clinical populations other than TBI (i.e., ADHD, depression). It was expected that high levels of experienced affect would be inversely correlated with accuracy in TBI, but not in healthy adults. Consistent with the emotion perception literature examining low intensity of experienced emotion (e.g., limited empathy, decreased reactivity, etc.), low levels of experienced affect intensity also were expected to hinder emotion perception performance. Regarding degree of depressive experienced emotion, it was expected that persons in the TBI group with very low levels of reported depression would demonstrate greater emotion perception impairment than other persons in the TBI group and healthy adults, as this pattern could reflect that low reporters may likely experience anosognosia, which could translate to awareness of others' experience as well.

Specific Aim 3. The present study also aimed to examine the pattern of perception accuracy for *individual* emotions (e.g., happy, sad, fear, etc.). This study aimed to clarify mixed findings in the literature regarding the extent to which the pattern of emotion perception deficits is global, influenced by (positive or negative) valence, or is specific to individual emotions among persons with TBI and healthy adults. In doing so, the study also built upon contemporary literature that has examined error patterns by exploring patterns of *misattributions* among the individual emotions to gain understanding of possible perceptual biases (i.e., how incorrectly classified emotions are categorized as other emotions).

Research to date has generally focused on relative accuracy and impairment in perceiving specific emotions, generating some debate and controversy about whether deficits observed after TBI are a global or emotion-specific deficit. Additionally, the relative roles of valence of emotions and item difficulty have yielded mixed findings. Gaps in this literature become apparent in that there is a focus on relative errors for specific emotions with limited investigation of the endpoint of the error, which is the nature of the misattribution (i.e., to which emotion the error was misattributed). Thus, the current aim enabled investigation of the response biases enacted during erred emotion recognition, not simply whether an error occurred. Specifically, the study investigated the extent to which patterns of misattribution errors demonstrated biases in perception associated with valence (e.g., positive emotions miscoded as negative emotions, negative emotions miscoded as other negative emotions, etc.).

Consistent with the literature, it was expected that persons with TBI would perform more poorly than healthy adults across all emotions. The mixed literature regarding individual emotion deficit patterns and exploration of valence made for murky hypothesis generation, as some studies posited that deficits among persons with TBI are stronger for negative than positive valence (i.e., Spikman et al., 2013; Croker & McDonald, 2005; Hopkins, Dywan, & Segalowitz, 2002; Spell & Frank, 2000; Williams & Wood, 2010) and research following these studies demonstrated that valence findings could be better accounted for by intensity of *expressed* affect and item difficulty (Zupan et al., 2014; Rosenberg et al., 2014; Rosenberg et al., 2015). Given the methodology used in the current study (i.e., it did not include tasks that account for item difficulty or *expressed* emotion intensity), it was hypothesized that findings would align with research that demonstrates negative response bias (i.e., valence effects). As research examining misattribution patterns is extremely rare, hypotheses were derived by considering qualitative findings in the one known study by Rosenberg and colleagues (2014) that reported misattribution patterns in persons with TBI. However, it should be noted that many direct comparisons and hypotheses could not be made, as many of the emotions examined (i.e., disgust and surprise) were not assessed during the present study. The current study expected a negative response bias for misattributions such that *positive* and *negative* emotions would be misperceived as *negative* emotions more often than the reverse. This negative response bias was expected to be greater for persons with TBI than for healthy adults. Theoretically, this phenomenon may exist because individuals may become overwhelmed by the greater number of response options available for *negative* compared to *positive* emotions, which may increase the difficulty in distinguishing between emotions during the task.

Specific Aim 4. The final aim of the current study was to examine the pattern of *neutral* errors and misattributions among persons with TBI and healthy adults. Examination of neutral emotions was of particular interest, as it has been given exceptionally less attention in the literature for TBI than in other clinical populations (i.e., depression). The current study assessed *neutral* emotions in facial and auditory modalities with slight variations in the method of investigation: Specifically, examination of *neutral* auditory emotion perception enabled bidirectional exploration in which sentences were read in a *neutral* voice *and* individuals were allowed to select *neutral* response options. Dissimilarly, facial emotion perception for *neutral* faces included presentation of *neutral* faces without offering a *neutral* response option. The study aimed to examine *neutral* emotion perception in this manner due to findings from the facial emotion perception literature in depression that has demonstrated the importance of forcing an emotion response (i.e., limiting selections to only emotion responses). Specifically, findings indicate that when emotion responses to *neutral* faces were forced, individuals with unipolar depression demonstrated negative response biases in which responses to *neutral* emotions were misperceived as *sad* (Langenecker et al., 2005) and *happy* emotions were misperceived as *neutral* (Gollan et al., 2008; Yoon et al., 2009). Thus, the current study aimed to examine the extent to which a similar response bias exists for *neutral* facial emotion perception in TBI by presenting *neutral* faces without offering a *neutral* response option.

Consistent with the limited TBI literature examining *neutral* emotions, persons TBI were expected to demonstrate more difficulty than their healthy adult counterparts in perceiving *neutral* emotion accurately (Williams & Wood, 2010; Zupan et al., 2014). The current study is unique in examining misattributions of *neutral* emotions, as the sparse literature examining misattribution patterns in TBI has not yet included inspection of *neutral* emotions. The current hypothesis regarding *neutral* misattribution was derived by integrating theory with *neutral* facial emotion perception in the depression literature; thus, it was expected that persons in the TBI group would demonstrate a response bias evidenced by high frequency of *neutral* emotions miscoded as *negative* emotions.

Summary of Aims and Purpose of Current Study

Research on emotion perception in TBI has received significant attention across the 1990's and early 2000's. Studies have demonstrated that individuals with TBI experience impairments in emotion perception accuracy in facial and auditory modalities. Research has attempted to explain these difficulties using neuroanatomical correlates and, to a smaller degree, patterns of emotion perception and neurocognitive performance; however, understanding of *why* emotion perception deficits occur remains unclear.

Calls for research have charged the field to establish and validate disseminable efficacious treatment options to implement in rehabilitation settings for individuals with TBI who experience emotion perception deficits (Duncan R. Babbage, 2014). Limited interventions have yet to be developed (Babbage, 2014), but studies targeting emotion perception have demonstrated efficacy (i.e., Neumann, Babbage, Zupan, & Willer, 2015). One explanation for the scarcity of treatment options is that the field continues to require knowledge of processes that influence emotion perception. Thus, the current study aimed to explore in detail the psychological, emotional, and cognitive patterns that may affect facial and auditory emotion perception accuracy to enhance understanding for researchers, providers, patients, and caregivers. With additional investigation of functional contributions to emotion perception accuracy, educational material and specific targets for intervention may be developed.

CHAPTER 2: METHOD

Participants

The study included 50 adults with moderate or severe TBI and 39 healthy comparison (*N* = 89) participants. Potential TBI participants were drawn from the Rehabilitation Institute of Michigan as part of the Southeastern Michigan Traumatic Brain Injury Model System (SEMTBIS) to ensure that each participant had a medically documented moderate to severe TBI. Healthy adults were recruited from the Detroit Metropolitan community and by referral from the TBI participants (e.g., family members and friends) consistent with the aim to obtain equivalent samples.

All participants were required to be between 18 and 79 years of age. Exclusionary criteria for healthy comparison adults included a history of brain injury, dementia, neurological conditions (e.g., stroke, epilepsy, multiple sclerosis, etc.), psychotic disorders, or the presence of medical conditions that likely affect cognition or vision. The current study was conducted concurrently with research examining neuropsychological performance using eye-tracking technology. As such, many participants were excluded due to their use of progressive and/or bifocal eyeglasses, as these individuals demonstrated difficulty calibrating with the technology. Exclusionary criteria for the TBI group were the same as for HC participants other than that they were positive for a history of brain injury. All participants with TBI were registered with the SEMTBIS, which enabled verification that each participant had a medically documented moderate to severe TBI. Severity of injury was confirmed via posttraumatic confusion $\geq$ 24 hours and Glasgow Coma Scale (GCS) $\leq$ 12 at the time of admission to the emergency department. All participants with TBI who were enrolled in the current study were selected based on their GCS score of $\leq$ 12 and were at least 6 months post injury.

Descriptive statistics for demographic characteristics for the TBI and HC groups are presented in Table 1, along with injury characteristics for the TBI group. As shown in Table 2a, the groups differed on education, $F(1, 87) = 24.12$, $p < .001$, with the HC group reporting approximately 2 more years education than the TBI group. Age was not significantly different between the groups, $F(1, 87) = 0.00$, $p = .948$. Table 1 also depicts that the groups were predominantly men and African American. Regarding injury characteristics for the TBI group illustrated in Table 1, participants were all within the moderate and severe ranges of severity based on the total score on the GCS with a mean score ($M = 7.4$) falling in the severe range. Similarly, the mean duration of posttraumatic confusion ($M = 21.3$ hours) was consistent with a classification of severe TBI, as most of the participants were in a confusional state for more than 24 hours.

Procedure

Recruitment. TBI participants were recruited from the pool of registered participants in the SEMTBIS who volunteered to be contacted for research. HC participants were a combination of individuals from the community and friends and family of persons in the TBI group. These individuals made contact with the research team at community recruitment events or via telephone in response to community advertisements or referral. All potential participants were screened for interest and basic inclusion criteria via telephone. If initial phone-screening criteria were met, individuals were scheduled for an in-person appointment.

Participants completed informed consent procedures per Institutional Review Board and hospital policy guidelines. Once eligibility was confirmed during a brief in-session interview, enrolled participants completed a battery of paper-and-pencil and computerized neuropsychological measures and questionnaires. Many computerized tasks included eye-tracking components as part of a larger study. Participants were paid $30 in cash for their time at the end of the session.

Measures

Emotion Perception Tasks.

Facial Emotion Perception Task [FEPT; influenced by (Langenecker et al., 2005; Rapport, Friedman, Tzelepis, & Van Voorhis, 2002)]. The FEPT is a computer-administered task that assesses accuracy and speed in recognizing facial emotional expressions. This author programmed two versions of the FEPT (FEPT and FEPT-Slow) using E-Prime 2.0 Professional that are similar to structure, design, and stimuli used in previous FEPT tasks.

During both versions of the task, participants were presented with black and white facial stimuli expressing various emotion expressions (Ekman & Friesen, 1976) and control (i.e., animal) stimuli. Emotion facial stimuli included *happy, sad, angry, neutral*, or *fearful* facial expression. During facial trials, participants were required to classify stimuli into *happy, sad, angry*, or *fearful* categories. Participants were not given the option to categorize faces as neutral, which forced classification of these *stimuli into an emotional category. Control stimuli consisted of dog, cat, primate, and bird* images and required participants to classify stimuli into the four corresponding categories. Accuracy and response times were recorded to measure facial emotion perception.

During the FEPT task, 63 images were presented for 350 milliseconds followed by a mask image for 100 milliseconds to reduce effects of afterimages. Participants were given 3100 milliseconds to provide responses using the response box. Trials were separated by the presentation of a fixation cross for 500 milliseconds.

A second version of the FEPT task (i.e., FEPT-Slow) was created to assess eye-tracking variables in facial emotion perception within the context of the overall study. Although eye-tracking data were not explored explicitly during this study, behavioral data from this second version are included. The overall FEPT-Slow task parallels the FEPT task with differences in presentation time and order to accommodate linking the program with the Tobii TX300 Eye-Tracking system. During the FEPT-Slow task, 66 images were presented for 2500 milliseconds, mask images were presented for 200 milliseconds, and participants were given 3100 milliseconds to provide responses. Fixation crosses to separate trials are presented for 500 milliseconds.

Psychometric properties and sensitivity. Tasks using a similar design and image composition have been used successfully in research that documents impaired facial emotion perception among people with moderate to severe TBI (Paradee et al., 2008). Reliability analyses were conducted on the tasks as used in the present sample and are presented in the Results.

Variable(s) of interest. The current study used percent correct of emotion stimulus trials (i.e., number correct divided by total stimuli) to measure facial emotion perception accuracy. Percent accuracy for each type of emotional stimuli (e.g., number correct *sad* divided by total *sad* stimuli) was used to examine extent to which individual emotion perception varied, and placed all emotions on a common metric. Secondary measures included individual error types in the form of misattribution (e.g., misperceiving *fearful* as *sad*) to evaluate patterns of misperceptions. Percent accuracy for animal stimuli (e.g., number correct *animals* divided by total animal stimuli) was also used as a control comparison to emotion perception accuracy.

Green's Emotional Perception Test [EPT; (Green & Allen, 1997)]. The 45-item computerized EPT includes an auditory presentation of non-emotional sentences read with an emotional tone. Participants were asked to indicate *how* the sentence was presented (e.g., emotional tone), ignoring the meaning of the sentence. Emotional stimuli were presented with one of five emotional tones: *happy, sad, angry, fearful*, or *neutral* and participants were asked to classify them into the appropriate categories. Psychometric properties have not been published on adults with TBI.

Psychometric properties and sensitivity. According to the test manual (Green & Allen, 1997), internal reliability and test-retest are high in healthy adult samples.

Variable(s) of interest. The current study used percent correct (e.g., number correct divided by total stimuli) to measure auditory emotion perception accuracy. Percent accuracy for each type of emotional stimuli again was used to examine extent to which individual emotion perception varied. Similar to FEPT and FEPT–Slow, secondary measures included the individual error types to evaluate patterns of misperceptions.

Neuropsychological Tests. All eligible participants were administered a comprehensive battery of neuropsychological tests. The following measures include the relevant tests used in the current study.

The Wechsler Test of Adult Reading [WTAR; (The Psychological Corporation, 2001)]. The WTAR is a word reading test that is widely accepted for use of estimating premorbid verbal intelligence. In this task, examinees were presented with 50 phonetically irregular words (e.g., tough) to pronounce aloud. Reading recognition has been found to be strongly related to IQ (R. Green et al., 2008) and is typically very robust to brain insult or neurological impairment (Johnstone, Hexum, & Ashkanazi, 1995); therefore, reading recognition tests are generally preserved in individuals who show decline in other cognitive domains following brain injury (R. Green et al., 2008; Kashluba, Hanks, Casey, & Millis, 2008), including individuals with TBI.

Psychometric properties and sensitivity. According to the test manual, internal consistency (.87-.97, depending on age), test-retest reliability (>.90), and external validity (e.g., AMNART r = .90) are high (The Psychological Corporation, 2001).

Variable(s) of interest. The current study used the WTAR standard score as determined by the manual as a proxy of estimated premorbid intelligence.

Warrington Recognition Memory Test [RMT - Faces; (Hermann, Connell, Barr, & Wyler, 1995; Warrington, 1984)]. The Warrington RMT for Faces (RMT-Faces) is comprised of 50 trials. Consistent with standardized administration, participants were presented with each of the 50 stimuli (i.e., black and white photographs of unfamiliar male faces) one at a time and then were asked to classify each stimulus as "pleasant" or "unpleasant" to facilitate maintained attention across the task. Participants were then presented with 50 forced-choice recognition trials immediately following completion of the learning trials. During the forced-choice paradigm, participants were asked to select the previously viewed target stimulus (either a face or word) from a novel foil.

Computerization. A computerized version of the RMT was paralleled from of the traditional paper-and-pencil version to enable examination of visual processing in the context of the broad battery in of which this study was a part. Thus, the traditional RMT task was transformed into a computerized version using E-Prime 2.0 Professional software. Consistent with standardized task administration, stimuli were presented side-by-side on a blank white screen for 3 seconds each. Examinees responded using a response box.

Psychometric properties and sensitivity. The RMT - Faces task was originally designed to assess non-verbal memory in a forced-choice recognition paradigm to reduce vulnerability of memory difficulties experienced in patients with psychiatric distress (e.g., depression, anxiety, etc.) and language difficulties (Strauss, Sherman, & Spreen, 2006). Internal consistency for the RMT–Faces has been found to be adequate overall (Cronbach's alpha of .77) and in TBI samples (Malina, Bowever, Millis, & Uekert, 1998).

Variable(s) of interest. The current study used the raw total number correct during the forced choice trial as a measure of non-verbal memory.

Wechsler Adult Intelligence Scale – Fourth Edition, Digit Span (WAIS-IV; Wechsler, 2008). The WAIS-IV Digit Span task is a three-part verbal measure of attention and working memory. Consistent with administration instructions included in the manual, examinees were asked to repeat numerical series of increasing lengths orally. In the first trial, Digits Forward, participants were asked to repeat numerical series in forward order. In the second trial, Digits Backward, participants were directed to repeat numerical strings aloud in reverse order from their presentation. In the last trial, Digits Sequencing, participants were instructed to repeat numerical strings aloud in sequential order.

Psychometric properties and sensitivity. According to the WAIS-IV manual, retest reliability, convergent validity, and discriminant validity are well documented for WAIS-IV subtests across various correlational studies and instruments (Wechsler, 2008).

Variable(s) of interest. The current study included the raw scores on Digits Forward and Digits Backward as measures of simple attention and working memory, respectively.

Symbol Digit Modality Test-Written [SDMT; (Smith, 1991)]. In the SDMT, participants were asked to substitute a number for corresponding geometrical figures that are paired in a legend at the top of the page. Examinees were given 90 seconds to complete as many items as possible of 110 total items.

Psychometric properties and sensitivity. The SDMT has been found to be highly sensitive to severe TBI and among individuals with diffuse axonal injury (Felmingham, Baguley, & Green, 2004). It is effective in demonstrating differences between individuals with neurological insults from healthy adults, and is capable of discriminating between phases along the TBI recovery process (Bate, Mathias, & Crawford, 2001). Test-retest reliability is adequate for research purposes (Smith, 1991) and has respectable concurrent validity with several similar tasks, including the Wechsler Digit Symbol/Coding, Letter Cancellation, Trail Making, and reaction time (Strauss et al., 2006).

Variable(s) of interest. The current study included the raw total of correct substitutions as a measure of processing speed and visual attention.

***Trail Making Tests [(TMT; (Reitan & Wolfson, 1985)*].** The two-part TMT (TMT-A and TMT-B) is a timed numeric and alpha-numeric sequencing task. In TMT-A, participants were instructed to connect circled numbers from 1 to 25 in numerical sequence quickly and accurately (i.e., 1-2-3, etc.). In TMT-B, participants were asked to connect circled numbers and letters in an alternating sequence between numbers and letters (i.e., 1-A-2-B-3-C, etc.; ranging from 1-13 and A-L).

Psychotropic Properties and Sensitivity. Research has established that participants with severe TBI with diffuse axonal injury perform significantly more slowly on TMT tasks, with slow TMT-A performance accounting for some difficulties observed in TMT-B (Felmingham et al., 2004). These findings remained up to five years after injury (Millis et al., 2001). Test-retest and interrater reliability have been found to be adequate but notable for variability depending on age and population studied (Strauss et al., 2006).

Variable(s) of interest. Consistent with research (e.g., (Strauss, 2006), the current study used the total time for TMT-A to examine processing/psychomotor speed and visual attention as well as TMT-B to assess components of executive functioning (i.e., set-shifting and cognitive flexibility).

Judgment of Line Orientation-Short form [JLO; (Benton, Hamsher, Varney, & Spreen, 1983; Qualls, Bliwise, & Stringer, 2000)]. The JLO is a task of visual perception. In this task, participants were required to identify the two lines, from a numbered response diagram, that match the position and orientation of the two stimulus lines. The current study uses a 15-item short form (Odd item, Form V) and calculates an estimated full score by multiplying total correct pairs by two.

Psychometric properties and sensitivity. Short forms of the JLO have been found to be highly correlated with the full 30-item version and maintain comparably high validity psychometric properties to the full 30-item versions (Qualls et al., 2000; Vanderploeg, LaLone, Greblo, & Schinka, 1997; Woodard et al., 1998). Short forms have also been found equivalent to full 30-item forms in samples of TBI participants (Mount, Hogg, & Johnstone, 2002; Vanderploeg et al., 1997; Woodard et al., 1996).

Variable(s) of interest. The current study used the raw estimated full score as a measure of non-motor visuospatial perception and orientation.

California Verbal Learning Test – 2nd Edition [CVLT-II; (Delis, Kramer, Kaplan, & Ober, 2000)]. The CVLT-II is a verbal list-learning task that consists of metrics of attention, encoding, learning, and components of retrieval and recognition memory for verbal information. Consistent with the manual administration instructions, the task required examinees to recall 16 aurally-presented words (ready by the examiner) immediately after each of five consecutive learning trials. Each of the 16 words belongs to one of four semantic categories. Following the fifth presentation of the list, examinees were read a 16-item distracter list to recall immediately.

At that time, participants were asked to complete a free-recall trial and a cued-recall trial (using the categorical cues) immediately and following a 20-minute delay. Subsequently, participants completed aurally administered recognition and forced-choice trials.

Psychometric properties and sensitivity. According to the test manual (Delis et al., 2000), psychometric properties are adequate for measures of internal consistency, test-retest correlations, and alternate form reliability; however, specific magnitudes of reliability appear to vary widely (i.e., from low to high) depending on the variable of interest. For instance, high test-retest reliability coefficients have been identified for the five immediate-recall learning trials, short- and long- delay free recall trials, and total recognition discrimination, whereas test-retest correlations are low for total repetitions across recall trials.

Variable(s) of interest. The current study used the sum raw score of the five initial learning trials to assess learning and memory.

Stroop Color and Word Test [Stroop; (Golden, 1978)]. The Stroop task is comprised of three 45-second trials: the Word trial, the Color trial, the Color-Word trial. During the Word trial, participants were instructed to read as many *words* of colors (printed in black ink) from a card of 100 words as quickly as possible. The Color trial used the same instructions, but contained X's printed in colored ink (i.e., red, blue, yellow) instead of words. Participants were asked to name the color of the *ink* in which X's were printed. The Color-Word trial was similar to the Color trial in that participants were asked to name the color of the *ink*; however, stimuli contained words of colors (colors of printed word and ink did not match) and participants were asked to ignore the printed word on the page (e.g., say, "red" when the *ink* is red in the presence of the written *word* "blue"). Throughout all portions of the task, participants were given quick and direct feedback for incorrect answers and asked to correct their responses.

Psychometric properties and sensitivity. Studies have found that TBI participants often perform significantly slower than healthy adults across all trials of the task (e.g., Felmingham et al., 2004). Reliability coefficients have been found to be consistently high for the Golden version of the Stroop test, with adequate test-rest reliability for the interference trial (Connor, Franzen, & Sharp, 1988; Franzen, Tishelman, Sharp, & Friedman, 1987; Golden, 1975).

Variable(s) of interest. The current study used the raw total number of words for the Color-Word trial as a measure of the cognitive inhibition component of executive functioning.

***Phonemic and Semantic Verbal Fluency [FAS and Animals; (Tombaugh, 1999)*].** In the word-list generation task of phonemic verbal fluency (FAS), participants were asked to produce as many words as possible that began with a given letter of the alphabet within three 1-minute oral trials. In a semantic fluency task (Animals), participants were asked to produce a list of as many distinct animals as possible within the 1-minute trial. For both portions of the task, participants were given credit for any novel word (i.e., not repeated) that was consistent with the trial criteria as defined by the standardized administration and scoring protocol.

Psychometric properties and sensitivity. These tasks have been widely used as measures of language, cognitive initiation, and cognitive flexibility and are often positively correlated with intellectual level in healthy individuals (e.g. Diaz-Asper, Schretlen, & Pearlson, 2004; Tombaugh, 1999). Measures of verbal fluency have been found to be sensitive to impairments in individuals following TBI and are able to discriminate by level of injury severity (e.g., Raskin & Rearick, 1996; Iverson, Franzen, & Lovell, 1999). Internal consistency across individual FAS trials using the total number of words generated for each trial is high (r = .83), as is test-retest reliability (e.g., Tombaugh, 1999).

Variable(s) of interest. The current study used the raw scores of the total correct words on the phonemic (FAS) and semantic (Animals) fluency trials as measures of language abilities.

Psychological Measures of Experienced Affect.

Affect Intensity Measure [AIM; (Larsen & Diener, 1987)]. The AIM is a self-report questionnaire comprised of items that assess intensity of participants' emotional reactions to positive and negative experiences (e.g., "My heart races at the anticipation of some exciting event"). Participants were asked to rate how they typically react to life-events using a 6-point scale, ranging from 1 (never) to 6 (always).

Psychometric properties and sensitivity. Psychometric properties in healthy and clinical samples (e.g., attention deficit/hyperactivity disorder) have been established (Rapport, Friedman, Tzelepis, & Van Voorhis, 2002).

Variable(s) of interest. The current study included the total raw score for the AIM as a measure of *experienced* affect intensity. Note that the term *affect intensity* in this context is referencing *experienced* emotion (e.g., intensity of experienced mood, reactions, etc.) rather than observed or perceived emotion intensity of others.

Brief Symptom Inventory-18 [(BSI-18; (Derogatis, 2001)]. The BSI-18 is a brief self-report questionnaire that assesses symptoms that generate three subscales: somatization, depression, and anxiety. Participants were asked to rate their level of distress experienced across the most recent 7 days using a 5-point scale ranging from 0 (*not at all*) to 4 (*extremely often*). Possible subscale scores range from 0-24.

Psychometric properties and sensitivity. The BSI-18 has strong validity supporting its factor structure through 2-factor analyses (Derogatis, 2001) and has been found to have strong reliability and validity in TBI samples (Meachen, Hanks, Millis, & Rapport, 2008).

Variable(s) of interest. The current study included the T score for the BSI-18 Depression subscale as a measure of depressive experienced affect.

Statistical Analyses

Descriptive statistics were conducted for the overall sample and the TBI and HC adult groups separately. Groups were examined for the extent to which performance differed on emotion perception as well as psychological and neuropsychological measures using a series of analysis of variance (ANOVAs). Follow-up analyses were conducted to examine a range of methods for adjustment of systematic confounding variables and nonsystematic covariates, including analysis of covariance (ANCOVAs), Propensity Score Analyses (PSA), and Matched-samples method. Of note, the use of ANCOVA is controversial in this context (Fleiss & Tanur, 1973; Lord, 1967) as it violates a core assumption (i.e., homogeneity of slopes for the covariate). As such, Matched-samples and PSA methods were also conducted to examine for parallel findings. In brief, PSA involved Propensity Score Matching Estimator analyses using pairwise contrasts with Nearest Neighbor Matching (nnmatch) for Average Treatment Effects (ATE) to address systematic covariates of age and education (Guo & Frasier, 2009). The Matched-samples method required matching the groups on characteristics of interest (i.e., age and education) believed to be related to the dependent variable (Kirk, 2012) in efforts to examine statistically equivalent groups. The current study used minimum distance metric matching, in which participants from each group were matched according to a fixed rule: age +/– 6 years and education +/– 2 years. Age and education were used as covariates for theoretical and statistical reasons. These demographic variables have been linked to neuropsychological and emotion outcomes; moreover, the relationships between these variables and the dependent variables differed by task (and occasionally by group). Furthermore, accounting for demographic effects on neuropsychological performance was important in order to clarify the unique relationship between neuropsychological and emotion perception performances. Race and ethnicity were not included as covariates. Because race/ethnicity and education were confounded, adjustments for education capture variance accounted for by race/ethnicity. Although gender has been linked to differing relationships with emotion competence (e.g., Langenecker et al., 2005; Briceño et al., 2013; Weisenbach et al., 2012), the current study did not adjust for gender as a covariate, because the disproportionate distribution of men in this TBI sample (and most TBI samples) would not have supported adequate experimental power.

Within group zero-order and partial correlations were used to examine the extent to which demographic, neuropsychological, and psychological constructs affected emotion perception accuracy. Lastly, nonparametric Mann-Whitney *U* and Friedman tests were conducted to examine the extent to which the pattern of misattributions overlap and differ between groups across emotion perception tasks. Effect sizes for all analyses were interpreted according to guidelines presented by Cohen (1988), in which $d = 0.20$ reflects a small effect, $d \geq 0.50$ reflects a medium effect, and $d \geq 0.80$ is large.

CHAPTER 3: RESULTS

Reliability of Emotion Perception Measures

Reliability coefficients for the three emotion perception measures were computed for this TBI and HC sample. Consistent with previous studies, Cronbach*'s alphas* for the facial emotion perception tasks were suggestive of high reliability for the overall tests (FEPT α = .85, FEPT-Slow α = .87). The Cronbach*'s alpha* for the EPT was similarly high (EPT α = .90).

General Group Performance Comparisons

Descriptive statistics and group comparisons for emotion perception and neuropsychological measures are presented in Table 2a. Most notably, ANOVAs revealed that TBI and HC groups differed on all three emotion perception tasks as measured by percent accuracy for emotional stimuli, with large effect sizes: FEPT $F(1,87) = 28.29$, $p < .001$, Cohen's $d = 1.14$; FEPT–Slow $F(1,82) = 12.28$, $p < .001$, Cohen's $d = 0.77$; EPT $F(1,87) = 19.01$, $p < .001$, Cohen's $d = 0.93$. Given the presence of systematic confounds (in educational attainment and estimated premorbid IQ), follow-up analyses were conducted to evaluate whether effects on the dependent variables change after accounting for covariates of age and education. Accounting for demographic effects on neuropsychological performance was important to establish the extent of unique variance accounted for within the relationship between neuropsychological and emotion perception performances. Adjustment methods used to address covariates included ANCOVA, Matched-sample analyses, and Propensity Score Analyses (PSA) for age and education. Table 2b compares percent accuracy across emotion perception tasks with ANOVA and the three adjustment methods. Findings were significant with large effects across ANOVA, ANCOVA, and Matched-samples methods for the FEPT (d = 1.01 – 1.25) and EPT tasks (d = 0.85 – 0.99). Similarly, findings were significant with medium-large effects across the ANOVA and the same two adjustment methods for the FEPT-Slow task (*d* =0.64 – 0.77). Although the same relative pattern was observed within PSA analyses (i.e., *Cohen's d* for FEPT and EPT was higher than for FEPT-Slow), the magnitude of findings was somewhat distinct from the other methods with medium effects estimated FEPT and FEPT-Slow (d = 0.52 – 0.68) and medium-large effect EPT (*d* = 0.73). Overall, however, the pattern of these findings provided support that the TBI group significantly underperformed on emotion perception tasks compared to HCs.

Also depicted in Table 2 are the ANOVAs for group differences on psychological measures assessing experienced affect, which yielded variable findings. Self-reported total on the affect intensity (AIM) was statistically equivalent between groups and showed a small effect (*d* = 0.2), with an average endorsement in the "occasionally-usually" range, whereas a significant group difference was observed for Depression (BSI-18) with a medium effect size, $F(1,86) = 7.25$, $p < .01$, Cohen's $d = 0.55$. Differences were evident in the frequency of endorsing clinically meaningful symptoms of depression (i.e., $T \geq 65$), as 16 percent of individuals in the TBI group endorsed symptoms at or above that level compared to no individuals in the HC group. However, it is noteworthy that means for depression symptoms for both groups were less than one standard deviation from the normative mean (TBI $M = 53.8$ and HC $M = 48.4$).

Regarding neuropsychological performance, Table 2a also depicts ANOVAs that demonstrate significantly poorer performances for TBI compared to HC participants on nearly all neuropsychological measures across cognitive domains. The one exception to this pattern was observed on task of line orientation, which was statistically equivalent between groups. Significant group differences on the neuropsychological tests reflected medium to large effect sizes (*d* = 0.51 – 1.29), with large effect sizes observed globally across domains (i.e., measures from processing speed, attention, executive functioning, learning and memory, and language) rather than isolated to specific cognitive domains.

Neuropsychological and Psychological Contributions to Emotion Perception Accuracy.

Demographic Correlates of Emotion Perception Tasks. There was a moderate relationship between age and percent emotion accuracy on FEPT (r = -.41) and EPT (r = -.41) tasks for TBI participants. A similar moderate relationship between age and performance was observed for HC participants as well, FEPT (r = -.27) and EPT (r = -.35). In contrast, FEPT-Slow showed no meaningful relationship to age among TBI or HC groups (r = -.01 to -.06). Relationships between education and the three emotion perception tasks were small (ranged from r = .06 - .20).

To refine the examination of correlates of emotion perception, partial correlations were conducted accounting for age and education. Processing speed (Trails A time), a hallmark impairment after TBI (e.g., Spikman et al., 2012), was also included as a covariate in partial correlations to examine emotion perception phenomena accounting for nonspecific impairment. Overall, both groups demonstrated moderate relationships between measures of processing speed and percent accuracy on the FEPT (TBI r = -.39, HC r = -.33), FEPT–Slow (HC r = -.52, TBI r = -.24) and EPT tasks (HC EPT r = -.45, TBI r = -.21) such that individuals with fast processing speed performed more accurately than individuals with slow processing speed.

Correlates Among Emotion Perception Tasks. As expected, within-group zero-order correlations revealed that the three emotion perception tasks were significantly correlated for both groups (Tables 3a and 3b). Partial correlations controlling for age, education, and processing speed demonstrated a relatively similar pattern to zero-order correlations, except that the relationship between FEPT–Slow and EPT was no longer significant.

Neuropsychological Correlates of Emotion Perception. Within-group zero-order

Pearson correlations between neuropsychological measures and emotion perception tasks revealed varied patterns across tasks and between groups (Tables 3a and 3b). As depicted on Tables 3a and 3b, both groups demonstrated significant moderate correlations between estimated premorbid intellectual functioning as measured by the WTAR Standard Score and FEPT performance for zero-order (TBI r = .24; HC r = .29), but not partial correlations (TBI r = .23; HC r = .15). The relationships between WTAR and the other two emotion perception tasks were not significant (TBI FEPT-Slow r = .05 and EPT r = .21; HC FEPT-Slow r = .06 and EPT r = .23). As could be expected, performance on a measure of memory for faces (RMT – Faces) was moderately to highly correlated with FEPT and FEPT–Slow tasks (TBI FEPT r = .37 and FEPT-Slow r = .36; HC FEPT r = .31 and FEPT-Slow r = .50), but not with the EPT (TBI r = .09; HC r = .21) for both groups. Partial correlations again yielded moderate and high correlations with FEPT and FEPT–Slow tasks (TBI FEPT pr = .34 and FEPT-Slow pr = .31; HC FEPT pr = .32 and FEPT-Slow pr = .54) but not with the EPT (TBI pr = .00; HC pr = .11) for both groups.

Regarding relationships between the remaining neuropsychological performances in other cognitive domains, patterns varied by emotion perception task and group membership. For FEPT, the pattern of neuropsychological correlates with percent accuracy for emotions appeared relatively global for both groups, with mostly medium and large effects; however, the number of medium to large correlations with neuropsychological performances was greater for TBI (r = .25 - .52; 10 medium to large correlations) than HC groups (r = .27 - .57; 5 medium to large correlations). After controlling for age, education, and processing speed, the global pattern was dampened somewhat for the TBI group (r = .25 - .55; 6 medium to large correlations) in which effects of Line Orientation, Trails- Part B, and FAS Fluency became small. Performance accuracy on FEPT became mainly correlated with performances on measures assessing attention and working memory with medium effects. Partial correlations for FEPT and neuropsychological performances for the HC group yielded a diminished result in which only 3 medium to large correlations remained in the profile for attention/processing speed, language, and learning and memory (*pr* = .33 - .50).

For FEPT–Slow, the pattern of zero-order neuropsychological correlates was again relatively global for the TBI group (*r* = .29 - .54; 6 medium to large correlations). Interestingly, zero-order correlations revealed generally domain-specific patterns for the HC group with measures of processing speed, set-shifting, as well as learning and memory indicating large effects (*r* = -.45 - .52). The pattern of partial correlations for neuropsychological performances remained relatively global for the TBI group (*pr* = .36 - .51; 5 medium to large correlations). Within the HC group, the large domain-specific relationship persisted only for learning and memory after controlling for covariates for the HC groups (*pr* = .50).

Similar to the FEPT and FEPT–Slow tasks, the pattern of zero-order correlations for neuropsychological performances and the EPT were relatively global (*r* = .26 - .53; 5 medium to large correlations) for the TBI group. As to be expected, the strongest loadings were observed on tasks of auditory attention and working memory (*r* = .47 and *r* = .53, respectively). Similar to the FEPT, a global pattern was seen again for HC participants (*r* = .39 - .52; 1 medium and 6 large effects) with the greatest relationships observed on verbally mediated or timed tasks. Partial correlations between EPT and neuropsychological performances for the TBI group revealed domain-specific relationships for tasks including auditory attention, auditory working memory, and verbal learning and memory (*pr* = .28 - .49; 3 medium to large effects). Partial correlation patterns for EPT accuracy and neuropsychological performances in the HC group yielded domain-specific findings with moderate and large relationships (*pr* = .29 - .43; 3 medium to large correlations) for verbal learning and memory as well as language.

Taken together, patterns of correlations between neuropsychological measures and emotion perception performances varied by tasks and groups; however, consistencies were also observed: First, the TBI group demonstrated a relatively global pattern of correlations with neuropsychological measures for the FEPT and FEPT-Slow tasks even after accounting for age, education, and processing speed. Second, after controlling for covariates, relatively domain-specific patterns were observed in the HC group for FEPT and FEPT-Slow and neuropsychological measures of learning and memory, with additional correlations seen in FEPT for attention, processing speed, and language. Last, for both groups on the EPT, a generally global correlation profile was reduced to a relatively domain-specific pattern for both groups with highest loadings for tasks that were verbally or aurally mediated. Thus, while the specific correlates of each task and group varied, general patterns were observed.

Psychological Correlates of Emotion Perception. As seen on Table 7, within-group zero-order Pearson correlations between experienced affect and total emotion perception accuracy varied by group membership and emotion perception task. Within the TBI group, percent accuracy on FEPT and FEPT–Slow tasks, but not EPT, was significantly inversely correlated with at least one measure of experienced affect (i.e., either AIM or BSI-18 Depression Index). Experienced affect did not show significant linear correlations with percent accuracy on the emotion perception tasks for the HC group.

Experienced Affect Intensity as measured by the AIM showed significant inverse relation to both face emotion perception tasks among participants with TBI (FEPT r = -.32; FEPT-Slow r = -.34), indicating disruption of emotion perception by *experienced* affect intensity. The potential for nonlinear trends were explored because *experienced* affect intensity has shown nonlinear relation to emotional competence in prior research (Laretzaki, Plainis, Argyropoulos, Pallikaris, & Bitsios, 2010; Yerkes & Dodson, 1908). Examination of bivariate scatterplots suggested the presence of nonlinear trends in the relationship between AIM and the FEPT tasks. Curve estimation analyses assessed quadratic and cubic models in the total sample, with follow-up analyses of the TBI and HC groups separately. The FEPT linear model was significant, $F(1, 83) = 4.29$, $p = .041$, $R^2 = .05$. The quadratic model also was significant, $F(2, 82) = 4.20$, $p = .018$, $R^2 = .09$. ANOVA indicated that addition of the quadratic trend accounted for significant unique variance, $t = 1.99$, $p = .050$. Follow-up analyses examined the quadratic phenomenon separately in the TBI and HC groups. These analyses revealed that the TBI group was driving the effect, $F(2, 43) = 5.22$, $p = .09$, $R^2 = .20$. The HC group did not show a similar nonlinear bend in the correlation between AIM and FEPT, $F(2, 36) = 0.21$, $p = .980$, $R^2 = .00$. Figure 1 depicts the quadratic relationship of AIM and FEPT in the TBI and HC groups. As seen in Figure 1, among TBI participants with low performance on the FEPT (e.g., < 70% correct, $n = 26$) there is a strong inverse correlation between AIM and FEPT, $r(27) = -.49$, whereas TBI participants with good performance on the FEPT ($n = 24$) show a positive relationship between AIM and FEPT, $r(21) = .29$. Of note, the high performers on the FEPT scored significantly higher on several neuropsychological indexes than did the low performers: Symbol Digit, $t(48)$ -3.12, $p = .003$; Digits Backward, $t(46)$ -2.05, $p = .047$; Trails B, $t(46)$ -2.26, $p = .029$; Trails A, $t(46)$ -2.17, $p = .035$.

The pattern of scores on the FEPT-Slow was very similar, although the quadratic trend was not statistically significant. For the linear model, $F(2, 42) = 5.45$, $p = .024$, $R^2 = .12$; for the quadratic model, $F(2, 41) = 2.81$, $p = .072$, $R^2 = .12$. As with the FEPT, HC group did not show a significant quadratic component to the relationship between AIM and FEPT-Slow, $F(2, 29) = 1.68$, $p = .203$, $R^2 = .10$.

For BSI *Depressive symptoms*, medium linear trends were observed again ($r = -.33$), although, significant quadratic trends were also observed in the total sample correlation between FEPT performance and experienced emotion. For the FEPT linear model, $F(1, 83) = 10.34$, $p = .002$, $R^2 = .11$. Thus, among the total sample, depressive symptoms generally undermined performance on FEPT. The quadratic model was significant, $F(2, 85) = 5.48$, $p = .006$, $R^2 = .11$; however, ANOVA indicated that the addition of the quadratic trend did not account for significant unique variance, $t = 0.29$, $p = .777$. The curve was not more pronounced in TBI versus HC groups; however, for the FEPT-Slow, the linear model was nonsignificant, $F(2, 81) = 2.71$, $p = .104$, $R^2 = .03$, whereas the quadratic model was significant, $F(2, 80) = 3.94$, $p = .023$, $R^2 = .09$. ANOVA indicated that the quadratic trend added significant unique variance to the linear model, $t = -2.25$, $p = .028$. As seen in Figure 2, the groups showed equivalent quadratic patterns in the relationship of depressive symptoms to FEPT-Slow. The graph suggests that very low-performing adults are facilitated by experience and recognition of negative emotion, and similar to the Yerkes-Dodson curve (Yerkes and Dodson, 1908), individuals become hindered by depressive symptoms after reaching an asymptotic point.

Analysis of Emotion Perception Errors

Correlates with Overall Emotion Perception and Individual Emotion Categories for TBI group. As expected, Pearson correlations for most of the separate emotion categories on FEPT, FEPT–Slow, and EPT tasks were medium to large when related to accuracy of the same emotion on other emotion perception tasks (*fear* across tasks ranged from $r = .51$ - .57; *anger* across tasks ranged from $r = .37$ - .42; *happy* across tasks ranged from $r = .11$ - .36, *sad* ranged from $r = .34$ -

.66). The strongest consistent correlations observed across tasks were for *fear* (FEPT - EPT r = .57 and FEPT-Slow - EPT r = .54) and *sad* emotional stimuli (FEPT - FEPT-Slow r = .66 and FEPT - EPT r = .47). Correlations for *happy*, which showed restricted range secondary to ceiling effects, were among the lowest of the correlations (FEPT - FEPT-Slow r = .36, FEPT - EPT r = .29, and FEPT-Slow - EPT r = .11).

As depicted on Tables 4a/b and 5a/b, percent accuracy on *animal* trials during the FEPT and FEPT–Slow tasks was independent of nearly all accuracy performances on separate emotion categories, as demonstrated by only one significant correlation (for FEPT *animals* and *happy*). Of note, accuracy for *happy* was skewed on FEPT and FEPT-Slow tasks for both groups; thus, nonparametric statistics were conducted to evaluate for distinct patterns. As the pattern of findings was consistent with that seen in parametric analyses, Pearson correlations were reported for all types of emotion errors.

Neuropsychological Correlates of Overall and Individual Emotion Perception. With regard to neuropsychological correlates (Tables 4a/b and 5a/b), among the TBI group, total FEPT accuracy was most strongly correlated with Symbol Digit, Trails B, and Digits Backward. In examining the correlations for individual emotions, *anger* and *fear* were generally driving the correlation of total accuracy and performance on neuropsychological measures. Mean correlation for *anger* and neuropsychological tests was .37 (median .36), with strongest relationships observed for *anger* and Symbol Digit (.53), Trails B (.52) and CVLTII 1–5 (.46). Generally, *sad* and *happy* accuracy showed few and substantially weaker correlations to neuropsychological tasks (range of r = .00 - .28). The HC group revealed a more diffuse and weaker pattern of relationships between neuropsychological tests and FEPT emotion accuracy than was observed for the TBI group. However, similar to the TBI group, CVLT-II 1-5 (r = .57) and Symbol Digit (*r* = 49) showed the most consistent and relatively strongest relationships to emotion perception accuracy across emotions. Exploration of individual emotions revealed that *happy* and *sad* showed the most significant relationships (*M* correlations .31 and .28, respectively).

Pearson correlations within the TBI group for the FEPT-Slow demonstrated a similar pattern of correlations for neuropsychological measures. The total accuracy for FEPT-Slow demonstrated the strongest and most consistent relationship across emotions to CVLT-II 1-5 (*M* correlation = .42). Following CVLT-II, Digits Backward, Digits Forward, and Symbol Digit showed medium to large correlations (*r* = .41 - .54) to total accuracy in the context of the slower presentation format. The relative contributions of pure processing speed (e.g., Trails A) somewhat diminished as compared to the faster version of the FEPT but remained moderately correlated with *anger* (*r* = .36). Similar to FEPT, *anger* and *fear* showed the most consistent and strongest relationships to neuropsychological tests. *Anger* appeared to predominate, generally driving the relationships observed for the total accuracy score (mean and median correlation = .38), followed by *fear* (mean correlation = .26, median = .35). The HC group again revealed a more global and weaker pattern of relationships between neuropsychological tests and FEPT emotion accuracy than the TBI group. Unlike the TBI group, pure contributions of processing speed remained apparent, as the relatively strongest correlations were observed by Trails A, CVLT-II 1-5, and Trails B (*r* = .45 - .52). Although there were fewer standout correlations than for the HC group, *sad* showed the most consistent and strongest relationships to neuropsychological tests (*r* = .39 - .48), with medium to large effects and were not present in TBI.

On the EPT, the TBI group again demonstrated a similar set of strongest and consistent correlations for neuropsychological measures (Tables 6a and 6b). Specifically, EPT Total

Accuracy yielded moderate correlations with Digits Backward (*M* correlation = .53), Digits Forward (r = .47), and then CVLT-II 1-5 (r = .36). Unlike FEPT and FEPT-Slow, no specific emotion showed a most consistent relationship to neuropsychological tests (i.e., all relationships were small, < .25). Pearson correlations within the HC group for the EPT demonstrated a global pattern of correlations for neuropsychological measures, most of which were moderate to large (r = .03 - .54). The total accuracy for EPT demonstrated the strongest and most consistent relationship across emotions to CVLT-II 1-5 (*M* correlation = .44) followed by Symbol Digit (*M* correlation = .40). Interestingly, the weakest relationships across emotions were for an auditory attention measure, Digits Forward (*M* correlation = .08), and for Line Orientation (*M* correlation = .12). *Fear* and *anger* showed the most consistent and strongest relationships to neuropsychological tests of all the individual emotions, which was dissimilar to HC patterns on other emotion perception tasks. *Fear* appeared to have the most influence on EPT total accuracy (*M* correlation= .33), followed by *anger* (*M* correlation = .29).

Emotion Error Types. Descriptive statistics and group differences in accuracy of separate emotion categories across the three emotion perception tasks are summarized in Table 8. For FEPT and FEPT–Slow tasks, ANOVAs revealed significant differences in percent accuracy of individual emotions between groups on nearly all of the emotions with the exception of *happy*. Effect sizes for group differences were large (d = 0.80 – 0.88) for FEPT task differences and medium-to-large (d = 0.50 – 0.86) for the FEPT–Slow task. On the EPT, ANOVAs revealed significant differences in percent accuracy of all individual emotions other than for neutral stimuli with medium effect sizes (d = 0.53 – 0.65). As mentioned in the previous section, accuracy for happy was skewed on FEPT and FEPT-Slow tasks for both group. Nonparametric Mann Whitney *U*'s were conducted to evaluate for distinct patterns and revealed a pattern of findings consistent with that seen in parametric analyses; thus, ANOVAs were reported.

Table 8 also summarizes the means and standard deviations for the percent accuracy of the emotion categories across groups and emotion perception tasks. On the FEPT, performance accuracy for emotions ranged from 52.9 – 96.5% for TBI participants and 70.6 – 98.6 % for HC participants. Performance accuracy for emotions on the FEPT–Slow ranged from 69.0 – 91.0% for TBI participants and 83.5 – 96.7 % for HC participants. Performance was generally poorer for both groups on the EPT than FEPT and FEPT–Slow, ranging from 26.0 – 74.0% for TBI participants and 37.0 – 80.3 % for HC participants.

Results on Table 8 enable examining the relative difficulty of each individual emotion. As depicted in the table, the relative rank order of accuracy for each emotion category varied slightly across tasks, but it was nearly identical for TBI and HC groups. In other words, the groups appeared to find similar emotional stimuli to be relatively more or less difficult to classify than one another. Although not entirely accounting for performance, speed of stimuli presentation likely contributed to performance across modalities. Specifically, as summarized in Table 8, participants in both groups demonstrated better emotion accuracy on FEPT–Slow than FEPT and EPT tasks. Both FEPT and EPT had quicker presentation and response times than FEPT–Slow, suggesting that processing speed and allotted response times may be affecting performance to some degree. Although this pattern is evident for both TBI and HC groups, TBI participants appear to be particularly hindered by speed, as demonstrated by their significantly poorer performance compared to HCs. Specifically, on the FEPT, both groups demonstrated most difficulty in classifying angry stimuli, followed by fearful, sad, and happy emotions. Friedman tests, a nonparametric statistic analogous to repeated-measures ANOVA, examined within-group pattern of percent accuracy among individual emotions for the HC and TBI groups separately. The tests were significant for both groups. For HC, $X^2(3, N = 39) = 60.29, p < .001$. Wilcoxon signed-ranks, a nonparametric statistic analogous to paired-sample t tests, were used for post hoc contrasts of the Friedman test ($p < .05$ criterion). On the FEPT, these paired contrasts indicated that accuracy for *happy* (mean rank = 3.7) was significantly greater than *sad* (mean rank = 2.5, Wilcoxon Z = -4.66, $p < .001$), which was significantly greater than *fear* (mean rank 2.0, Wilcoxon Z = -2.45, $p = .014$), whereas accuracy for *fear* and *anger* (mean rank = 1.7) were statistically equivalent, Wilcoxon Z = -0.26, $p = .794$). All other paired contrasts of the emotions within the HC group were significant at $p < .001$. For the TBI group, Friedman $X^2(3, N = 50) = 85.71, p < .001$. Post hoc Wilcoxon indicated the same pattern of relative accuracy among the emotions as the HC group: Accuracy for *happy* (mean rank = 3.9) was significantly greater than *sad* (mean rank = 2.4, Wilcoxon Z = -6.00, $p < .001$), which was significantly greater than *fear* (mean rank 1.9, Wilcoxon Z = -2.96, $p = .003$), with statistically equivalent accuracy for *fear* and *anger* (mean rank = 1.8, Wilcoxon Z = -0.31, $p = .757$). All other paired contrasts of the emotions within the HC group were significant at $p < .005$.

A slightly different pattern of emotion accuracy was observed for the FEPT–Slow task, with participants demonstrating most difficulty in classifying *sad*, followed by *fear*, *angry*, and *happy*. Of note, a minor alteration in the rank order was observed for HC participants for whom *fear* (83.5%) was slightly more difficult for HC participants to classify than *sad* (83.6%). Friedman tests to examine within-group pattern of percent accuracy on individual emotions for the HC and TBI groups separately were significant for both groups. For HC, $X^2(3, N = 36) = 28.14, p < .001$. Wilcoxon signed-ranks indicated that accuracy for *happy* (mean rank = 3.4) was significantly greater than *sad* (mean rank = 2.2, Wilcoxon Z = -4.38, $p < .001$). *Sad* was statistically equivalent with *fear* (mean rank 2.2, Wilcoxon Z = -0.32, $p = .750$), which also was statistically equivalent with *anger* (mean rank = 2.2, Wilcoxon Z = -0.27, p = .979). Likewise, *anger* was statistically equivalent with *sad* (Wilcoxon Z = -0.31, p = .757). Paired contrasts within the HC group for *happy* and *fear* as well as *happy* and *anger* were significant at $p < .001$. For the TBI group, Friedman $X^2(3, N = 48) = 50.99$, $p < .001$. Post hoc Wilcoxon indicated a similar pattern as the HC group in relative accuracy among the emotions: Accuracy for *happy* (mean rank = 3.6) was significantly greater than *anger* (mean rank = 2.4; Wilcoxon Z = -4.47, $p < .001$). *Anger* was statistically equivalent with *fear* (mean rank 2.2, Wilcoxon Z = 9.47, p = .343), as was *fear* with *sad* (mean rank = 1.8, Wilcoxon Z = -0.79, p = .430). All other paired contrasts of the emotions within the HC group were significant at $p < .005$.

For the EPT task, the relative rank order of difficulty in classifying stimuli for each emotion category (from greatest difficulty to easiest emotions) was *fear*, *happy*, *angry*, *sad*, and then *neutral* for both groups. Friedman tests to examine within-group pattern of percent accuracy for the HC and TBI groups separately were significant for both groups. For HC, $X^2(3, N = 39) = 80.58$, $p < .001$. Wilcoxon signed-ranks indicated that accuracy for *neutral* (mean rank = 4.0) was statistically equivalent to *sad* (mean rank = 3.9, Wilcoxon Z = -0.50, p = .620), which was statistically equivalent to the next highest ranked emotion, *anger* (mean rank = 3.5, Wilcoxon Z = -1.49, p = .136). *Anger* was significantly greater than *happy* (mean rank = 2.4, Wilcoxon Z = -3.51, $p < .001$). *Happy* was also significantly greater than *fear* (mean rank = 1.3, Wilcoxon Z = -4.94, $p < .001$). All other paired contrasts of the emotions within the HC group were significant at $p < .001$. For the TBI group, Friedman $X^2(3, N = 50) = 91.17$, $p < .001$. Post hoc Wilcoxon indicated a similar pattern of relative accuracy among the emotions as the TBI group: Wilcoxon signed-ranks indicated that accuracy for *neutral* (mean rank = 4.1), was significantly equivalent to accuracy for *sad* (mean rank = 3.7, Wilcoxon Z = -2.18, p =.030). Again, accuracy for *sad* was statistically equivalent with *anger* (mean rank = 3.3, Wilcoxon Z = -1.50, p = .134), which was statistically greater than accuracy for *happy* (mean rank = 2.4, Wilcoxon Z = -2.27, p = .023). *Happy* was also statistically greater than *fear* accuracy (mean rank 1.5, Wilcoxon Z = -3.98, $p < .001$). Again, all other paired contrasts of the emotions within the HC group were significant at $p < .001$, other than the contrast for *anger* and *neutral*, which was significant at $p < .05$.

It is also notable that participants in both groups consistently demonstrated more difficulty with accuracy of emotions with negative valence (i.e., sad, fearful, and angry) on FEPT and FEPT–Slow tasks than positive (i.e., happy) stimuli. A consistent pattern of difficulty on stimuli with negative valence across both FEPT tasks demonstrates that speed of stimulus presentation is likely not accounting for the entire pattern of performance for TBI participants. A clear pattern of emotions with negative valence was not evident for the EPT task, as participants had substantial difficulty classifying happy emotions, but not *neutral* emotions. This distinct pattern may be related, in part, to differences in stimuli and/or modality of stimulus presentation (i.e., visual versus auditory).

Specific Misattribution Error Types. Patterns of emotion misattributions were explored in order to understand the types of errors made by HC and TBI participants and determine to what extent the patterns compared. Tables 9a-9c depict the separate percentage of TBI and HC groups that made each type of emotion misattribution error on the FEPT, FEPT–Slow, and EPT. Ranges and medians of each error type are also included. Given that these data were highly skewed, nonparametric Mann-Whitney tests were used to conduct group comparisons.

On the FEPT, individuals in the TBI group made significantly more errors of omission (i.e., “no response”) across all emotion stimuli other than *happy* when compared to the HC group

(Table 9a). With the exception of happy stimuli, which had few emotion misattribution errors, the TBI group had significantly more emotion misattributions than the HC group across nearly all possible misattribution combinations with a total of 14 group differences in misattribution errors. Greatest group differences were observed between TBI than HC groups for *anger* as *happy* ($d = 0.62$), *anger* as *sad* ($d = 0.59$), *neutral* as *fearful* ($d = 0.76$), and *neutral* as *anger* ($d = 0.53$). In examining pattern of errors with significant effects (i.e., medium effect $d > .5$, large effect $d > .8$) within the TBI group, it became evident that omissions (i.e., providing no response) and misattributing emotions as *sad* and then *anger* were most prominent. Specifically, the most common errors were observed when responses were omitted, with *fear* as *no response* (92.0%), followed by *anger* as *sad* (92.0%), *fearful* as *anger* (72.0%), *sad* as *anger* (64.0%), *sad* as *no response* (60.0%), *neutral* as *fear* (44%), *neutral* as *anger* (34%), and then *anger* as *happy* (18%).

On the FEPT–Slow, at least one significant group difference was observed between TBI and HC groups across all emotion misattributions in the expected direction, with 12 group differences in misattribution errors (Table 9b). Individuals in the TBI group again made significantly more errors of omission than the HC group across emotion stimuli other than for *anger* (Table 9b). Interestingly, the pattern of greatest group differences was otherwise distinct from that identified on the FEPT, as greatest group differences on the FEPT–Slow were observed for *fearful* as *sad* ($d = 0.56$) and *neutral* as *fearful* ($d = 0.68$) misattributions. Similar to the pattern observed for FEPT, examination of significant error differences revealed that omission errors (i.e., providing no response) and misattributing emotions as *sad* and *anger* were most prominent in the TBI group. Specifically, the most common errors were observed for *neutral* as *no response* (97.9%), followed by *neutral* as *sad* (70.8%), *fear as anger* (66.7%), *sad* and *fear* as *no response* (62.5%), *sad* as *anger* (56.2%), *fear* as *sad* (47.9%), *happy* as *no response* (43.7%), and then *neutral* as *no response* (33.3%).

On the EPT, at least one significant group difference was again observed between TBI and HC groups across all emotion misattributions in the expected direction (Table 9c); however, there were approximately half the number of significant group differences (7) in misattributions than the other two emotion perception tasks. Additionally, unlike the relatively global pattern of omissions seen in the FEPT and FEPT–Slow, the TBI group only made significantly more omission errors than the HC group when presented with *fearful* (d = 0.45) and *anger* stimuli (d = 0.47). The pattern of greatest group differences was otherwise somewhat similar to that identified on the FEPT–Slow task as one of the greatest group differences was seen for the *neutral* as *fearful* (d = 0.58) misattribution. The TBI group also made significantly more *happy* as *sad* misattributions than the HC group (d = 0.65). Examination of significant misattribution errors in the EPT revealed somewhat distinct patterns from the FEPT and FEPT-Slow tasks within the TBI group. The most common errors were observed for *anger* as *no response* (30.0%), followed by *neutral* as *fearful* (30.0%), *fearful* as *no response* (28.0%), and then *happy* as *sad* (26.0%).

CHAPTER 4: DISCUSSION

The current study supports prior research documenting impaired emotion perception across visual and auditory modalities among adults with TBI. These findings held even after accounting for age, education, and processing speed , which can influence emotion perception, using multiple statistical methods of adjustment; however, it appears that common statistical methodologies such as ANOVA and ANCOVA may somewhat overestimate the magnitude of impairment as compared to healthy adults compared to Matched Sample and PSA methodologies. Although the same general findings persisted across adjustment methods, findings from PSA suggested the lowest magnitude of group differences compared to other methodologies. The relatively weaker magnitude of group differences may be in part related to nuances associated with the methodology, including that matching within PSA is somewhat limited by the use of continuous covariates. Furthermore, although PSA is beneficial in reducing bias by allowing for multiple matches in a single analysis (i.e., through *matching with replacement*), the method is limited by the individual values of the criterion group and may increase the variance in the estimator so that it may maintain power by reducing the number of excluded cases. As such, PSA tends to yield relatively conservative estimates.

Also consistent with prior research, the present study found evidence to support both global and specific-domain patterns of relation between neuropsychological function and emotion perception, depending on the emotion perception task and group membership. The present study extended prior research on the degree and valence of emotions prone to error after TBI by explicating the nature of misattributions committed. Although adults with TBI and healthy adults tended to find similar emotions difficult, they made different misperception errors, and the types of errors differed by the modality (i.e., auditory or visual) in which the emotion information was presented. Importantly, this study established relatively novel findings about the role of experienced emotion in disrupting or accurate facilitating emotion perception. Studies of emotion perception abilities after TBI have generally failed to account for the internal experience of the person engaged in the task of emotion perception. This study found evidence that intensity and content (i.e., depression) of *experienced* emotion each influence emotion perception accuracy for individuals with TBI and their healthy adult counterparts.

Emotion Perception Accuracy after TBI

Consistent with well-established findings that persons with TBI demonstrate emotion perception difficulties (see Babbage et al., 2011 for review; Rosenberg et al., 2014; Zupan et al., 2014, Rosenberg et al., 2015, etc.), this study also found that adults with TBI performed well below healthy adults on emotion perception. The impairment in emotion perception abilities was not modality-specific; it was observed with some consistency across auditory and facial modalities, even after accounting for age, education, and global deficits due to slowed processing. Relative improvement in accuracy was observed after the facial emotion perception task was slowed to tap aspects of power (rather than speed). The removal of some of the processing speed demands may have facilitated ceiling effects on certain relatively simple emotions (i.e., happy). However, enhanced emotion perception abilities were not as strong as would be expected given the substantial slowing of presentation of emotion faces. It is possible that a small degree of increased accuracy on the slowed presentation version was related to participants' exposure to the task demands and materials, as the task with slowed presentation times was always administered subsequent to the standard (fast) presentation version, it is unlikely to account for the majority of improvements. Should emotion perception improvements be related mostly to practice or exposure, rather than true deficits, evidence of benefits would be seen through ceiling effects across the slowed task and with all of the emotions. Yet, enhanced emotion perception abilities did not match the expected magnitude based on the substantial increase in time for face presentations. Furthermore, the day-to-day experience of persons with TBI who demonstrate difficulties in perceiving emotion from faces of familiar individuals (i.e., their family, friends, caregivers, etc.) suggests that mere exposure and practice with emotions cannot account for the entirety of deficits.

Although slowing down the challenge of perceiving facial emotion diminished the impairment somewhat relative to healthy adults, the relative patterns of relation to cognitive and emotional characteristics remained remarkably similar. The findings are consistent with neuroanatomical locations (i.e., orbital surface and within the frontal and temporal lobes) often affected by traumatic brain injury (e.g., on the orbital surface, within frontal and temporal lobes, etc.; Bornhofen & McDonald, 2008; Fontaine et al., 1999). Additionally, a prominent relationship between age and emotion perception performance was observed to be more profound in TBI than in healthy adults, where younger individuals performed more accurately than older individuals. A very small relationship was observed between education and emotion perception accuracy, which was beneficial to this current project, as the groups differed on education. Thus, although education was systematically confounded with group, it does not likely explain differences observed between them.

Also of interest were the varied performances and relationship patterns for the two facial emotion perception tasks, as the differences depicted common methodological phenomena related to power and speed tasks. Specifically, whereas strong relationships were evident between age and facial emotion perception when faces were presented at their standard rate (i.e., within the context of a speeded test), essentially no relationship was seen when the presentation times were slowed (i.e., within the context of a power test).

Consistent with the TBI literature examining the delineation of emotion errors in individuals with TBI compared to healthy adults (e.g., Rosenberg et al., 2014; Rosenberg et al., 2015), the present study demonstrated that individuals with TBI and healthy adults experienced difficulty in accurately labeling the same types of emotions; however, the frequency and degree of difficulty varied between groups as expected. The current study also examined pattern of individual emotion errors between groups. On facial emotion perception tasks, the groups differed in accuracy in the expected direction for all individual emotions other than for *happy*. This finding was consistent with other research (e.g., Rosenberg et al., 2014; Rosenberg et al., 2015) likely related to the measure's ceiling effects because few individuals made errors in classifying *happy* stimuli. Consistent difficulty with emotion perception for negative valence across facial emotion perception tasks demonstrates that speed of stimulus presentation is likely not accounting for the entire pattern of performance for TBI participants. Thus, it is likely that other processes (e.g., visual working memory, psychological experience, etc.) may be contributing to performance accuracy. Furthermore, the greater number of *negative* response options relative to *positive* ones may in part explain the increased error rate for emotions with *negative* valence, as participants are required to decide among several *negative* emotions quickly.

For the auditory modality, the groups differed in the expected direction for most of the individual emotions (including *happy*) but not for *neutral* emotions. Comparable perception of *neutral* voices between the groups is distinct from findings observed in the limited research examining *neutral* emotions, which has found that persons with TBI have greater difficulty deciphering neutral than positive or negative valence emotions even after accounting for multimodal presentation (i.e., Zupan et al., 2014; Williams and Wood, 2010). Discrepancy of findings may be related to task-specific differences or variations in *expressed* intensity (i.e., measurement error) of emotions presented.

Findings related to brain mechanisms across perception of individual emotions also suggest evidence that activation is variable among neuroanatomical areas dependent on individual emotions being perceived during neurocognitive tasks (Lane et al., 1997; Gobbini & Haxby, 2007; McDonald, 2013; Kark & Kensinger, 2015). Thus, it is possible that disparate performances in response to emotional and non-emotional information may be explained in part by activation of diverse brain areas in auditory emotion perception tasks. Should that be the case, the finding could suggest that areas implicated in responding to auditory *neutral* stimuli are less affected or damaged in TBI than areas needed to recognize and process emotion information and/or neutral information when it is presented visually.

Consistent with the current literature, performance patterns for both groups revealed the highest accuracy for *happy* emotions followed by emotions with negative valence when emotions were presented visually (e.g., Spikman et al., 2003; Zupan et al., 2014; Williams & Wood, 2010; Rosenberg et al., 2014; Rosenberg et al., 2015). Auditory emotion perception was somewhat distinct, with best performance for *neutral* accuracy followed by a mixed order of positive and negative emotions (i.e., most to least accurate = *sad, anger, happy, fearful*). Variable order of relative accuracy for emotions with positive and negative valence across tasks is suggestive that valence hypotheses may be specific to modality of emotion presentation. Alternatively, it is possible that these findings could be specific to *task* characteristics (i.e., presentation time, iconic versus subtle presentation of included emotion stimuli, degree of similarity of stimuli between category stimuli for different emotions, etc.). Further, it is likely that subtleties related to emotion expression intensity of faces and voices could account for some variability, as research has found that pattern of performances change with presented *expressed* intensity of the emotion (i.e., Rosenberg et al., 2014; Rosenberg et al., 2015).

Patterns of Misattributions of Individual Emotion Perception Accuracy. Unlike in healthy adults, the most common type of error for individuals with TBI was omitting a response (i.e., providing no response). High rates of response omission in TBI may be related to slow processing speed, indecision, or perceived difficulty of the task. This finding is especially noteworthy because focus on omissions in examining misattribution patterns of emotions has been very limited in TBI. Having knowledge that persons with TBI are making most errors in omission is important from an ecological perspective, as education about delayed or omitted responding may improve live interactions with persons with TBI for caregivers, providers, and/or loved ones of persons with TBI. Following omission errors, the next most common error was consistent with the limited prior research (i.e., Rosenberg et al., 2014) in miscoding *anger.*

Perhaps most interesting from the current study were findings related to *neutral* emotion perception. First, the current study diverged from prior studies examining *neutral* emotion (Zupan et al., 2014; Williams and Wood, 2010), as the present study found that both groups exhibited equivalent and strongest abilities for auditory *neutral* emotion perception. However, examination of *neutral* errors for facial and auditory modalities revealed that the most common error for individuals in the TBI group (second to omission) was in misperceiving *neutral* emotions as other *negative* emotions (i.e., *fear, anger, sad*) more often than healthy adults. It is, however, important to remember that the design used in this study to examine *facial* emotion perception was unique in that it forced errors on *neutral* emotions, thereby compelling a positive or negative response bias. Additionally, both auditory and facial emotion perception tasks included three *negative* emotions (i.e., *fearful, sad, angry*) and only one *positive* emotion (i.e., happy), which enabled a higher probability of selecting negative compared to positive responses when faced with *neutral* emotion. Nonetheless, the findings from the current study are consistent with suggestions that persons with TBI have difficulty deciphering subtleties and nuances of *neutral* emotions (Zupan et al., 2014; Williams and Wood, 2010) and are in line with the current study's hypothesis regarding a negative response bias. These findings may explain some of the frustrations for persons with TBI and their families in interpersonal functioning, as persons with TBI often might perceive affect when it is not present. For example, individuals with TBI may not respond initially to social bids for connection from caregivers or family members, which could be related to processing speed and/or difficulty decoding emotions. Furthermore, these findings may explain some of the reactivity observed by loved ones of individuals with TBI, as persons with TBI may be responding to *neutral* or other emotions as negative and respond as such. Education to family and caregivers about the type of emotion errors made may improve overall understanding and social interactions.

Emotion Perception Accuracy and Neuropsychological Functioning

Relatively strong relationships between processing speed and emotion perception performance were observed among both groups for facial emotion perception when information was presented quickly and when presentation times were decelerated. This finding suggests that intact processing speed may benefit performance but is not the only factor that contributes to emotion perception accuracy. Interestingly, processing speed was not related to auditory emotion perception. Auditory emotion perception is likely complicated by serial processing and auditory working memory limitations. The divergent relationship between processing speed across modalities may reflect the frequency of the day-to-day difficulties experienced by individuals with TBI, as much of success during social interactions comes via processing visual information quickly (e.g., facial expressions, body language, etc.; Allerdings & Alfano, 2006; Croker & McDonald, 2005; Green et al., 2004; Jackson & Moffat, 1987; McDonald & Saunders, 2005; Milders et al., 2003). Given these relationships, interventions and rehabilitation targeting neuropsychological functioning may inadvertently improve facial emotion perception performance.

For facial emotion perception, the relationship between neuropsychological functioning and emotion accuracy was generally global for individuals with TBI, with the weakest effects seen for visuocognitive functioning. Thus, emotion perception accuracy for faces cannot be attributed solely to basic visuoperceptual deficits as some might expect. Speed of presentation may also have influenced performance patterns, as suggested by the strongest relationships with attention and working memory when facial emotion perception information was presented rapidly. For healthy adults, a global pattern was also observed when information was presented rapidly but revealed domain-specific relationships for processing speed and learning and memory when presentation rate was reduced. The pattern of global and domain-specific neuropsychological relationships with auditory emotion perception accuracy diverged from the facial modality: specific relationships between emotion perception and auditory attention, working memory, and verbal learning and memory became most noteworthy for individuals in the TBI group, whereas language and verbal learning memory was observed for healthy adults. The deviation in relationship patterns may be reflecting that for adults with TBI, difficulties in auditory attention and working memory during auditory emotion perception may hinder their ability to encode information efficiently enough to make use of other cognitive resources.

After considering effects of age, education, and processing speed, findings revealed both global and specific relationship patterns of neuropsychological abilities and emotion perception accuracy. Pattern of relationships with neuropsychological functioning depended on emotion perception modality and group membership. These findings are not unexpected, given that prior studies have found both global (i.e., Costa et al., 2015) and specific domain relationships (i.e., Rosenberg et al., 2015; Mancuso et al., 2015), depending on the study.

Individual Emotion Perception Accuracy and Neuropsychological Functioning Across Modalities. The current study also uniquely highlighted that the relationships between neuropsychological functioning and *individual* emotion accuracy varied by group membership. For the facial modality, strong relationships between individual emotion perception accuracy and strong neuropsychological functioning were observed. In the TBI group, the most prominent relationships were found for accuracy of *anger* and *fear* emotions with strong performances in processing speed, attention, working memory, and learning and memory. Healthy adults differed in that *sad* accuracy was identified as strongly related to intact processing speed and learning and memory functioning for facial emotion perception.

Patterns of findings for the auditory modality were distinct from those in the facial modality of emotion perception. Specifically, there were no prominent relationships between neuropsychological functioning and accuracy for any individual emotion accuracy for the TBI group; however, *anger* and *fear* demonstrated the most robust relationships with learning and memory and working memory for individuals in the HC group. Divergence in findings may be related to increased difficulty for auditory compared to facial task. Additionally, cues that communicate distinct emotions (e.g., cadence, prosody, squinting and eye shape, etc.) vary by modality; thus, it is possible that neuropsychological correlates are related to these discrete cues that are not well understood.

Experienced Affect and Emotion Perception Accuracy

The current study demonstrated that on average, individuals with TBI and healthy adults had relatively equivalent levels of experienced affect overall, but that persons with TBI more frequently endorsed clinically meaningful levels of depression than did their healthy adult counterparts. The relatively elevated report of depressive symptoms is consistent with a large body of literature supporting that persons with TBI are at increased risk for developing depression following injury often secondary to a combination of neurological, psychological, and other adjustments factors following TBI (e.g., Dikmen et al. 2004; Jorge et al. 2004; Hibbard et al. 2004, Koponen et al. 2002; Iverson & Lange, 2011). Findings indicating equivalent levels of experienced affect intensity was somewhat surprising given prior evidence that individuals with TBI may experience increased apathy, emotional lability and other changes to the manner in which they experience and react to emotion (e.g., O'Shanick & O'Shanick, 2005; Milders et al., 2008; Lezak, Howieson, & Loring, 2004; Shoenberg & Scott, 2011; Iverson & Lange, 2011). It is noteworthy that TBI can be associated with contrasting extreme lows in *experienced* affect intensity, such as with apathy (e.g., inertia, anosodiaphoria, etc.), as well as high experienced emotion (e.g., lability, overwhelm, reactivity, etc.) and content (e.g., high levels of depression, anxiety, etc.) Thus, it is likely that there are subsets of persons with these presentations within the present TBI sample. In sum, findings about experienced affect suggest a moderating effect that is consistent with the notion of divergent roles played by experienced emotion depending on the intensity and content. Specifically, an important and interesting moderating relationship was observed with facial emotion perception accuracy and affect intensity, such that *experienced* emotion can disrupt or facilitate emotion perception accuracy for persons with TBI depending on level. There was an inverse relationship between experienced affect intensity and emotion perception for persons with poor performance, such that high experienced affect intensity disrupted abilities to recognize emotions in others; however, a positive relationship was observed between performance and intensity of experienced emotion among individuals with intact emotion perception, such that their personal sensitivity enabled accuracy of reading others' emotions. Additionally, individuals with TBI who demonstrated high facial emotion perception accuracy also demonstrated better processing speed, attention, working memory, and executive functioning than those with high affect intensity. These findings could suggest that *experienced* affect intensity demonstrates a similar effect on facial emotion perception and neuropsychological performance in persons with TBI. Alternatively, it is likely that cognitive impairment might drive the moderating effect, such that persons with cognitive impairment and high experience affect are disrupted in accurately reading others' emotions, whereas persons with intact cognition are not. Contrastingly, emotion perception and neuropsychological performance for healthy adults did not demonstrate this level of reliance on experienced affect intensity. When experienced affect was high in the healthy adult group, performance on facial emotion perception was also strong, suggesting that emotional sensitivity and understanding of one's own experience benefitted understanding of others' emotion expression in healthy adults. Thus, the relationship between neuropsychological and facial emotion perception accuracy with experienced affect intensity was dependent on group membership.

Regarding content of experienced emotion, among both healthy adults and those with TBI, depressive symptoms were strongly related to hindered facial emotion perception. This finding is consistent with the literature that persons who report depression with (Rapoport et al., 2005; Chamelian & Feinstein, 2006) and without TBI (Langenecker, Lee, & Bieliauskas, 2009; Leppänen et al., 2004) underperform compared to healthy adults on emotion perception tasks. A pattern of underperformance among individuals with depressive symptoms may, in part, be explained by slow processing speed, which could be one explanation that a similar pattern was not observed when facial emotion was presented in a slowed paradigm. Interestingly, when presented with emotion information in a slow paradigm, personal experience and recognition of negative emotion facilitated improved performance in persons in both groups who demonstrated relatively poor emotion accuracy. This finding may be related to the fact that among people who recognize and acknowledge their own depressive symptoms, awareness of their own emotional experience could be facilitative in identifying emotions of others. However, once depression hits a certain level, the arousal and activation experienced by the presence of that emotion becomes disruptive to identifying facial emotions accurately. This u-shaped pattern parallels those observed in previous literature consistent with the Yerkes- Dodson law (Yerkes & Dodson, 1908; Rapport et al., 2002; Mather & Sutherland, 2011).

Limitations and Future Research

One limitation of the current study is that it was observational and restricted by non-randomization of the groups. This study was also limited by recruitment difficulties that resulted in imbalanced education levels between the groups and a relatively small sample. Although education was not meaningfully related to the dependent variables and efforts were made to address possible contributions of age and education, it would have been ideal for the groups to be balanced demographically. Relatedly, because gender presents as a methodological confound in this sample and in the general TBI population, the gender proportions are so skewed that it essentially becomes collinear with the experimental condition. Limits to inequalities in cells sizes required by the statistical models, as well as requirements for adequate experimental power could not be met to examine gender as a covariate. Given that men and African Americans tend to demonstrate more difficulty with facial emotion perception (when using Caucasian faces) than their counterparts (e.g., Goldby, Gabrieli, Chiao, & Eberhardt, 2011; Tanaka, Kiefer, & Buskach, 2004; Bouhuys, Geerts, & Gordiin, 1999; Bouhuys et al., 1996), some may attribute the findings of this study to demographic characteristics of the samples. However, the current study aimed to mitigate these effects by conducting within group analyses. Furthermore, facial emotion perception was related to neuropsychological functioning broadly during the current study. Future studies should aim to recruit groups with equivalent gender and race compositions. Also, findings from this study may not generalize to all individuals with TBI, as the TBI sample included mostly persons with severe injuries and was predominately made up African American men. Although including a sample with disproportionate numbers of African Americans compared to Caucasians could be viewed as a relative weakness, this study viewed the ability to examine injury in a minority group as a strength that will help understand and treat this underserved population. Lastly, given the explorative nature of this study, numerous measures were included and analyses were conducted to evaluate relationships with emotion perception accuracy. Such integration has enabled evaluation of interesting questions but this practice has a cost in that it inflates the probability of Type I error. Therefore, findings should be replicated in an independent sample to establish stability.

Future replication studies should examine the hypotheses of the current study while addressing the limitations identified (i.e., recruitment difficulties, injury and demographic diversity of sample, etc.), which may enable for a clearer picture of the intricate patterns of emotion perception performance in TBI. Although individuals with TBI demonstrate problems with emotion perception accuracy when presented via facial and auditory modalities, intricacies of performance and potential targets of interventions are nuanced between modalities; thus, future research should include at least emotion perception task in each modality. Additionally, research may wish to explore the extent to which adults and individuals with TBI differ in their visual processing (e.g., gaze direction, response time, etc.) while evaluating facial emotion as well as the degree to which this processing relates to emotion perception accuracy.

Potentially of most importance for establishing new efficacious interventions (Bornhofen & McDonald, 2008a; Bornhofen & McDonald, 2008b; Babbage, 2014), future research may wish to explore how targeting the identified processes that hinder emotion perception performance (e.g., *experienced* affect intensity, pattern of misattribution errors, etc.) may improve performance as well as social and occupational integration outcomes (Struchen et al., 2008). Interventions may benefit from teaching mindfulness skills so that individuals with TBI may learn how to identify internal states of high affect intensity. Interventions may also focus on teaching persons with TBI how to apply coping skills (e.g., deep breathing, emotion regulation, etc.) when they observe themselves to be in high intensity states, Such studies should examine whether utilization of these skills contributes to improved emotion perception accuracy in TBI and healthy adult samples. Once developed, longitudinal follow up may be beneficial to assess for lasting changes. Lastly, future studies may wish to explore how family education about experienced affect intensity and patterns of emotion errors may affect interpersonal functioning. Specifically, studies may wish to assess if education about the types of errors made by persons with TBI decreases perceived conflict by caregivers and/or individuals with TBI and/or increases caregiver empathy.

Conclusions

The findings in this study provide some evidence of the underlying processes that may interfere with emotion perception for individuals with TBI. Specifically, the presence of low and high levels of experienced affect, specific neuropsychological relationships, and the pattern of misattribution errors were distinct for persons following TBI compared to their healthy counterparts. Additionally, this study provided additional support to the literature that individuals with TBI show substantially poorer auditory and facial emotion perception than their healthy counterparts. Lastly, the study identified that the pattern of relationships between emotion perception accuracy and neuropsychological functioning was variable and dependent on emotion perception modalities (i.e., facial and auditory) as well as group membership. These findings will enable for additional research exploring methods (i.e., visual gaze processing) and performance patterns that affect outcomes. Additionally, the study provides important information for education of individuals with TBI as well as their family, caregivers, and providers. Lastly, these findings provide researchers with target processes from which interventions may be developed. Altogether, as interpersonal and social functioning have been linked with reading emotions (e.g., Blair, 2003; Bornhofen & McDonald, 2008; Jonker et al., 2015), findings from this current study enable education and additional research that improve social/interpersonal functioning and quality of life for persons with TBI.

APPENDIX A

Table 1. *Descriptive Statistics for Traumatic Brain Injury (TBI) and Healthy Comparisons (HC).*

	TBI (*n* = 50)		HC (*n* = 39)		Total (*N* = 89)		
Variable	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*Range*
Age (years)	45.3	(11.9)	45.5	(16.5)	45.4	(14.0)	18 – 70
Education (years)	12.2	(2.1)	14.4	(2.2)	13.2	(2.4)	8 – 20
WTAR Standard Score	83.7	(11.9)	99.0	(11.7)	90.5	(15.0)	66 – 120
Glasgow Coma Scale	7.4	(2.7)	--	--	--	--	3 – 12
Post-traumatic confusion (days)	21.3	(14.7)	--	--	--	--	1 – 63
Sex							
Men (Percent)	84.0		59.0				
Women (Percent)	16.0		41.0				
Reported Race (Percent)							
African American	90.0		64.1				
Non-Hispanic/Caucasian	6.0		25.6				
Hispanic/Latino	0.0		2.6				
Asian American	2.0		2.6				
Mixed	2.0		5.1				

Note. WTAR = Wechsler Test of Adult Reading.

Table 2a. *Descriptive Statistics and Group Comparisons of Emotion Perception (Percent Accuracy), Psychological and Neuropsychological Measures and Demographics for Traumatic Brain Injury (TBI) and Healthy Comparison (HC) Groups.*

	TBI (n = 50)		*HC (n = 39)*				
Variable	*M*	*SD*	*M*	*SD*	*F*	*df*	*d*
Emotion Perception							
FEPT (Faces)	66.4	(12.5)	80.3	(11.8)	28.29**	1, 87	1.14
FEPT–Slow (Faces)	76.1	(15.0)	86.8	(12.0)	12.28**	1, 82	0.77
EPT	54.4	(12.1)	65.3	(11.2)	19.01**	1, 87	0.93
Psychological							
Affect Intensity (AIM)	153.8	(32.7)	147.3	(30.7)	0.90	1, 83	0.21
Depression T (BSI-18)	53.8	(11.0)	48.6	(6.9)	7.25**	1, 86	0.55
Neuropsychological[1]							
RMT – Faces	34.0	(5.7)	38.0	(5.5)	10.60**	1, 86	0.70
Digits Forward	8.9	(2.3)	10.3	(2.3)	8.72*	1, 85	0.64
Symbol Digit	52.9	(14.7)	71.7	(20.4)	25.38**	1, 87	1.08
Trails – Part A (sec)	38.0	(14.0)	29.5	(11.4)	9.19**	1, 85	0.66
Line Orientation	20.1	(5.6)	21.4	(4.1)	0.77	1, 84	0.19
CVLT-II Trials 1–5	34.9	(10.7)	46.2	(11.9)	22.37**	1, 87	1.01
Digits Backward	6.5	(2.3)	7.9	(2.3)	7.45*	1, 85	0.59
Trails – Part B (sec)	123.4	(67.0)	68.8	(27.7)	22.69**	1, 85	1.03
Stroop–Color/Word	31.6	(11.1)	39.1	(12.2)	8.93**	1, 86	0.64
FAS Fluency	35.6	(10.7)	41.2	(11.4)	5.43**	1, 85	0.51
Animal Naming	15.3	(4.3)	20.9	(4.8)	32.63*	1, 83	1.24
Demographic							
Age (years)	45.3	(11.9)	45.5	(16.5)	0.00		
Education (years)	12.2	(2.1)	14.4	(2.2)	24.12**		

Note. FEPT = Facial Emotion Perception Test; EPT = Emotional Perception Test; RMT = Recognition Memory Test; CVLT-II = California Verbal Learning Test – Second Edition; WTAR = Wechsler Test of Adult Reading, Standard Score. *d* = Cohen's d.
1. Raw scores
$^{*}p < .05$, $^{**}p < .01$.

Table 2b. *Group Comparisons of Emotion Perception (Percent Accuracy) for Traumatic Brain Injury (TBI) and Healthy Comparison (HC): Unadjusted ANOVA, Age- and Education-Adjusted ANCOVA, Matched Sample, and Propensity Score Methods.*

		ANOVA		*ANCOVA*		*Matched Sample*[1]		*Propensity Score*	
Variable	*df*	*p*	*d*	*p*	*d*	*p*	*d*	*p*	*d*
FEPT (Faces)	87	< .001	1.14	< .001	1.25	< .001	1.01	.002	0.68
FEPT–Slow (Faces)	82	< .001	0.77	< .001	0.77	.018	0.64	.020	0.52
EPT	87	< .001	0.93	< .001	0.99	< .001	0.85	.001	0.73

Note. Facial Emotion Perception Test; EPT = Emotional Perception Test.
1. N = 60 for Matched Sample

Table 3a. *Traumatic Brain Injury Group (n = 50) – Emotion Perception (Percent Accuracy), Neuropsychological, and Demographic Characteristics: Zero- Order and Partial Correlations (Controlling for Age, Education, and Processing Speed).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. FEPT (Faces)	--	.55**	.36**	.34*	.23	.27*	.30*	.22	.25	.35*	-.23	.26*	.12	.30*	--	--
2. FEPT–Slow (Faces)	.54*	--	.40**	.31*	-.05	.43**	.37*	.01	.51**	.49**	.01	.19	.13	.36*	--	--
3. EPT	.46**	.41**	--	.00	.17	.45**	.10	.08	.28*	.49**	.06	.15	.06	.08	--	--
4. RMT – Faces	.37**	.36**	.09	--	.10	-.09	.13	.21	.20	-.01	.20	.34*	.06	.11	--	--
5. WTAR	.24*	.05	.21	.27*	--	.41**	.05	.35*	-.08	.19	-.29	.26	.23	-.09	--	--
6. Digits Forward	.29*	.46**	.47**	.02	.47**	--	.15	.27	.20	.60**	-.20	.01	.35*	.29	--	--
7. Symbol Digit	.52**	.41**	.26*	.23	.15	.23	--	.20	.29*	.25*	-.40**	.45**	.43**	.25	--	--
8. Line Orientation	.25*	.09	.13	.29*	.42**	.33*	.29*	--	.01	.21	-.20	.41**	.16	.14	--	--
9. CVLT-II 1–5	.37**	.54**	.36**	.29*	.07	.27*	.42**	.11	--	.31*	-.22	.21	.22	.32*	--	--
10. Digits Backward	.43**	.53**	.53**	.12	.27*	.63**	.38**	.29*	.40**	--	-.14	.32*	.29	.41**	--	--
11. Trails – Part B (sec)	-.46**	-.18	-.16	-.11	-.42**	-.31*	-.64**	.35**	-.41**	-.35**	--	-.08	-.42**	-.24	--	--
12. Stroop C/W	.42**	.29*	.26*	.45**	.38**	.15	.61**	.49**	.37**	.44**	-.46**	--	.22	.07	--	--
13. FAS Fluency	.30*	.24	.17	.19	.31*	.41**	.58**	.29*	.34**	.40**	-.60**	.43**	--	.51**	--	--
14. Animal Naming	.42*	.39**	.17	.14	-.06	.30*	.44**	.21	.38**	.45**	-.40**	.24	.57**	--	--	--
15. Trails – Part A (sec)	-.39**	-.24	-.21	-.26*	-.27*	-.22	.57**	-.30*	-.32*	-.32*	.70**	-.53**	-.51**	-.41**	--	--
16. Age	-.41**	-.01	-.41**	.05	.19	.04	-.34**	.08	-.12	-.08	.16	-.11	-.09	-.24	.15	--
17. Education	.14	.14	.17	.35**	.47**	.23	.17	.20	.24*	.23	-.41**	.33*	.18	-.06	-.31*	.22

Note. FEPT = Facial Emotion Perception Test; EPT = Emotional Perception Test; RMT = Recognition Memory Test; CVLT-II 1-5= California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial; WTAR SS = Wechsler Test of Adult Reading, Standard Score. Partial correlations (above diagonal) control for age, education and processing speed (Trail Making Test – Part A). $^{*}p < .05$, $^{**}p < .01$, *one-tailed test.*

Table 3b. *Healthy Comparison Group (n = 39) – Emotion Perception (Percent Accuracy), Neuropsychological, and Demographic Characteristics: Zero- Order and Partial Correlations (Controlling for Age, Education, and Processing Speed).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. FEPT (Faces)	--	.70**	.41**	.32*	.15	-.27	.33*	-.14	.50**	-.25	-.06	.06	-.01	.34*	--	--
2. FEPT – Slow (Faces)	.61**	--	.38*	.54**	.10	-.21	.04	-.20	.50**	-.26	-.09	-.07	-.02	.11	--	--
3. EPT	.53**	.46**	--	.11	.14	-.04	.27	-.25	.43**	.11	-.13	.17	.29*	.29*	--	--
4. RMT – Faces	.31*	.50**	.16	--	.39*	.29*	.42**	.28	.45**	.02	-.26	.34*	.05	.29*	--	--
5. WTAR	.29*	.06	.23	.27	--	.42**	.32*	.50**	.31*	.48**	-.48**	.34*	.30*	.29*	--	--
6. Digits Forward	-.10	-.15	.09	.28*	.46*	--	.22	.26	.06	.54**	-.22	.38*	.06	.02	--	--
7. Symbol Digit	.49**	.23	.52**	.40**	.33*	.33*	--	.18	.55**	.36*	-.31*	.64**	.13	.48**	--	--
8. Line Orientation	.02	-.12	-.03	.32*	.40**	.32*	.39**	--	-.05	.22	-.44**	.48**	-.03	.18	--	--
9. CVLT-II 1–5	.57**	.49**	.54**	.47**	.32*	.15	.64**	.12	--	.17	-.36*	.39*	.20	.27	--	--
10. Digits Backward	-.08	-.11	.25	.07	.45**	.57**	.47**	.32*	.28*	--	-.35*	.34*	.37*	-.04	--	--
11. Trails – Part B (sec)	-.25	-.45**	-.39**	-.28*	-.34*	-.23	-.55**	-.40**	-.44**	-.40**	--	-.60**	-.44**	-.35*	--	--
12. Stroop – C/W	.27*	.21	.43**	.37**	.31*	.41**	.78**	.55**	.52**	.45**	-.57**	--	.18	.44**	--	--
13. FAS Fluency	.16	.07	.40**	.06	.41**	.16	.29*	.05	.29*	.42**	-.44**	.30*	--	.34*	--	--
14. Animal Naming	.44**	.20	.43**	.34*	.28*	.12	.61**	.32*	.40**	.11	-.45**	.57**	.39**	--	--	--
15. Trails – Part A (sec)	-.33*	-.52**	-.45**	-.12	-.19	-.15	-.55**	-.15	-.30*	-.24	-.71**	-.55**	-.28*	-.31*	--	--
16. Age	-.27*	-.06	-.35*	-.18	-.04	-.21	-.60**	-.46**	-.35*	-.29*	.28*	-.47**	-.16	-.39*	.31*	--
17. Education	.20	-.15	.06	-.18	.49**	.15	-.01	-.11	-.01	-.01	.13	-.09	.23	-.06	-.04	.26

Note. FEPT = Facial Emotion Perception Test; EPT = Emotional Perception Test; RMT = Recognition Memory Test; CVLT-II 1-5= California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial; WTAR = Wechsler Test of Adult Reading, Standard Score. Partial correlations (above diagonal) control for age, education and processing speed (Trail Making Test – Part A). $^{*}p < .05$, $^{**}p < .01$, *one-tailed test.*

Table 4a. *Correlations for Facial Emotion Perception Test (FEPT): Component Accuracy with Neuropsychological Performance for Traumatic Brain Injury Group (n = 50).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total Faces (%)	--															
2. Fearful (%)	.78**	--														
3. Sad (%)	.50**	.16	--													
4. Angry (%)	.83**	.52**	.12	--												
5. Happy (%)	.37**	.16	.09	.25*	--											
6. Animals (%)	.21	.15	.13	.13	.26*	--										
7. RMT – Faces	.37**	.30*	.16	.32*	.10	-.01	--									
8. Digits Forward	.29*	.15	.22	.28*	-.00	-.05	.02	--								
9. Symbol Digit	.52**	.37**	.16	.53**	.18	.30*	.23	.23	--							
10. Trails – Part A[1]	-.39**	-.21	.12	-.41**	-.30*	-.15	-.26*	-.22	-.57**	--						
11. Line Orientation	.25*	.27*	.28*	.07	.03	.33*	.29*	.33*	.29*	-.30*	--					
12. CVLT-II 1–5	.37**	.35**	-.07	.46**	-.02	-.04	.29*	.27*	.42**	-.32*	.11	--				
13. Digits Backward	.43**	.32*	.25*	.36**	-.08	-.12	.12	.63**	.38**	-.32*	.29*	.40**	--			
14. Trails – Part B[1]	-.46**	.32*	-.10	-.52**	-.03	-.14	-.11	-.31*	-.64**	.70**	-.35**	-.41**	-.35**	--		
15. Stroop – C/W	.42**	.29*	.26*	.35**	.12	.10	.45**	.15	.61**	-.53**	.49**	.37**	.44**	-.46**	--	
16. FAS Fluency	.30*	.11	.26*	.29*	.01	.16	.19	.41**	.58**	-.51**	.29*	.34**	.40**	-.60**	.43**	--
17. Animal Naming	.42**	.23	.27*	.40**	.11	.04	.14	.30*	.44**	-.41**	.21	.38**	.45**	-.40**	.24*	-.59**

Note. RMT = Recognition Memory Test; SDMT = Symbol Digit Modality Test; Stroop C/W= Color/Word Trial; CVLT-II 1-5 = California Verbal Learning Test – Second Edition, Total Trials 1-5. $^{*}p < .05$, $^{**}p < .01$, *one-tailed test*.
1. Raw scores (seconds)

Table 4b. *Correlations for Facial Emotion Perception Test (FEPT): Component Accuracy with Neuropsychological Performance for Healthy Comparisons Group (n = 39).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total Faces (%)	--															
2. Fearful (%)	.81**	--														
3. Sad (%)	.70**	.33*	--													
4. Angry (%)	.83**	.46**	.52**	--												
5. Happy (%)	.46**	.16	.61**	.49**	--											
6. Animals (%)	.01	-.13	.14	.03	.24*	--										
7. RMT – Faces	.31*	.36*	.31*	.05	-.04	.09	--									
8. Digits Forward	-.10	-.02	-.28*	-.02	-.15	-.08	.28*	--								
9. Symbol Digit	.49**	.45**	.28*	.35*	.34*	.30*	.40**	.33*	--							
10. Trails – Part A[1]	-.33*	-.21	-.36*	-.28*	.55**	-.14	-.12	-.15	-.55**	--						
11. Line Orientation	.02	.10	-.05	-.10	-.16	.20	.32*	.32*	.39**	-.15	--					
12. CVLT-II 1–5	.57**	.45**	.53**	.37**	.36*	.14	-.47**	.15	.64**	-.30*	.12	--				
13. Digits Backward	-.08	.08	-.34*	-.08	-.12	.02	.07	.57**	.47**	-.24	.32*	.28*	--			
14. Trails – Part B[1]	-.25	-.10	-.40**	-.19	.47**	-.07	-.28	.23	-.55**	.71**	-.40**	-.44**	-.40**	--		
15. Stroop – C/W	.27*	.20	.27*	.19	.30*	.13	.37**	.41**	.78**	-.55**	.55**	.52**	.45**	-.73**	--	
16. FAS Fluency	.16	.07	.03	.23	.32*	.21	.06	.16	.29*	-.28*	.05	.29*	.42**	-.44**	.30*	--
17. Animal Naming	.44**	.29*	.30*	.42**	.34*	.46**	.34*	.12	.61**	-.31*	.32*	.40**	.11	-.45**	-.57**	-.39**

Note. RMT = Recognition Memory Test; CVLT-II 1-5 = California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial. $^{*}p < .05$, $^{**}p < .01$, *one-tailed test*.
1. Raw scores (seconds)

Table 5a. *Correlations for Facial Emotion Perception Test (FEPT) – Slow: Component Accuracy with Neuropsychological Performance for Traumatic Brain Injury Group (n = 48).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total Faces (%)	--															
2. Fearful (%)	.87**	--														
3. Sad (%)	.70**	.53**	--													
4. Angry (%)	.71**	.38**	.35**	--												
5. Happy (%)	.71**	.54**	.38**	.41**	--											
6. Animals (%)	-.03	-.05	.05	-.09	.08	--										
7. RMT – Faces	.36**	.30*	.39	.30*	.06	-.02	--									
8. Digits Forward	.46**	.42**	.22	.38**	.34*	.21	.02	--								
9. Symbol Digit	.41**	.40**	.23	.35**	.18	-.01	.23	.23	--							
10. Trails – Part A[1]	-.24	-.16	-.04	-.36**	-.04	-.06	-.26*	-.22	-.57**	--						
11. Line Orientation	.09	.03	.18	.13	-.02	.16	.29*	.33*	.29*	-.30*	--					
12. CVLT-II 1–5	.54**	.39**	.35**	.52**	.41**	-.10	.29*	.27*	.42**	-.32*	.11	--				
13. Digits Backward	.53**	.43**	.26*	.49**	.41**	.05	.12	.63**	.38**	-.32*	.29*	.40**	--			
14. Trails – Part B[1]	-.18	-.11	-.04	-.35**	.05	.04	-.11	-.31*	-.64**	.70**	-.35**	-.41**	-.35**	--		
15. Stroop – C/W	.29*	.20	.23	.34**	.04	-.08	.45**	.15	.61**	-.53**	.49**	.37**	.44**	-.46**	--	
16. FAS Fluency	.24	.11	.09	.40**	.13	.14	.19	.41**	.58**	-.51**	.29*	.34**	.40**	-.60**	.43**	--
17. Animal Naming	.39**	.35**	.09	.45**	.21	.06	.14	.30*	.44**	-.41**	.21	.38**	.45**	-.40	.24	.59**

Note. RMT = Recognition Memory Test; CVLT-II 1-5 = California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial. *$p < .05$, **$p < .01$, *one-tailed test*.

1. Raw scores (seconds)

Table 5b. *Correlations for Facial Emotion Perception Test (FEPT) – Slow: Component Accuracy with Neuropsychological Performance for Healthy Comparisons Group (n = 36).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total Faces (%)	--															
2. Fearful (%)	.88**	--														
3. Sad (%)	.80**	.53**	--													
4. Angry (%)	.75**	.42**	.62**	--												
5. Happy (%)	.73**	.78**	.42**	.28*	--											
6. Animals (%)	.02	-.04	.13	.04	-.08	--										
7. RMT – Faces	.50**	.33*	.53**	.46**	.10	.28	--									
8. Digits Forward	-.15	-.23	.06	-.06	-.25	-.00	.28*	--								
9. Symbol Digit	.23	.28*	.20	.12	-.02	.19	.40**	.33*	--							
10. Trails – Part A[1]	-.52**	-.49**	-.48**	-.33*	-.30*	.05	-.12	-.15	-.55**	--						
11. Line Orientation	-.12	-.02	.15	-.10	-.28	.24	.32*	.32*	.39**	-.15	--					
12. CVLT-II 1–5	.49**	.45**	.39**	.42**	.19	.10	.47**	.15	.64**	-.30*	.12	--				
13. Digits Backward	-.11	-.05	-.08	-.14	-.16	-.13	.07	.57**	.47**	-.24	.32*	.28*	--			
14. Trails – Part B[1]	-.45**	-.33*	-.48**	-.44**	-.02	-.01	-.28*	-.23	-.55**	.71**	-.40**	-.44**	-.40**	--		
15. Stroop – C/W	.21	.17	.21	.29*	-.17	.08	.37*	.41**	.78**	-.55**	.55**	.52**	.45**	-.73**	--	
16. FAS Fluency	.07	.05	.06	.12	-.06	-.06	.06	.16	.29*	-.28*	.05	.29*	.42**	-.44**	.30*	--
17. Animal Naming	.20	.12	.28	.25	-.13	.32*	.34*	.12	.61**	-.31*	.32*	.40**	.11	-.45**	.57**	.39**

Note. RMT = Recognition Memory Test; CVLT-II 1-5 = California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial. $^{*}p < .05$, $^{**}p < .01$, *one-tailed test*.

1. Raw scores (seconds)

Table 6a. *Correlations for Emotional Perception Test (EPT): Component Accuracy with Neuropsychological Performance for Traumatic Brain Injury Group (n = 50).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total (%)	--															
2. Fearful (%)	.61**	--														
3. Sad (%)	.66**	.28*	--													
4. Angry (%)	.50**	.34**	.16	--												
5. Happy (%)	.55*	.16	.11	.11	--											
6. Neutral (%)	.49**	.01	.25*	-.14	.19	--										
7. RMT – Faces	.09	.32*	.21	.04	.21	-.11	--									
8. Digits Forward	.47**	.05	.41**	.08	.32*	.43**	.02	--								
9. Symbol Digit	.26*	.31*	.14	.07	.30*	-.07	.23	.23	--							
10. Trails – Part A[1]	-.21	-.24	.04	-.10	-.38**	.06	-.26*	-.22	-.57**	--						
11. Line Orientation	.13	.21	.12	.05	.01	-.02	.29*	.33*	.29*	-.30*	--					
12. CVLT-II 1–5	.36**	.34**	.30*	.22	.31*	-.15	.29*	.27*	.42**	-.32*	.11	--				
13. Digits Backward	.53**	.31*	.31*	.19	.27*	.42**	.12	.63**	.38**	-.32*	.29*	.40**	--			
14. Trails – Part B[1]	-.16	-.17	-.00	-.20	-.24*	.14	-.11	-.31*	.64**	.70**	-.35**	-.41**	-.35**	--		
15. Stroop – C/W	.26*	.33*	.24	.10	.06	.01	.45**	.15	.61**	-.53**	.49**	.37**	.44**	-.46**	--	
16. FAS Fluency	.17	.07	-.01	.16	.15	.10	.19	.41**	.58**	-.51**	.29*	.34**	.40**	-.60**	.43**	--
17. Animal Naming	.17	.21	-.20	.10	.23	.14	.14	.30*	.44**	-.41**	.21	.38**	.45**	-.40**	.24	.59**

Note. RMT = Recognition Memory Test; CVLT-II 1-5 = California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial. $^{*}p < .05$, $^{**}p < .01$, *one-tailed test*.

1. Raw scores (seconds)

Table 6b. *Correlations for Emotional Perception Test (EPT): Component Accuracy with Neuropsychological Performance for Healthy Comparisons Group (n = 39).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total (%)	--															
2. Fearful (%)	.78**	--														
3. Sad (%)	.64**	.23	--													
4. Angry (%)	.42**	.37**	.17	--												
5. Happy (%)	.74**	.69**	.32*	.18	--											
6. Neutral (%)	.46**	.14	.13	-.10	.08	--										
7. RMT – Faces	.16	.21	.21	.26	.01	-.15	--									
8. Digits Forward	.09	.08	.03	.17	-.05	.06	.28*	--								
9. Symbol Digit	.52**	.52**	.26	.37*	.46**	.05	.40**	.33*	--							
10. Trails – Part A[1]	-.45**	-.43**	-.16	-.33*	-.28*	-.25	-.12	-.15	-.55**	--						
11. Line Orientation	-.03	.14	-.23	.08	-.02	-.05	.32*	.32*	.39**	-.15	--					
12. CVLT-II 1–5	.54**	.47**	.40**	.39**	.50**	-.04	.47**	.15	.64**	-.30*	.12	--				
13. Digits Backward	.25	.23	-.01	.01	.27*	.21	.07	.57**	.47**	-.24	.32*	.28*	--			
14. Trails – Part B[1]	-.39**	-.34*	-.16	-.30*	-.26	-.22	-.28*	-.23	-.55**	.71**	-.40**	-.44**	-.40**	--		
15. Stroop – C/W	.43**	.43**	.11	.39**	.32*	.16	.37*	.40**	.78**	-.55**	.56**	.52**	.45**	-.73**	--	
16. FAS Fluency	.40**	.34*	.15	.36*	.42**	.06	.06	.16	.29*	-.28*	.05	.29*	.42**	-.44**	.30*	--
17. Animal Naming	.43**	.35**	.26	.48**	.25	.10	.34*	.12	.61**	-.31*	.32*	.40**	.11	-.45**	.57**	.39**

Note. RMT = Recognition Memory Test; CVLT-II 1-5 = California Verbal Learning Test – Second Edition, Total Trials 1-5; Stroop C/W = Color/Word Trial. $^{*}p < .05$, $^{**}p < .01$, *one-tailed test*.

1. Raw scores (seconds)

Table 7. Zero-Order Pearson *Correlations for Emotion Perception Tasks Overall and Component Accuracy with Psychological Measures for Healthy Comparison (HC) and Traumatic Brain Injury (TBI) Groups.*

	TBI (n = 50)		HC (n = 39)	
Variable	*Affect Intensity*	*Depression*	*Affect Intensity*	*Depression*
FEPT				
Total (%)	-.32*	-.25*	-.03	-.19
Fearful (%)	-.20	-.17	.06	-.21
Sad (%)	-.37**	-.16	-.15	-.05
Angry (%)	-.17	-.16	.01	-.14
Happy (%)	-.08	-.26*	.02	.04
Animals (%)	-.21	-.18	.31*	.33*
FEPT – Slow				
Total (%)	-.34*	-.06	.24	-.18
Fearful (%)	-.37**	-.15	.26	-.05
Sad (%)	-.38**	-.06	.01	-.20
Angry (%)	-.11	.01	.21	-.31*
Happy (%)	-.02	.12	.30*	.08
Animals (%)	-.19	-.01	-.26	-.04
EPT				
Total (%)	-.04	-.19	-.03	-.04
Fearful (%)	.00	-.02	.11	.07
Sad (%)	.07	-.06	-.25	.04
Angry (%)	-.15	-.04	.03	.13
Happy (%)	-.01	-.30*	-.05	-.03
Neutral (%)	-.04	-.09	.14	-.26

Note. FEPT = Facial Emotion Perception Test; EPT = Emotional Perception Test; $^{*}p < .05$, $^{**}p < .01$, *one-tailed test*.

Table 8. *Group Comparisons of Individual Component Accuracy on Facial Emotion Perception Test (FEPT), Facial Emotion Perception Test – Slow (FEPT-Slow), and Emotional Perception Test (EPT).*

	TBI (n = 50)		*HC (n = 39)*				
Variable	*M*	*SD*	*M*	*SD*	*F*	*df*[1]	*d*
FEPT							
Angry (%)	52.9	(23.4)	70.6	(19.8)	14.26**	1, 87	0.81
Fearful (%)	54.3	(19.5)	71.8	(22.2)	15.57**	1, 87	0.84
Sad (%)	65.3	(22.4)	81.7	(17.9)	13.98**	1, 87	0.80
Happy (%)	96.5	(6.8)	98.6	(4.9)	2.51	1, 87	0.35
Animals (%)	79.2	(18.5)	92.7	(10.0)	17.02**	1, 87	0.88
FEPT – Slow							
Sad (%)	69.0	(17.7)	83.6	(16.0)	15.23**	1, 82	0.86
Fearful (%)	70.5	(24.6)	83.5	(19.1)	6.90**	1, 82	0.58
Angry (%)	75.5	(19.6)	84.7	(15.2)	5.47*	1, 82	0.52
Happy (%)	91.0	(13.7)	96.7	(7.2)	5.01*	1, 82	0.50
Animals (%)	88.5	(12.8)	97.0	(7.0)	12.08**	1, 82	0.79
EPT							
Fearful (%)	26.0	(20.2)	37.0	(21.1)	6.31*	1, 87	0.53
Happy (%)	44.7	(21.5)	57.3	(16.4)	9.21**	1, 87	0.65
Angry (%)	57.0	(30.7)	71.4	(17.5)	6.81*	1, 87	0.56
Sad (%)	64.7	(23.1)	77.2	(22.2)	6.69*	1, 87	0.55
Neutral (%)	74.0	(17.0)	80.3	(15.1)	3.36	1, 87	0.39

Note. FEPT = Facial Emotion Perception Test; EPT = Emotional Perception Test; 1. Group sizes varied slightly as reflected in *df*. *d* = Cohen's d. $^{*}p < .05$, $^{**}p < .01$.

Table 9a. *Descriptive Statistics for Traumatic Brain Injury (TBI) and Healthy Comparisons (HC): Facial Emotion Perception Test Errors.*

	TBI (n = 50)			HC (n = 39)					
Emotion	*% Err*	*Range*	*Mdn*	*% Err*	*Range*	*Mdn*	*U*	*z*	*d*
Sad	94.0	0 – 8	3.0	71.8	0 – 7	1.00			
as Fearful	52.0	0 – 5	1.0	41.0	0 – 3	0.0	817.0	-1.44	0.31
as Angry	64.0	0 – 3	1.0	41.0	0 – 3	0.0	731.0	-2.17^{*}	0.47
as Happy	12.0	0 – 2	0.0	2.6	0 – 1	0.0	881.0	$-1.67^{\dagger}$	0.36
as NR	60.0	0 – 4	1.0	25.6	0 – 6	0.0	619.5	-3.27^{**}	0.74
Fearful	96.0	0 – 11	5.0	82.1	0 – 9	3.0			
as Angry	72.0	0 – 4	1.0	43.6	0 – 2	0.0	687.5	-2.53^{*}	0.56
as Happy	64.0	0 – 6	1.0	41.0	0 – 3	0.0	769.5	$-1.82^{\dagger}$	0.39
as Sad	62.0	0 – 4	1.0	48.7	0 – 5	0.0	782.0	$-1.69^{\dagger}$	0.37
as NR	92.0	0 – 6	1.5	60.2	0 – 6	1.0	665.5	-2.68^{**}	0.59
Angry	98.0	1 – 12	6.0	94.9	0 – 12	4.0			
as Fearful	76.0	0 – 8	1.0	74.4	0 – 5	1.0	782.0	$-1.66^{\dagger}$	0.36
as Happy	18.0	0 – 4	0.0	00.0	0 – 0	0.0	799.5	-2.78^{**}	0.62
as Sad	92.0	0 – 7	2.0	69.2	0 – 7	1.0	659.0	-2.66^{**}	0.59
as NR	66.0	0 – 7	1.0	46.2	0 – 10	0.0	754.5	-1.95^{*}	0.42
Happy	26.0	0 – 3	0.0	10.3	0 – 3	0.0			
as Fearful	8.0	0 – 2	0.0	2.6	0 – 1	0.0	921.5	-1.11	0.24
as Angry	2.0	0 – 1	0.0	00.0	0 – 0	0.0	955.5	-0.88	0.19
as Sad	6.0	0 – 1	0.0	5.1	0 – 1	0.0	966.5	-0.18	0.04
as NR	16.0	0 – 2	0.0	5.1	0 – 2	0.0	871.0	-1.57	0.34
Neutral									
as Fearful	44.0	0 – 3	0.0	10.3	0 – 2	0.0	652.0	-3.34^{**}	0.76
as Angry	34.0	0 – 4	0.0	12.8	0 – 2	0.0	756.0	-2.40^{*}	0.53
as Happy	66.0	0 – 6	1.0	64.1	0 – 6	2.0	863.5	-0.95	0.20
as Sad	90.0	0 – 6	3.0	87.2	0 – 6	3.0	772.5	$-1.70^{\dagger}$	0.37
as NR	40.0	0 – 5	0.0	28.2	0 – 3	0.0	849.5	-1.23	0.26

Note. NR = no response; % *Err* = the percentage of the sample that made this error type.
$^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$.

Table 9b. *Descriptive Statistics for Traumatic Brain Injury (TBI) and Healthy Comparisons (HC): Facial Emotion Perception Test - Slow Errors.*

	TBI (n = 48)			HC (n = 36)					
Emotion	*% Err*	*Range*	*Mdn*	*% Err*	*Range*	*Mdn*	*U*	*z*	*d*
Sad	93.7	0 – 3	3.00	69.4	0 – 5	1.00			
as Fearful	56.2	0 – 4	1.00	47.2	0 – 3	0.00	769.5	-0.92	0.20
as Angry	56.2	0 – 4	1.00	33.3	0 – 3	0.00	627.5	-2.37^{*}	0.52
as Happy	8.3	0 – 2	0.00	00.0	0 – 0	0.00	792.0	$-1.76^{\dagger}$	0.38
as NR	62.5	0 – 3	1.00	22.2	0 – 4	0.00	526.0	-3.39^{**}	0.77
Fearful	85.4	0 – 14	3.50	60.4	0 – 10	1.00			
as Angry	66.7	0 – 7	1.00	38.9	0 – 3	0.00	601.5	-2.52^{*}	0.55
as Happy	27.1	0 – 5	0.00	36.1	0 – 4	0.00	784.0	-0.89	0.19
as Sad	47.9	0 – 4	0.00	19.4	0 – 3	0.00	611.0	-2.69^{**}	0.56
as NR	62.5	0 – 8	1.00	36.1	0 – 5	0.00	618.5	-2.39^{**}	0.53
Angry	85.4	0 – 8	2.00	75.0	0 – 7	1.50			
as Fearful	58.3	0 – 4	1.00	47.2	0 – 3	0.00	713.0	-1.47	0.32
as Happy	6.2	0 – 1	0.00	00.0	0 – 0	0.00	810.0	-1.52	0.33
as Sad	45.8	0 – 5	0.00	33.3	0 – 3	0.00	680.5	$-1.88^{\dagger}$	0.41
as NR	43.7	0 – 6	0.00	36.1	0 – 6	0.00	811.0	-0.54	0.12
Happy	47.9	0 – 6	0.00	22.2	0 – 3	0.00			
as Fearful	2.1	0 – 1	0.00	00.0	0 – 0	0.00	846.0	-0.87	0.18
as Angry	2.1	0 – 2	0.00	00.0	0 – 0	0.00	846.0	-0.87	0.18
as Sad	4.2	0 – 1	0.00	2.8	0 – 1	0.00	852.0	-0.34	0.07
as NR	43.7	0 – 6	0.00	22.2	0 – 3	0.00	670.0	-2.09^{*}	0.45
Neutral									
as Fearful	33.3	0 – 3	0.00	5.6	0 – 2	0.00	623.0	-3.04^{**}	0.68
as Angry	39.6	0 – 6	0.00	19.4	0 – 3	0.00	696.5	$-1.86^{\dagger}$	0.40
as Happy	58.3	0 – 5	1.00	55.6	0 – 8	1.00	798.0	-0.62	0.13
as Sad	97.9	0 – 9	4.00	94.4	0 – 9	6.00	624.5	-2.18^{*}	0.48
as NR	70.8	0 – 6	1.00	25.0	0 – 9	0.00	481.0	-3.70^{**}	0.85

Note. NR = no response; % *Err* = the percentage of the sample that made this error type. $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$.

Table 9c. *Descriptive Statistics for Traumatic Brain Injury (TBI) and Healthy Comparisons (HC): Emotional Perception Test Errors.*

	TBI (n = 50)			HC (n = 39)					
Emotion	*% Err*	*Range*	*Mdn*	*% Err*	*Range*	*Mdn*	*U*	*z*	*d*
Sad	94.0	0 – 8	2.50	97.1	0 – 8	2.00			
as Fearful	38.0	0 – 5	0.00	25.6	0 – 2	0.00	817.5	-1.58	0.34
as Angry	46.0	0 – 4	0.00	35.9	0 – 3	0.00	859.0	-1.09	0.23
as Happy	2.0	0 – 1	0.00	0.0	0 – 0	0.00	955.5	-0.88	0.19
as Neutral	76.0	0 – 6	1.00	53.8	0 – 6	1.00	779.5	-1.69†	0.36
as NR	12.0	0 – 1	1.00	10.3	0 – 3	0.00	961.0	-0.21	0.05
Fearful	100.0	2 – 9	7.00	97.4	2 – 9	6.00			
as Angry	70.0	0 – 3	1.00	46.2	0 – 4	0.00	786.0	-1.67†	0.36
as Happy	28.0	0 – 2	0.00	33.3	0 – 2	0.00	914.5	-0.62	0.13
as Sad	72.0	0 – 5	1.00	79.5	0 – 3	1.00	938.5	-0.31	0.07
as Neutral	100.0	0 – 8	3.00	89.7	0 – 8	3.00	801.5	-1.47	0.32
as NR	28.0	0 – 2	0.00	10.3	0 – 2	0.00	801.0	-2.06*	0.45
Angry	94.0	0 – 8	2.00	87.2	0 – 4	2.00			
as Fearful	34.0	0 – 3	0.00	38.5	0 – 3	0.00	926.5	-0.47	0.10
as Happy	12.0	0 – 3	0.00	12.8	0 – 1	0.00	969.5	-0.08	0.02
as Sad	16.0	0 – 1	1.00	7.7	0 – 1	0.00	894.0	-1.17	0.25
as Neutral	76.0	0 – 7	1.00	69.2	0 – 2	1.00	777.0	-1.76†	0.38
as NR	30.0	0 – 2	0.00	10.3	0 – 2	0.00	788.0	-2.17*	0.47
Happy	100.0	1 – 9	5.00	100.0	1 – 7	4.00			
as Fearful	22.0	0 – 2	0.00	11.3	0 – 2	0.00	856.0	-1.51	0.33
as Angry	58.0	0 – 5	1.00	56.4	0 – 3	1.00	889.5	-0.78	0.17
as Sad	26.0	0 – 3	0.00	2.6	0 – 2	0.00	751.0	-2.93**	0.65
as Neutral	96.0	0 – 6	3.00	97.4	0 – 6	3.00	871.5	-0.88	0.19
as NR	34.0	0 – 4	0.00	20.5	0 – 3	0.00	836.5	-1.46	0.31
Neutral	88.0	0 – 7	3.00	79.5	0 – 6	2.00			
as Fearful	30.0	0 – 4	0.00	7.7	0 – 2	0.00	754.0	-2.61**	0.58
as Angry	70.0	0 – 6	1.00	69.2	0 – 6	1.00	960.0	-0.13	0.03
as Happy	34.0	0 – 2	0.00	20.5	0 – 2	0.00	848.5	-1.33	0.29
as Sad	32.0	0 – 4	0.00	17.9	0 – 2	0.00	827.0	-1.60	0.34
as NR	16.0	0 – 1	0.00	5.1	0 – 3	0.00	873.0	-1.54	0.33

Note. NR = no response; % *Err* = the percentage of the sample that made this error type. $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$.

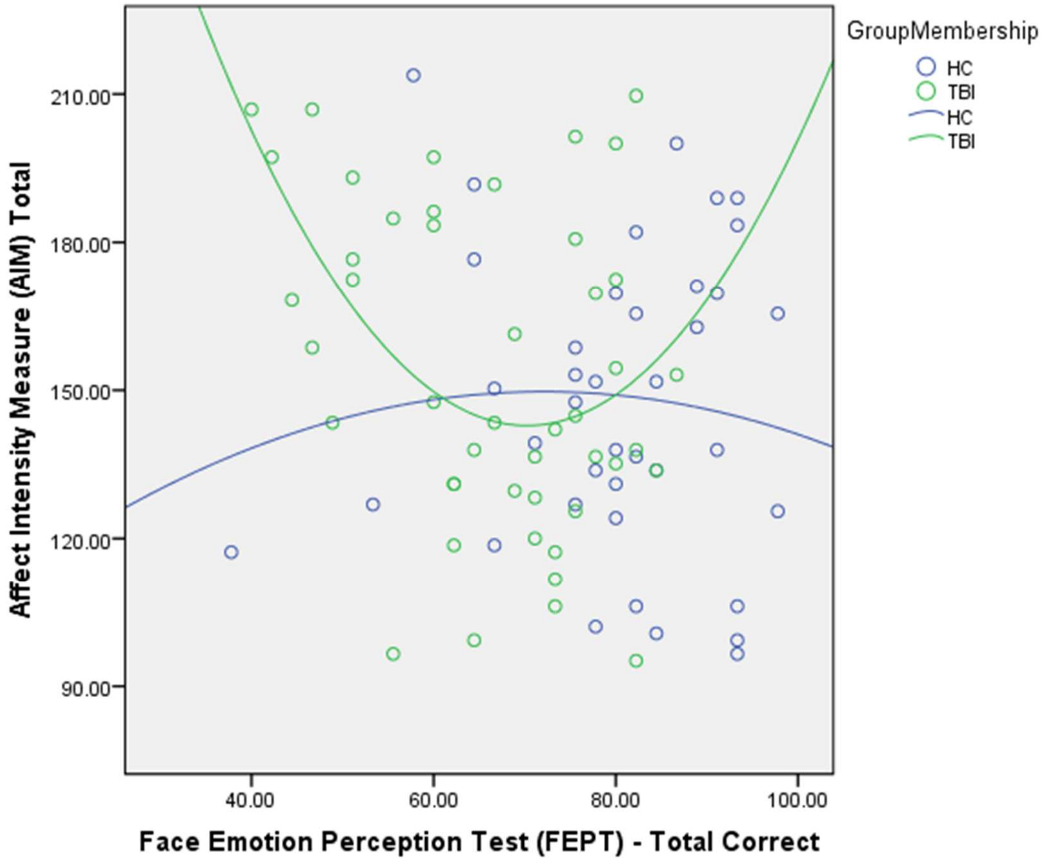
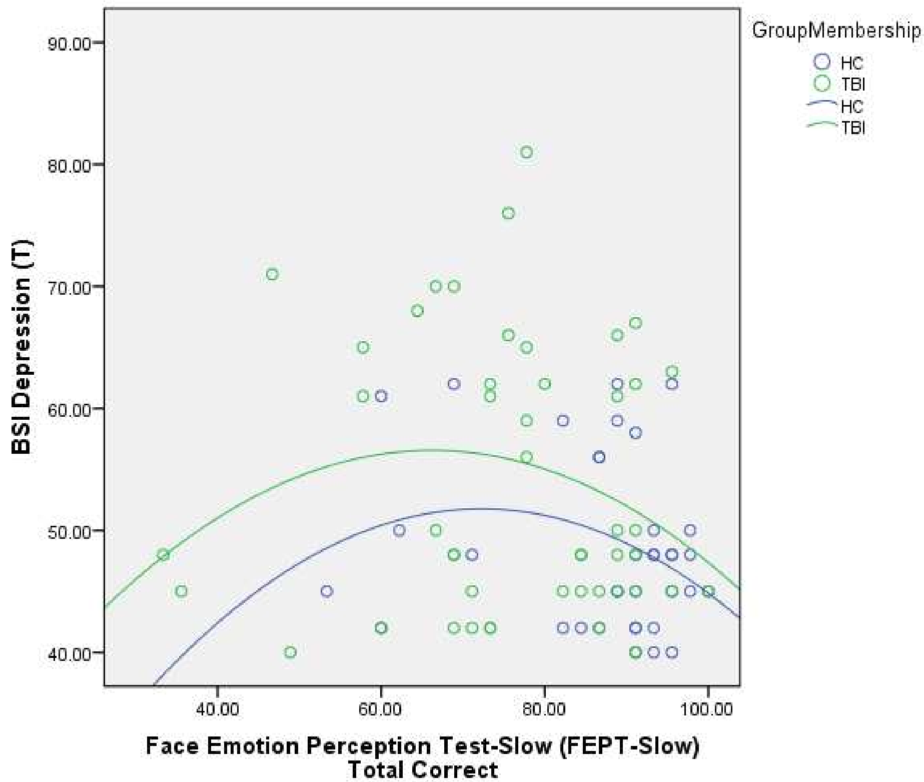


Figure 1. Nonlinear Relationship between Affect intensity (AIM) and Facial Emotion Perception (FEPT) in TBI versus HC Groups. TBI shows linear inverse relationship (*r* = -.32) and quadratic trends (TBI quadratic R^2 = .20), with inverse relation to AIM among poor-performing adults (-.48) and positive relation to AIM among high-performing adults (.28). Among HC, no significant relationship (quadratic R^2 = .00).



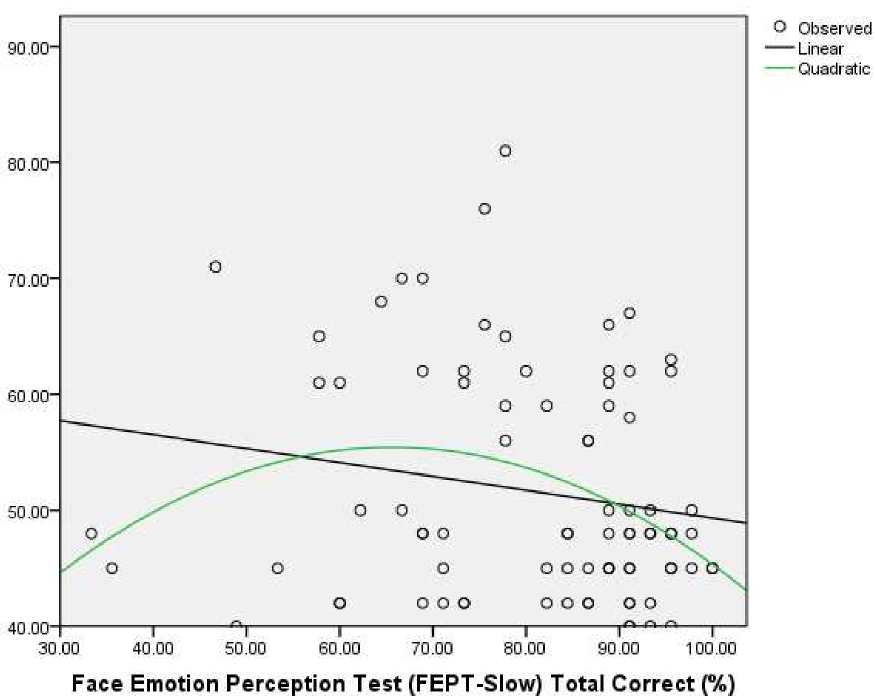


Figure 2. Nonlinear Relationship between Depressive Symptoms (BSI- Depression) and Facial Emotion Perception (FEPT) in TBI and HC Groups. Total Sample Dep T – FEPT-Slow: R2 = .09

APPENDIX B

WAYNE STATE UNIVERSITY

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NOTICE OF EXPEDITED APPROVAL

To: Rachel Kay
Psychology

From: Dr. Deborah Ellis or designee J. Wirth / RB
for Chairperson, Behavioral Institutional Review Board (B3)

Date: November 08, 2014

RE: IRB #: 105614B3E

Protocol Title: Neuropsychological Correlates of Facial Emotion Perception (FEP) in Moderate and Severe Traumatic Brain Injury

Funding Source: Sponsor: Wayne State University Office of Vice President for Research
Unit: Psychology

Protocol #: 1410013508

Expiration Date: November 07, 2015

Risk Level / Category: Research not involving greater than minimal risk

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The above-referenced protocol and items listed below (if applicable) were **APPROVED** following *Expedited Review* Category (#7)* by the Chairperson/designee *for* the Wayne State University Institutional Review Board (B3) for the period of 11/08/2014 through 11/07/2015. This approval does not replace any departmental or other approvals that may be required.

- Revised Protocol Summary Form (received in the IRB Office 10/20/2014)
- Protocol (received in the IRB Office 10/13/2014)
- Behavioral Research Informed Consent - TBI Group (dated 10/20/2014)
- Behavioral Research Informed Consent - Healthy Adults (dated 10/20/2014)
- Study Flyer - Healthy Volunteers
- Advertisement for Detroit Metro Times - Healthy Volunteers
- Data Collection Tools: WMS-IV, Trail Making Part A and B, DVT Test Booklet, Recognition Memory Test, Test of Premorbid Functioning Record Form, Animal Naming, Brief Symptom Inventory 18, Rey Complex Figure Test and Recognition Trial Test Booklet, Stroop Color and Word Test - Adult Version, Ten-Item Personality Inventory, AIM Questionnaire, and Positive and Negative Affect Schedule (PANAS) Questionnaire

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- Federal regulations require that all research be reviewed at least annually. You *may* receive a *"Continuation Renewal Reminder"* approximately two months prior to the expiration date; however, it is the Principal Investigator's responsibility to obtain review and continued approval ***before*** the expiration date. Data collected during a period of lapsed approval is unapproved research and can never be reported or published as research data.
- All changes or amendments to the above-referenced protocol require review and approval by the IRB **BEFORE** implementation.
- Adverse Reactions/Unexpected Events (AR/UE) must be submitted on the appropriate form within the timeframe specified in the IRB Administration Office Policy (http://www.irb.wayne.edu//policies-human-research.php).

NOTE:

1. Upon notification of an impending regulatory site visit, hold notification, and/or external audit the IRB Administration Office must be contacted immediately.
2. Forms should be downloaded from the IRB website at **each** use.

*Based on the Expedited Review List, revised November 1998

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ABSTRACT

EMOTION PERCEPTION CORRELATES IN MODERATE AND SEVERE TRAUMATIC BRAIN INJURY

by

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Advisor: Dr. Lisa J. Rapport

Major: Psychology (Clinical)

Degree: Doctorate of Philosophy

Introduction: Individuals with traumatic brain injury (TBI) experience impairments in emotion perception (EP) accuracy in facial and auditory modalities; however, patterns of emotion perception and their relation to neurocognitive performance are not fully understood. The current study assessed *why* EP deficits occur via psychological and cognitive relationships as well as patterns of emotion misattributions.

Methods: 50 adults with a bona-fide moderate or severe TBI and 39 healthy comparison adults were included in the study. Eligible participants completed a battery of paper-and-pencil and computerized neuropsychological measures. Facial (Facial Emotion Perception Test) and auditory (Emotional Perception Test) EP tasks and psychological questionnaires were included.

Results: The TBI group underperformed on auditory and two facial EP tasks compared to healthy adults. After adjusting for age, education, and processing speed, facial EP accuracy demonstrated a global pattern of neuropsychological correlates for the TBI group. Contrastingly, a domain-specific pattern of neuropsychological correlates (i.e., attention, processing speed, and language) was identified for the healthy adult group. Unlike the facial modality, domain-specific

relationships with auditory EP were observed for both groups. Intensity of experienced affect moderated EP performance; an inverse relation was observed among low performers and a positive relationship was observed among high performers for the facial EP tasks in the TBI group. Depression symptoms for facial EP tasks also demonstrated influence on EP performance such that depression symptoms undermined EP accuracy for the total sample. A quadratic relationship was also observed when the facial EP task was slowed; for individuals with poor EP accuracy, recognition of depression symptoms facilitated performance until an asymptotic point at which point recognition hindered EP accuracy. Misattribution patterns revealed that individuals in the TBI group demonstrated significantly more omission errors compared to healthy adults. Additionally, they demonstrated a bias in which they made significantly more errors for negative emotions and miscoded emotions as negative more than healthy adults.

Conclusions: The presence of low and high levels of experienced affect, specific neuropsychological relationships, and the pattern of misattribution errors were distinct for persons following TBI compared to their healthy counterparts in auditory and facial modalities of emotion perception. Findings from this current study enable education of providers and loved ones as well as additional research to improve social/interpersonal functioning and quality of life for persons with TBI.

AUTOBIOGRAPHICAL STATEMENT

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Education

August 2016 (Expected)	Doctorate of Philosophy in Psychology Wayne State University, Detroit, Michigan Major: Clinical Psychology, Minor: Neuropsychology
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