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An Eye-Tracking Investigation of Facial Affect Recognition in Traumatic Brain Injury and Healthy Individuals

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Abstract

Traumatic Brain Injury (TBI) is considered a public health issue and affects millions of people worldwide. While individuals with TBI suffer from a variety of motor and cognitive deficits, this project focused on the social cognitive problems that individuals with TBI experience, specifically facial affect recognition. The primary goal of this study was to better understand facial affect recognition and how it is affected by attention abilities in individuals with TBI. In Experiment 1, we examined how facial affect recognition is associated with attentional abilities using correlational analyses in a sample of 28 participants. In Experiment 2, which was divided into 2 conditions, using a smaller sample size, we examined whether individuals with TBI process emotional faces fundamentally differently than healthy individuals using eye-tracking. Additionally in Experiment 2, we examined whether attentional abilities affected the way individuals with TBI process emotional faces using eye-tracking. In Condition 2A, participants had full attention in which they decided on what emotion a face was displaying. The hypothesis for Condition 2A was that TBI participants would perform worse on a facial affect recognition task than healthy controls (HC) and that gaze patterns would differ between TBI individuals and healthy controls. In Condition 2B, participants had divided attention as they also performed a distractor task while selecting what emotion was being displayed. The hypothesis for Condition 2B was both groups of participants would have a relatively worse performance on a facial affect recognition task when their attention was divided (compared to undivided), but TBI participants' performance on the facial affect recognition task would decrease more significantly than healthy controls. Also in this condition, the hypothesis was that gaze patterns would differ between TBI individuals and healthy controls. Results for Experiment 1 showed a relationship between a measure of facial affect recognition abilities and two measures of attention. In Experiment 2, Condition 2A and 2B, we found significant differences in performance on the facial affect recognition task between TBI and HC participants as TBI participants were less accurate on correctly identifying the emotions that were displayed on faces compared to HC participants. In Condition 2A, we found a significant difference in the amount of total fixations in critical areas of the face that TBI and HC participants made while viewing an emotional face when they had full attention. In Experiment 2, Condition 2A and 2B, we found a significant difference in the amount of time TBI and HC participants viewed (dwelled on) critical areas of an emotional face as TBI participants viewed critical areas of the face for less time compared to HC participants. This research is important because it may serve as an example of how gaze patterns differ between TBI individuals and healthy individuals and be used to plan better treatments for individuals with TBI that suffer from impaired facial affect recognition abilities.

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By

Joseph Walter DeAngelis

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Introduction

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This thesis is constructed in the following ways: in the section of the introduction, it presents a background of Traumatic Brain Injury (TBI), why it is necessary to study it, how it occurs and its symptoms, and the research methods used in studying it. Next, the thesis will focus on social cognition by giving a description of it, its importance to study, and methods used in studying it. Then the thesis will focus on the method used in the current study to examine social cognition in TBI: eye-tracking. The introduction will then focus on the study, hypotheses, and specific aims and goals of the experiment. In the second section, the experiment, methods, and results will be presented. In the third section, the thesis will conclude with a general discussion of the experiment.

What is Traumatic Brain Injury?

TBI can be defined as an alteration in brain function caused by an injury/impact to the head or brain. It may manifest into seizure, coma, confusion, altered levels of consciousness, sensory or motor neurological deficits, and more (Bruns & Hauser, 2003). It is important to understand the distinction between TBI and Head Injury (HI). HI is a nonspecific term that includes external injuries to the head, face and scalp. It may also include contusions, lacerations, abrasions, and fractures and may or may not be associated with TBI (Bruns & Hauser, 2003). TBI, however is damage to the brain or the tissues in the brain (Bruns & Hauser, 2003). Acquired Brain Injury (ABI) is an umbrella term that includes TBI but TBI refers to an acquired, sudden-onset, non-progressive, and non-degenerative condition while ABI includes all brain injuries (Bruns & Hauser, 2003).

There are 3 main classifications for TBI severity: mild, moderate, and severe. The Glasgow Coma Scale is currently the most widely used clinical assessment tool in classifying TBI severity. It is based on an individual's responses of eye opening, verbal function, and motor function to different stimuli. Traditionally, a score of 13 to 15 is considered mild, 9 to 12 is considered moderate, and < 9 is considered severe (Teasdale et al., 1979).

Prevalence of TBI

TBI affects millions of people worldwide and is considered a public health problem (Stocchetti & Zanier, 2016). Due to more people aging in the Western hemisphere, falls in the elderly increase the incidence of TBI (Roozenbeek et al., 2013). Individuals with TBI require prolonged hospital care, require long-term rehabilitation, and may suffer from cognitive, physical, and mental disabilities that affect them throughout their lifetime. Globally, TBI survivors generally have a lower life expectancy than the general population (Rosenfeld et al., 2012). This may be due to the difficulties that TBI individuals experience including motor and cognitive complications. A motor or cognitive difficulty may affect an individual's life expectancy because an individual with a motor difficulty may not be able to perform tasks that require motor skills, like walking or exercising. Individuals with cognitive difficulties may not be able to make logical or healthy choices in their life, which may lead them to make poor/risky decisions regarding their health.

The consequences of TBI also present economic costs to individuals that suffer from severe TBI. In the United States of America, the total lifetime cost of severe TBI per case is approximately $400,000.00 and this figure is attributed to lost productivity and disability of the individual affected (Rosenfeld et al., 2012). With TBI as a public health problem and the obvious economic consequences of TBI, researchers should invest more time into studying TBI.

Causes and Symptoms of TBI

TBI usually occurs when some form of external or mechanical force acts on the head or body causing brain dysfunction. The most common causes of TBI in the USA are: falls, motor vehicle accidents, assault, or being struck by another individual or an object (Thurman et al., 1999). This section will first provide an understanding of the biology behind TBI and then present the symptomology.

Individuals that suffer from TBI are affected by a variety of brain dysfunctions that include white matter degradation and protein misfolding. When TBI occurs, it may cause alterations or disruptions in the axonal cytoskeleton and possibly impair axonal transport. TBI may damage structural networks in the brain and damage communication between neurons (Rodriguez-Paez et al., 2005). Individuals with TBI may be at risk for developing other neurodegenerative disorders including dementia and Alzheimer’s disease (Johnson et al., 2010). It has been shown that individuals with TBI accumulate amyloid- β peptides and have defective tau proteins, both of which are associated with Alzheimer’s disease (Johnson et al., 2010).

Individuals affected by TBI may have physical disabilities, cognitive impairments, a higher rate of developing other psychiatric disorders, and impairments in social functioning. In terms of physical disabilities, people with TBI may have motor deficits that include balance and gait issues and spasticity problems. Individuals with TBI may experience difficulties balancing, standing, and walking at a normal rate (Basford et al., 2003). Individuals with TBI may also experience muscle over-activity, muscle rigidity, muscle tremors, and motor weakness (Bergfeldt et al., 2006).

In terms of cognitive issues, TBI may cause deficits in learning, attention, memory, information processing speed, and other high-level cognitive functions (Stocchetti & Zanier, 2016). TBI individuals may experience prolonged memory loss after TBI and may also have difficulties in short-term and working memory (Lyeth et al., 1990). People affected by TBI may experience difficulties in executive functioning. This can include difficulties in planning and motivation. For example, an individual with TBI may find it difficult to plan their day and have motivation to perform the tasks of their day (Cicerone et al., 2006). Also, individuals affected by TBI may be at higher risk for developing psychiatric disorders including, anxiety, depression, psychosis, and other disruptive behaviors and personality changes. The comorbidity of TBI with these disorders makes an individual at greater risk for substance abuse (Zgaljardic et al., 2015).

One issue that individuals with TBI experience and one of the main focuses of this project is attention. Individuals with TBI experience difficulties in goal oriented behavior because this behavior depends on sustaining attention (Bonnelle et al., 2011). It is also known that individuals with TBI have difficulty in divided attention, or performing more than one thing/paying attention to more than one thing at a time. Many studies show that individuals with TBI consistently perform worse than healthy controls on tasks that require divided attention and this might be due to the fact that individuals with TBI are not be able to sustain the required cognitive resources to pay attention to more than one thing for long periods of time (Azouvi et al., 2004). In Azouvi et al., (2004), participants with moderate to severe TBI and healthy controls completed an experimental task and a distractor task simultaneously and were measured on the speed and accuracy of their responses. The experimental task was a visual go-no go task and the distractor task was a random number generation test. The visual go-no go task consisted of a cross and a circle presented on a computer screen. Participants were instructed to respond by pressing a button on the computer keyboard whenever the cross appeared and to not respond whenever the circle appeared. The distractor task was a random number generation test in which participants had to randomly say a number aloud between 1 and 10. Participants were instructed to avoid patterns (i.e., saying 1,2,3,4 and 2,4,6,8) while saying the numbers aloud. The study found that TBI individuals rated both tasks as more difficult and responded less frequently and less accurately than the healthy controls did in the go-no go task (Azouvi et al., 2004).

The combination of cognitive, physical, and emotional processing difficulties that an individual with TBI may experience may lead to difficulties reintegrating into their communities and may affect their overall quality of life (QoL). Individuals with TBI may have poor conversation abilities that include making poor or crude jokes, suddenly changing topics, focusing too much on oneself, making uninhibited remarks or unwanted advances, and over disclosing personal information (McDonald et al., 2003).

It has been shown that individuals with TBI experience difficulties in social cognition, a set of skills which includes recognizing emotions on faces, Theory of Mind (ToM), and interpreting social cues (Croker & McDonald, 2005, Babbage et al., 2011). Furthermore, individuals with TBI experience interpersonal problems including difficulties in social communication (effectively communicating their thoughts, opinions, and/or desires to their friends, family, and peers) and difficulties in maintaining social and romantic relationships (Struchen et al., 2011). These problems in interpersonal communication are important to study because of the social nature of today's society. People need to communicate effectively with others in order to achieve their goals. Often, the first step in effective communication is recognizing and understanding the emotions an individual is displaying on their face (facial affect recognition) (Crocker & McDonald, 2005). If an individual with TBI cannot effectively recognize and interpret emotion being displayed on someone's face, this may lead to a negative social interaction. Since individuals with TBI experience interpersonal problems, this thesis focuses on social cognition impairments, specifically in facial affect recognition, how which individuals with TBI suffer.

What is Social Cognition?

Social cognition is a broad term used to describe the way social information is processed. This includes the ability to detect what emotions people are feeling (or showing) and appropriately respond to these emotions (Henry et al., 2015). Two main components of social cognition are facial affect recognition and Theory of Mind (ToM). Facial affect recognition refers to an individual's ability to accurately recognize the emotion displayed on someone's face and ToM refers to one's ability to attribute mental states (beliefs, desires, intents, etc.) to themselves and others. It also describes the ability to understand that other people have different perspectives and intentions from their own. This thesis will focus on facial affect recognition.

Why Study Social Cognition

While many studies focus on motor and physical problems of individuals with TBI, it is also important to focus on the social deficits of individuals with TBI. This is an important aspect to study because people live social lives. People live in a social environment in which they express their feelings and emotions. Often, individuals with TBI rely on caretakers, family, and friends for help accessing/providing medical services and social care. For example, an individual with TBI may need to have a friend drive them to the doctor's office. This involves social planning as both individuals have to communicate about the pick-up time, the appointment time, and the drop off time. If an individual with TBI cannot successfully communicate with others then this may lead to social isolation and trouble reintegrating into society after the brain injury. If an individual with TBI becomes socially isolated due to impairments in social cognitive abilities, then this may lead to negative thoughts and emotions because they are isolated (e.g., nobody to talk to/spend time with, nobody to express feelings to, etc.). For this reason, it is important to understand how individuals with TBI function socially.

Individuals with TBI have difficulty in facial affect recognition (recognizing emotions displayed on faces). A meta-analysis of 296 adults with moderate to severe TBI from 13 different studies conducted by Babbage et al., (2011), showed that up to 39% of individuals with severe TBI have difficulty in recognizing emotions from static presentations of facial expressions. It is also known that recognition of emotional expression in voice is impaired following TBI (Dimoska et al., 2010). This is important due to the role attention may play in facial affect recognition. An individual with TBI may have to focus on what someone is saying and their facial expression at the same time.

While Individuals with TBI have difficulty recognizing all emotions presented on a face compared to healthy controls, and they have particular difficulties in recognizing negative emotions. One study found that individuals with TBI experience a greater deficit in recognizing negative emotions (e.g., sadness, anger, and disgust) than positive emotions (e.g., happiness and surprise) (Croker & McDonald, 2005). This is important because individuals with TBI may observe negative emotions often. For example, an individual with TBI's caretaker or family member may be upset about a particular issue. An individual with TBI may mistake the sadness on their caretaker's or family member's face as anger and assume the caretaker or family member is angry with them. This could result in a possible argument or a strained relationship between them. The primary goal of this study was to understand how individuals with TBI view different facial/emotional expressions.

This project also sought to understand how attention contributes to facial affect recognition. In order for an individual with TBI to recognize the emotion being displayed on a face, they must first pay attention to that face. In terms of divided attention, an individual with TBI may experience situations in which they are talking to/discerning the facial expression of someone in a noisy or loud environment (e.g., a party or another social setting like the mall, grocery store, etc.) or may have to recognize the facial expressions of two people at the same time. Further, an individual with TBI may have to recognize the facial expression of someone whose facial expression does not match what he or she is saying. For example, someone might say they are happy but their facial expression shows anger. An individual with TBI may have to divide their attention to what that person is saying and their facial expression while saying it. A good example of this is sarcasm and lying. It has been shown that individuals with TBI experience difficulties in understanding when someone is being sarcastic and determining if someone is lying (Honan et al., 2016). This is important because sarcasm is used by people in daily conversations and is used to make jokes. If an individual with TBI does not understand that someone is being sarcastic, then this could lead to a negative social engagement. If an individual with TBI does not understand if/when someone is lying, then this could also lead to a negative social engagement.

Studying Facial Affect Recognition

The most common way to assess social cognition, specifically facial affect recognition abilities, is by displaying static images of faces showing different emotions to the participants and having the participants state what emotion is being shown on the face (Henry et al., 2015). Many studies have used the standardized Ekman & Friesen (1971) stimuli set. These stimuli consist of different black and white photographs of actors displaying 6 basic emotions (happiness, sadness, disgust, fear, anger, surprise, and a neutral facial expression). While studies that use static images are helpful, they do present some disadvantages. One of the main disadvantages of using static stimuli is that they are not ecologically valid. In a more real-world setting, people are usually interacting with each other in a noisy environment with sounds and other distractions taking place. This may make it more difficult for an individual with TBI to focus and recognize the emotion presented on someone’s face. Another main disadvantage of the studies mentioned before is they do not provide an explanation of how an individual with TBI processes facial expressions. These studies show that TBI individuals have difficulty in facial affect recognition but do not explain how they experience these difficulties or how they are making the mistakes leading up to incorrectly identifying a specific emotion presented on a face.

Eye-Tracking

Eye-tracking is used to investigate gaze behavior and can provide insight into social cognition. Eye-tracking studies are generally conducted by illuminating the eye with an infrared beam and then capturing the reflected image on a video camera. The cornea and the pupil are two parts of the eye that are captured from the reflected image. This gives one enough information to determine what and where on a screen/image a participant is looking (Boraston & Blakemore, 2007).

The current project utilized eye-tracking as one of the main paradigms because understanding how an individual with TBI views facial expression is important. Studies show that individuals have difficulties in facial affect recognition but not how these difficulties occur. This study is different than many studies examining facial affect recognition in individuals with TBI because it investigated how individuals with TBI viewed facial expression. Understanding how these difficulties occur is important because it can help develop treatments/interventions for individuals suffering from TBI. For example, if an individual is focusing on a part of the face for too long/too short then this information can be integrated into treatments/interventions designed to improve facial affect recognition abilities.

This project sought to understand if TBI individuals view a face fundamentally different than healthy individuals (e.g., TBI individuals may fixate on a part of a face for too long or too short a time period compared to healthy controls). This project also investigated full vs. divided attention of facial affect recognition in individuals with TBI. Specifically, how facial affect recognition performance changes when participants have full attention or divided attention on the task. This is important because this study sought to achieve higher ecological validity than other studies investigating facial affect recognition. This study may serve as an example for other researchers investigating social cognition in TBI using eye-tracking and be used to plan better treatments for individuals with TBI that suffer from impaired facial affect recognition abilities. For example, if an individual with TBI has difficulty recognizing the emotion sadness on a face, then a treatment/intervention could be developed to remedy this. Specifically, eye-tracking helps plan better treatments because it allows researchers and other individuals to understand where a socially impaired individual is looking at on a facial expression and for how long. It is not enough to just know that an individual is impaired on recognizing an emotion on a face. Eye-tracking allows researchers to understand whether an individual with TBI has difficulty recognizing emotion on a face is viewing the mouth, nose, or eyes for too long or too short a time period compared to healthy individuals. This information can then be used as feedback for that individual and this information can be used to initiate changes in the individual's gaze behavior.

How Healthy Individuals View a Face

Since this project focuses on how TBI individuals and healthy individuals view a face, it is important to understand the ways healthy individuals view a face. In a study conducted by (Dalton et al., 2005), autistic and healthy children viewed emotional facial expressions and non-emotional facial expressions while their eyes were being tracked. Healthy children viewed the eyes and mouth of an emotional and non-emotional face for a significantly longer amount of time than the autistic children. In adult studies, it has been shown that healthy adults fixate mainly on the eyes, the nose, and the mouth (the "core features" of a face). Healthy adults first fixate on the eyes of an emotional facial expression then the nose, and then the mouth with the eyes being the most fixated on area (Boraston & Blakemore, 2007). Most normal adults spend different amounts of time fixating on different areas of a face for each emotion (Boraston & Blakemore, 2007). For example, a healthy participant may view the mouth region of a surprised face for a longer amount of time compared to other areas on the face if that face has an open mouth, which may indicate the feeling of surprise. A healthy participant may view the nose region of an angry face for a longer amount of time compared to other areas on the face if that face has a scrunched nose, which may indicate the feeling of anger (Boraston & Blakemore, 2007).

Current Study

The current study focused on facial affect recognition and consisted of two experiments. Experiment 1 sought to understand how facial affect recognition was associated with attentional abilities. This was done by correlating measures of attention and a measure of facial affect recognition abilities. This would lead to the understanding if attention positively or negatively affects facial affect recognition abilities. In Experiment 2, there were 2 conditions, which both utilized eye-tracking. The first condition (Condition 2A), sought to understand how TBI and healthy individuals' performance differs in identifying emotions and how participants' gaze patterns differ. This was conducted using eye-tracking and, in this condition, participants had full attention on the task. The second condition (Condition 2B), also sought to understand how TBI and healthy individuals' performance differs on identifying emotions and how participants' gaze patterns differed when their attention was divided. This was also conducted using eye-tracking. In this condition, participants had divided attention on the task as they engaged in a distractor task while simultaneously completing the facial affect identification task.

Aims and Hypotheses

The question that this project sought to answer is why social cognitive deficits occur in individuals with TBI. In experiment 1, the hypothesis was that there would be a positive relationship between attention and facial affect recognition (i.e., if a participant scores high on a measure of attention, then they will also score high on a measure of facial affect recognition). This might be because an individual needs to pay attention to the expressions on a face in order to correctly identify the emotion being displayed.

In Experiment 2, in condition 2A, the hypothesis was that TBI participants would perform worse on the facial affect recognition task than healthy controls. In terms of eye-tracking in condition 2A, the hypothesis was that gaze patterns would differ between TBI individuals and healthy controls. Specifically, the prediction was that TBI individuals would fixate more on non-regions of interest (ROI) than the main ROIs compared to healthy controls. ROIs are regions or areas on a face that individuals can view in order to gain information on a face. In experiment 2, the main ROIs were the eyes, nose, and the mouth and the non-ROIs were the ears, hair, and other facial area. The eyes, nose, and mouth were determined as the main ROIs because they have been shown to provide more information about emotion compared to the non-ROIs, in both adult and child studies (Boraston & Blakemore, 2007; Dalton et al., 2005). For example, a surprised individual may have their mouth open when they express surprise. Thus, someone viewing the mouth may be viewing it in order to distinguish what emotion is being displayed.

In condition 2B, the hypothesis was that both groups of participants would have relatively low performance on the facial affect recognition task when their attention was divided (compared to undivided), but TBI participants' performance on the facial affect recognition task would reduce more significantly than healthy controls. In the eye tracking aspect of condition 2B, the hypothesis was also that gaze patterns would differ between TBI individuals and healthy controls. Specifically, TBI participants would lose focus on the facial affect recognition task and may make fewer fixations of the main ROIs of an emotional facial expression compared to healthy controls when they are asked to simultaneously view a face and complete a distractor task. This is because an individual with TBI may not be able to fixate on the main ROIs of an emotional face as often as healthy controls due to issues in divided attention.

Experiment 1 - Methods

Participants

Data was drawn from a randomized clinical trial that examined social cognitive deficits in individuals with TBI conducted by Kessler Foundation. Participants were recruited from Kessler Foundation's participant information database. There were 28 TBI participants (23 males and 5 females). The TBI participants met the criteria of the current study, which were:

(1) Age 25 – 65 years

(2) Had sustained a moderate or severe TBI as determined by the Glasgow Coma Scale score less than or equal to 12 or post-traumatic amnesia or loss of consciousness of at least 24 hours.

(3) Age 18 or older at the time of injury.

(4) At least one year after injury.

Participants were excluded from the study if they possessed impaired vision or hearing, had pre-injury psychiatric history, and/or had substance dependence. The mean age of TBI participants was 45 years (SD = 12.3) and they were on average 9.5 years post injury (SD = 11). The mean length of education was 14 years (SD = 2.19). Participants sustained mild TBI (4%), moderate TBI (11% of participants), and severe TBI (46% of participants). 39% of TBI participants in this sample had an injury severity that was unknown.

Measures

These 3 assessments were utilized in order to evaluate the relationship between facial affect recognition ability and attention.

- Digit Span: Each segment of this test (forward and backward) consisted of seven pairs of random number sequences that the examiner read aloud at the rate of one per second. Both segments depended upon auditory attention and working memory to be performed effectively. In the digit span forward segment, the participant was instructed to repeat the string of digits in the same order in which they were presented by the examiner. Conversely, in the digit span backward segment, the subject was instructed to repeat the string of digits in the reverse order. The Digit Span test has also shown high internal consistency reliability (r=.90) (Wechsler, 1997).
- Symbol Digit Modalities Test (SDMT): The SDMT involved the conversion of a set of simple geometric designs into a written response. It has been demonstrated to be sensitive to the presence of brain damage in numerous studies. The SDMT

required the examinee to substitute a number for a randomized presentation of a geometric figure. The appropriate number was shown in a key containing the Arabic numbers 1 through 9, each with a different geometric figure. The SDMT has shown good test-retest ($r=.76$) and alternate forms ($r=.82$, $r=.84$) reliability. The sensitivity of the SDMT to the cognitive effects of a number of neurological illnesses and injuries has been demonstrated repeatedly (Smith, 1982).

- Task of Facial Emotion Recognition (TOFER): The TOFER consisted of 36 black and white images that are of faces expressing one of the following 6 emotions: happiness, fear, anger, sadness, surprise, or disgust. The images were taken from The Karolinska Directed Emotional Faces (KDEF)—a database of 4900 pictures of humans expressing different emotions at different angles (Goeleven et al., 2008). All of the faces faced directly toward the camera or screen, and 6 images of each emotion were presented. Participants taking part in a study utilizing the TOFER are asked to "select the emotion that best fits the actor's facial expression," and to "respond as quickly as possible." A total score on the TOFER is the sum of the number of correct responses, and each subscore is the sum of correct responses within a particular emotion. The psychometric properties of the KDEF database have been examined to ensure that the stimuli are valid (Goeleven et al., 2008). To ensure that the emotions portrayed by the stimuli are accurately identified at a rate higher than chance; chance proportion scores were calculated for each emotion separately. Analyses suggested that selection of the intended emotion was far above chance level for every emotion ($p<.0001$) (Goeleven et al., 2008). Test-retest reliability was high for the KDEF pictures: 87.96% of the emotions were rated the same at time point 1 and time point 2 (separated by 1 week) (Goeleven et al., 2008).

We conducted Pearson correlations (one-tailed) between the TOFER and the two measures of attention (Digit Span and SDMT). This was conducted in order to measure if facial affect recognition ability is associated with attention.

Experiment 1 - Results

Relationship Between Facial Affect Recognition Ability & Attention

Pearson correlations were conducted between the one measure of facial affect recognition ability (TOFER) and the two measures of attention (Digit Span and SDMT) (See Illustration 1 in the "Supplemental Figures & Tables" section for all correlations). The correlations were based on the one-tailed level because we had a specific hypothesis of the direction of the relationship between facial affect recognition ability and attention (i.e., an individual must utilize attention in order to accurately identify an emotion on a face). There was a significant positive correlation between the TOFER and the Digit Span (forward version) r (26) = .44, p = .011. There was a significant positive correlation between the TOFER and the Digit Span (backward version) r (26) = .36, p = .034. There was a significant positive relationship between the TOFER and the total score of the Digit Span r (26) = .41, p = .017. There was a significant positive correlation between the TOFER and the SDMT r(26) = .57, p = .001. These significant positive correlations indicate that attention has a role in the ability to identify emotions on faces.

Experiment 1 – Summary of Findings

In Experiment 1, we found that there was a significant positive correlation between the TOFER and the Digit Span and the TOFER and the SDMT. This suggests that there is a link between facial affect recognition abilities and attention. Our hypothesis for Experiment 1 was confirmed.

Experiment 2 – Methods

Participants

The participants for Experiment 2 were 6 individuals recruited from Kessler Foundation's participant information database. There were 2 TBI participants (2 male and 0 female) and 4 healthy control participants (0 male and 4 female). More information on the participants in Experiment 2 can be seen in Table 1.

Participant	Age	Years of Education	Injury Severity	Cause of Injury
TBI1	46	16	Moderate-Severe	Car Accident
TBI2	32	9	Moderate-Severe	Gunshot
HC1	45	16		
HC2	43	14		
HC3	24	18		
HC4	44	16		

Table 1. Participant information in Experiment 2.

Eye-Tracker

The eye-tracking apparatus used was the EyeLink 1000 Plus. This system contained a camera, a camera mount, and a head/chin rest. Eye-tracking is conducted by directing infrared light towards the center of the eyes (pupil), which then causes visible reflections in the cornea. These reflections can then be detected by the camera, which allows eye movements to be tracked. The mount was used to keep the camera in place and steady. The head/chin rest was used to stabilize a participant's head so that eye movements could be tracked efficiently.

Stimuli

The emotional faces that were viewed by participants came from the Karolinska Directed Emotional Faces (KDEF) database (Goeleven et al., 2008). The emotional expressions were five basic "universal" emotions: sad, surprised, disgust, anger, and afraid (see Figure 1.). Both male and female faces were used. A total of 60 faces were used with 30 in Condition 2A and 30 in Condition 2B.

Figure 1. Example of each emotion from left to right: sadness, surprised, disgust, anger, and fear

In Condition 2A, participants viewed emotional faces presented on a computer screen for a short period of time (6 seconds) and then were asked to identify what emotion the face was displaying. Participants identified which emotion a face was displaying by pressing the corresponding key on the keyboard. On the keyboard, the "D" key represented the emotion anger, the "F" key represented the emotion fear, the "L" key represented the emotion sadness, the ";" represented the emotion surprise, and the ' key represented the emotion disgust. Participants were able to practice responding to the faces before the experiment began.

In Condition 2B, participants viewed emotional faces presented on a computer screen for a short period of time (6 seconds) and were asked to identify which emotion the face was displaying while simultaneously completing a distractor task. The distractor task for condition 2B consisted of listening to and responding to low, medium, and high tones while viewing an emotional face. The low tone played at a frequency of 100 Hz, the medium tone played at a frequency of 150 Hz, and the high tone played at a frequency of 200Hz. The tones were delivered via external speakers, were randomly presented to participants and were played for no longer than 3 seconds. Participants responded to the emotional faces in the same manner as in Condition 2A. Participants responded to the tones by pressing the corresponding key on the keyboard. On the keyboard, the “L” key represented the low tone, the “;” key represented the medium tone, and the “‘” key represented the high tone. Participants would view the face while simultaneously listening to and responding to the tones, and then they would be asked to identify the emotion expressed on the face shown. Participants were able to practice the distractor task by itself and were also able to practice the distractor task with the facial affect recognition task simultaneously before the experiment began.

ROI Creation

ROIs help to separate and distinguish different areas of the face from each other. For example, if an individual is viewing the eyes on a face, it is important to understand what part of the face constitutes the eye region, where the eye region starts, and where the eye region ends. In this project, all ROIs were free-drawn using the EyeLink Data Viewer program. The guidelines for drawing the ROIs were based off of (Wells et al., 2016 & Arizpe et al., 2016) and were adapted to fit the faces used in this project. Two ROIs made up the eyes, one ROI on the left eye and one ROI on the right eye. The ROIs began right above the top of the eyebrows, continued to the outer most part of the eyebrows, and ended at the molar fold (the groove in the skin where the upper cheek muscles meet the eye sockets). For the nose, the ROI began at the bottom of the eyes, continued to the edges of the bulbs of the nostrils, and ended at the bottom of the nose. For the mouth, the ROI began at the philtrum (the vertical groove in the middle of the upper lip), continued to the outer most part of the mouth muscles, and ended at the labiomedial crease (the crease where the mouth meets the chin) (see Figure 2). In order to understand if we were forming the ROIs accurately, two independent researchers (the principal investigator – Joseph DeAngelis and a research assistant) drew the ROIs initially on five facial stimuli. Interrater reliability for the ROIs was established by correlating the total number of fixations in the eyes ROIs that the principal investigator drew with the total number of fixations in the eyes ROI that the research assistant drew. There was a strong positive correlation between the total number of fixations in the principal investigator's eyes ROIs and the total number of fixations in the research assistant's eyes ROIs (r = .86).


Figure 2. Example of eyes, nose, and mouth, ROIs.

Experiment 2 – Design

Experiment 2 was a 2 by 2 within participants design. There were 2 levels of the independent variable – group (TBI and HC) and there were 2 levels of the independent variable – attention (full attention and divided attention). Each participant (TBI and HC) participated in the full attention condition (Condition 2A) and the divided attention condition (Condition 2B).

Procedure

Participants entered the experiment room and were given informed consent. The experiment room was sound reduced and contained the eye-tracker. Participants were then familiarized with the eye-tracker and they put their head and chin on the head and chin rest. Once participants were comfortable, they engaged in practice trials for both conditions 2A and 2B. Participants' eyes were not tracked during the practice and was conducted in order to familiarize participants with the task. After the practice trials, participants' eyes movements were calibrated and validated. This was done in order to ensure the highest level of eye-tracking accuracy. Once this was done, participants either began condition 2A or 2B as the order of the conditions was randomly assigned.

In condition 2A (Full Attention Condition), participants viewed each face for 6 seconds for a total of 30 trials. After 15 trials, participants received a short break and eye movements were recalibrated and revalidated. In order to determine what emotion was being displayed, participants hit the corresponding key on the keyboard that aligned with the emotion being displayed. Before starting the other experiment, participants received a break and calibration and validation was conducted again.

In condition 2B (Divided Attention Condition), participants responded to the tone that was being played (approximately 3 or 4 tones per trial) and then responded to the emotional face for a total of 30 trials with 6 seconds viewing each face. Participants selected the tones and the emotion displayed on the face by selecting the corresponding key on the keyboard. After 15 trials, participants were given a short break and eye movements were recalibrated and revalidated. Once this was done, participants finished the remaining 15 trials. After both experiments were completed, participants were debriefed and exited the experiment room.

Statistical Analyses

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS). Statistical significance was set at an alpha level of 0.05. For the behavioral data, participants' performance on the facial affect recognition task in both the full attention and divided attention conditions was examined. Participants' accuracy on correctly identifying each specific emotion in both the full and divided attention conditions (i.e., how accurate participants were on correctly identifying the emotion sadness when the emotional face was displaying sadness) was also examined. These variables were compared across groups using a Mann – Whitney U test and an independent samples t-test. An ANOVA was not conducted because the small sample size would affect the power of the test. A Mann-Whitney U test was conducted because this study had a small sample size and because we believed the behavioral data would not be normally distributed (i.e., TBI participants would be less accurate on the facial affect recognition task compared to HC participants). For the eye-tracking data, the amount of time both groups of participants in both conditions spent fixating on the main ROIs (left eye, right eye, mouth, and nose) compared to the amount of time spent fixating on the supplemental/non-ROIs was examined. These variables were compared across groups using an independent samples t-test.

Experiment 2 - Results

Accuracy Rates on Condition 2A vs. Condition 2B

Participants' accuracy on the facial affect recognition task for both Condition 2A (Full Attention Condition) and Condition 2B (Divided Attention Condition) was first examined. In Condition 2A (Full Attention Condition), TBI participants identified the emotion correctly 50% of the time and HC participants identified the emotion correctly 88% of the time. In Condition 2B (Divided Attention Condition), TBI participants identified the emotion correctly 42% of the time and HC participants identified the emotion correctly 71% of the time (See Figure 3). TBI individuals performed worse on the facial affect recognition task than the HC participants in the Full and Divided Attention conditions.

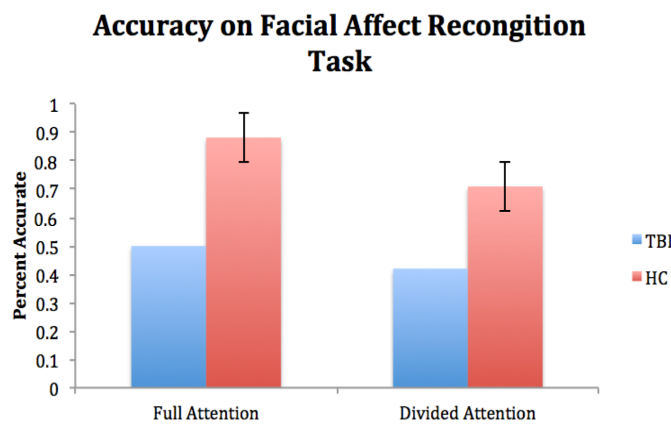

Figure 3. Mean accuracy on the Facial Affect Recognition Task.

Accuracy Rates on Each Emotion in Condition 2A

Next, participants' accuracy on identifying each emotion in Condition 2A (Full Attention Condition) was examined (See Table 2). TBI participants and HC participants differed in accuracy in identifying specific emotions when they had full attention on the facial affect recognition task (See Figure 4).

Emotion	TBI Accuracy	HC Accuracy
Fear	17%	70%
Anger	33%	91%
Disgust	66%	95%
Sadness	50%	100%
Surprise	83%	83%

Table 2. Emotion accuracy rates in Condition 2A.

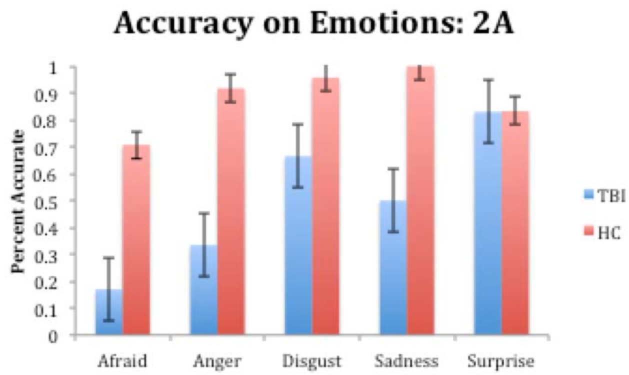

Figure 4. Mean accuracy rates on each emotion in Condition 2A.

Accuracy Rates on Each Emotion in Condition 2B

Participants' accuracy on identifying each emotion in Condition 2B (Divided Attention Condition) was examined (See Table 3). TBI participants and HC participants differed in accuracy in identifying specific emotions when their attention was divided on the facial affect recognition task (see Figure 5). In this condition, there were no differences in accuracy on the emotion afraid.

Emotion	TBI Accuracy	HC Accuracy
Afraid	41%	41%
Anger	25%	75%
Disgust	33%	75%
Sadness	33%	70%
Surprise	75%	91%

Table 3. Emotion accuracy rates in Condition 2B.

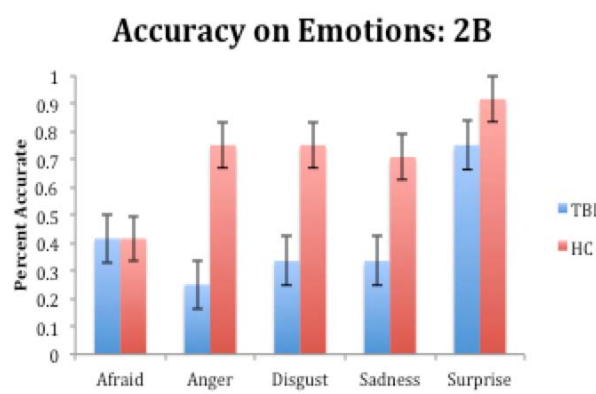

Figure 5. Mean accuracy rates on each emotion in Condition 2B.

Interaction Between Participant Group and Attention

A possible interaction between participant group (TBI or HC) and attention (full attention or divided attention) for performance on the facial affect recognition task was then investigated. There was no interaction but there was a trend in which performance reduces from the Full Attention Condition to the Divided Attention Condition for both groups of participants (See Figure 6).

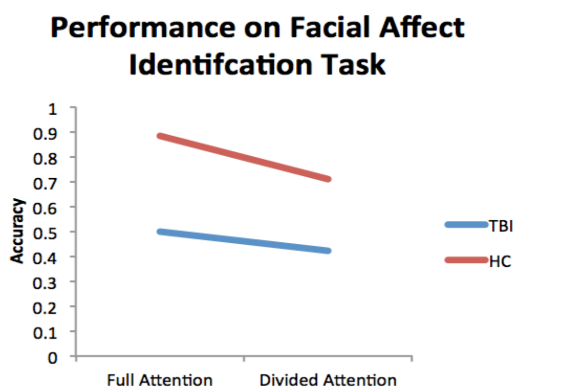

Figure 6. Line chart depicting performance on the facial affect recognition task in the full and divided attention conditions for both groups of participants.

A Mann – Whitney U test revealed no significant differences between groups in participants' performance on the facial affect recognition task for Condition 2A (Full Attention Condition) and Condition 2B (Divided Attention Condition). An independent samples t-test was conducted to compare accuracy of the responses on the facial affect recognition task for HC participants and TBI participants in Condition 2A (Full Attention Condition) and Condition 2B (Divided Attention Condition). In Condition 2A (Full Attention Condition), HC participants (M = 26.5, SD = 1.91, N = 4) were more accurate on the facial affect recognition task compared to TBI participants (M = 15, SD = .00, N = 2), t (4) = 8.0, p = .001 (two-tailed), d = 8.15, 95% CI [7.51, 15.4]. In Condition 2B (Divided Attention Condition), HC participants (M = 21.2, SD = 1.5, N = 4) were more accurate on the facial affect recognition task compared to TBI participants (M = 12.5, SD = 2.12, N = 2), t (4) = 6.02, p = .004 (two-tailed), d = 4.73 95% CI [4.71, 12.78]. An inspection of the data revealed that both groups of participants were responding to the tones at least 50% of the time in Condition 2B (Divided Attention Condition).

Eye-Tracking Analysis

The data analysis for the eye-tracking portion of Experiment 2 contained 5 participants (2 TBI and 3 HC) as 1 participant was removed from the analysis due to unreliable data. An ANOVA was not conducted because the small sample size would affect the power.

Number of Fixations Inside and Outside of the ROIs in Condition 2A

The average total number of fixations participants made inside the ROIs and outside of the ROIs in Condition 2A (Full Attention Condition) (See Table 4 & Figure 7) was first examined.

Group	Fixations Inside ROIs	Fixations Outside ROIs
TBI	81	413
HC	426	298

Table 4. Number of fixations inside and outside of the ROIs in Condition 2A.

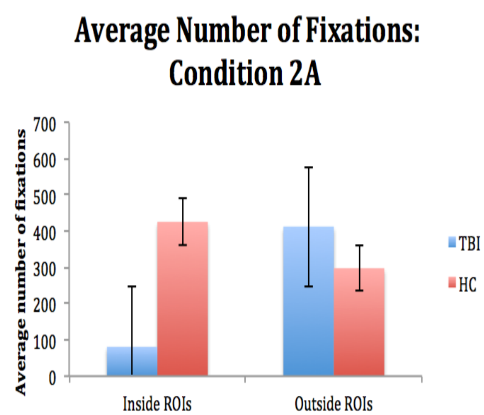

Figure 7. Average number of total fixations made on faces throughout the facial affect recognition task in Condition 2A.

An independent samples t-test was conducted to compare the total number of fixations made in the ROIs for HC participants and TBI participants in Condition 2A (Full Attention Condition). HC participants (M = 427, SD = 29.3, N = 3) made more total fixations in the ROIs compared to TBI participants (M = 81, SD = 63.6, N = 2), t (3) = 8.64, p = .003 (two-tailed), d = 7.05, 95% CI [218, 473].

Number of Fixations Inside and Outside of the ROIs in Condition 2B

Next, the average total number of fixations participants made inside the ROIs and outside of the ROIs in Condition 2B (Divided Attention Condition) (See Table 5 & Figure 8) was examined.

Group	Fixations Inside ROIs	Fixations Outside ROIs
TBI	313	516
HC	482	492

Table 5. Number of fixations inside & outside of the ROIs in Condition 2B.

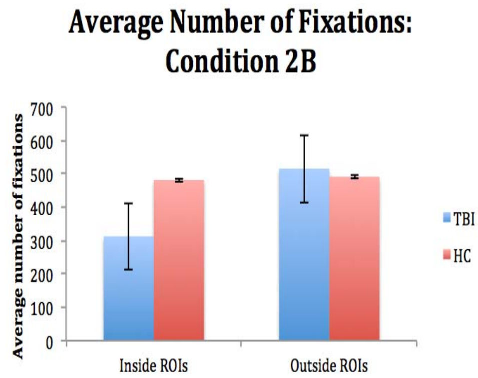

Figure 8. Average number of fixations made on faces throughout the facial affect recognition task in Condition 2B.

An independent samples t-test revealed no significant differences in the total amount of fixations inside and outside of the ROIs between TBI and HC participants.

Fixations in Specific ROIs in Condition 2A

Next, the amount of fixations made in the specific ROIs (eyes, nose, and mouth) in condition 2A (See Table 6 and Figure 9) was examined.

Group	Fixations on Eyes	Fixations on Nose	Fixations on Mouth
TBI	41	21	19
HC	282	74	70

Table 6. Number of fixations on the eyes, nose, and mouth ROIs in Condition 2A.

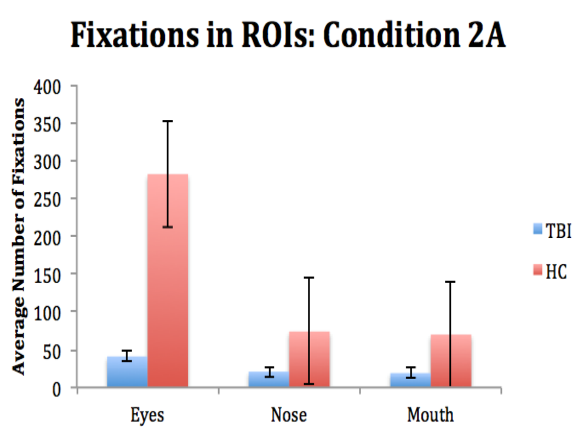

Figure 9. Average number of fixations made in the eyes, nose, and mouth ROIs in Condition 2A.

Fixations in Specific ROIs in Condition 2B

Next, the amount of fixations made in the specific ROIs (eyes, nose, and mouth) in condition 2B (See Table 7 and Figure 10) was examined.

Group	Fixations on Eyes	Fixations on Nose	Fixations on Mouth
TBI	92	163	58
HC	363	86	33

Table 7. Number of fixations on the eyes, nose, and mouth ROIs in Condition 2B.

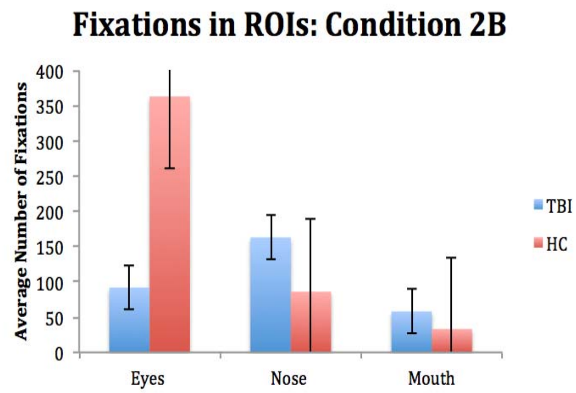

Figure 10. Average number of fixations made in the eyes, nose, and mouth ROIs in Condition 2B.

Dwell Time Inside & Outside of ROIs in Condition 2A

Next, participants' mean dwell time (the amount of time spent looking inside an ROI) in the ROIs and outside of the ROIs (i.e., viewing the non – ROIs) in Condition 2A (See Table 8 and Figure 11) was examined. Participants had 6 seconds to view each face and viewed 30 faces. This equates to participants having 180 seconds in total viewing time.

Group	Dwell Time Inside of ROIs	Dwell Time Outside of ROIs
TBI	14% (25 secs)	86% (155 secs)
HC	56% (100 secs)	44% (80 secs)

Table 8. Dwell time inside and outside of ROIs in Condition 2A.

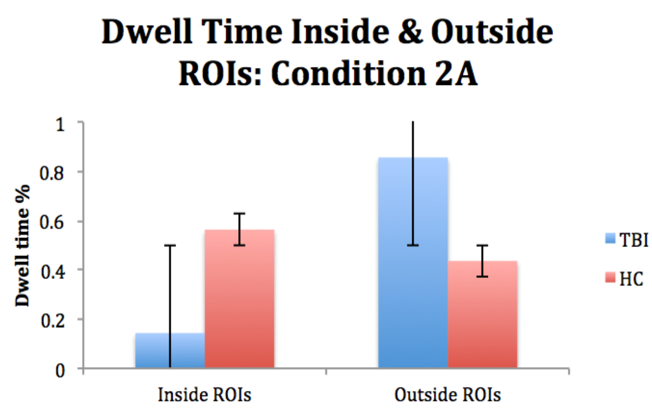

Figure 11. Dwell time inside and outside of the ROIs for Condition 2A

An independent samples t-test was conducted to compare the dwell time (in seconds) in the ROIs for HC and TBI participants in Condition 2A (Full Attention Condition). HC participants (*M* = 101, *SD* = 26.6, *N* = 3) spent more time viewing the ROIs compared to TBI participants (*M* = 25, *SD* = 26, *N* = 2), *t* (3) = 3.12, *p* = .05 (two-tailed), *d* = 2.8, 95% CI [-1.3, 152.62]. An independent samples t-test was conducted to compare the dwell time (in seconds) outside of the ROIs (the non-ROIs) for HC and TBI participants in Condition 2A (Full Attention Condition). HC participants (*M* = 78.85, *SD* = 26.69, *N* = 3) spent less time viewing the non-ROIs compared to TBI participants (*M* = 98.72, *SD* = 18.19, *N* = 2), *t* (3) = -3.12, *p* = .05 (two-tailed), *d* = -2.8, 95% CI [-152.26, 1.3].

Dwell Time Inside & Outside of ROIs in Condition 2B

Participants' dwell time on the ROIs and outside of the ROIs (i.e., viewing the non – ROIs) in Condition 2B. (See Table 9 and Figure 12) was examined as well. Participants had 6 seconds to view each face and viewed 30 faces. This equates to participants having 180 seconds in total viewing time.

Group	Dwell Time Inside of ROIs	Dwell Time Outside of ROIs
TBI	38% (68 secs)	62% (112 secs)
HC	77% (139 secs)	23% (41 secs)

Table 9. Dwell time inside and outside of ROIs in Condition 2B.

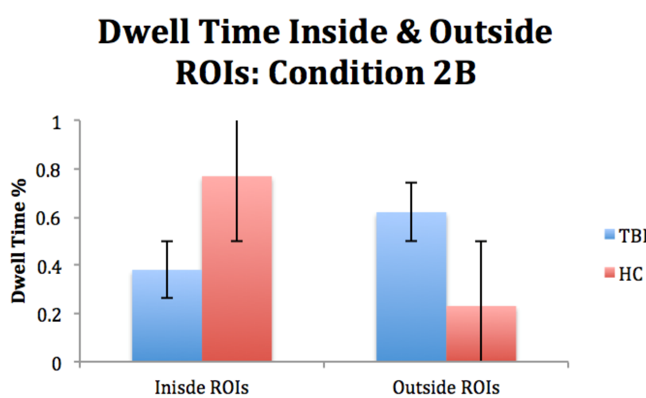

Figure 12. Dwell time inside and outside of the ROIs for Condition 2B.

An independent samples t-test was conducted to compare the dwell time (in seconds) in the ROIs for HC and TBI participants in condition 2B (Divided Attention

Condition). HC participants (*M* = 138.41, *SD* = 12.44, *N* = 3) spent more time viewing the ROIs compared to TBI participants (*M* = 98.72, *SD* = 18.19, *N* = 2), *t* (3) = 2.97, *p* = .05 (two-tailed), *d* = 2.54, 95% CI [-2.77, 82.15]. An independent samples t-test was conducted to compare the dwell time (in seconds) outside of the ROIs (the non-ROIs) for HC and TBI participants in Condition 2B (Divided Attention Condition). HC participants (*M* = 41.58, *SD* = 12.44, *N* = 3) spent less time viewing the non – ROIs compared to TBI participants (*M* = 81.27. *SD* = 18.19, *N* = 2), *t* (3) = -2.97, *p* = .05 (two-tailed), *d* = -2.54, 95% CI [-82.15, 2.77].

Dwell Time Inside & Outside of Specific ROIs in Condition 2A

Next, the specific ROIs that participants were viewing in Condition 2A (Full Attention Condition) (See Table 10 and Figure 13) was investigated.

Group	Dwell Time on Eyes	Dwell Time on Nose	Dwell Time on Mouth	Dwell Time on non - ROIs
TBI	8% (14 secs)	3% (5 secs)	3% (5 secs)	86% (156 secs)
HC	39% (70 secs)	8% (14 secs)	9% (17 secs)	44% (79 secs)

Table 10. Dwell time inside and outside of specific ROIs in Condition 2A.

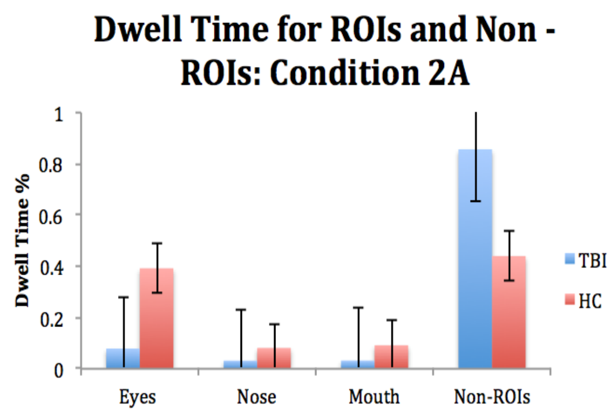

Figure 13. Dwell time on the eyes, nose, mouth, and non – ROIs in Condition 2A.

Dwell Time Inside & Outside of Specific ROIs in Condition 2B

Finally, the specific ROIs that participants were viewing in Condition 2B (Divided Attention Condition) (See Table 11 and Figure 14) was examined.

Group	Dwell Time on Eyes	Dwell Time on Nose	Dwell Time on Mouth	Dwell Time on non - ROIs
TBI	17% (30 secs)	27% (49 secs)	11% (20 secs)	45% (81 secs)
HC	60% (108 secs)	13% (23 secs)	4% (7 secs)	23% (42 secs)

Table 11. Dwell time inside and outside of specific ROIs in Condition 2B.

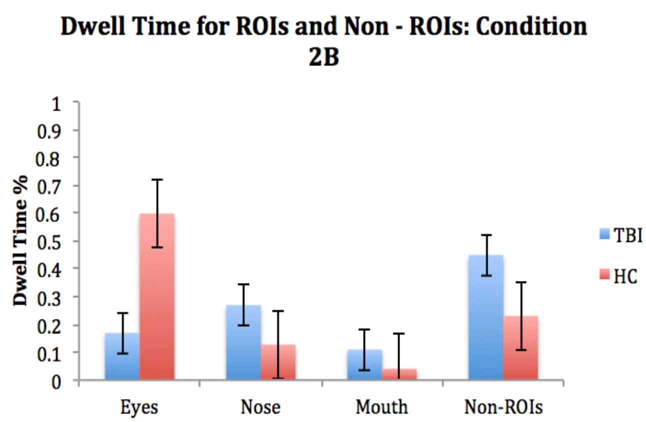

Figure 14. Dwell time on the eyes, nose, mouth, and non – ROIs in Condition 2B.

Experiment 2 – Summary of Findings

Experiment 2 investigated if TBI and HC participants' performance would differ on a task of facial affect recognition. There were significant differences in performance on the facial affect recognition task between TBI and HC participants with TBI participants performing worse than HC participants in Condition 2A and Condition 2B. In Condition 2A, TBI participants identified the emotion correctly 50% of the time and HC participants identified the emotion correctly 88% of the time. In Condition 2B, TBI participants identified the emotion correctly 42% of the time and HC participants identified the emotion correctly 71% of the time (See Figure 3).

In terms of eye-tracking, the investigation was if participants' gaze patterns would differ while viewing emotional facial expressions. There was a significant difference in the amount of total fixations that TBI and HC participants made inside and outside of the ROIs while viewing an emotional face when they had full attention. Compared to HC participants, TBI participants made fewer fixations inside of the ROIs and made more fixations outside of the ROIs (viewing the non-ROIs) when they had full attention during the facial affect recognition task (See Figure 7). Interestingly, there was no significant difference in the amount of total fixations that TBI and HC participants made inside the ROIs and outside of the ROIs while viewing a face when their attention was divided (See Figure 8). Additionally, there was a significant difference in the amount of time TBI and HC participants viewed (dwelled on) inside the ROIs and outside of the ROIs of an emotional face when they had full attention and when their attention was divided during the facial affect recognition task. Compared to HC participants, TBI participants spent more time viewing the non-ROIs (outside of the ROIs) of an emotional face and spent less time viewing the ROIs of an emotional face when they had full attention and when their attention was divided on the facial affect recognition task (See Figures 11 & 12).

There was also differences between the amounts of fixations that TBI participants and HC participants made on specific ROIs (i.e., the eyes nose and mouth ROIs) and found differences in the amount of time TBI participants and HC participants spent viewing specific ROIs. Compared to HC participants, TBI participants made fewer fixations on the eyes, nose, and mouth ROIs when they had full attention on the facial affect recognition task (See Figure 9) but made more fixations on the nose and mouth ROIs when their attention was divided during the facial affect recognition task (See Figure 10). Compared to HC participants, participants with TBI spent less time viewing the eyes, nose, and mouth ROIs when they had full attention on the facial affect recognition task (See Figure 13) but spent more time viewing the nose and mouth ROIs when their attention was divided during the facial affect recognition task (See Figure 14).

Discussion

The overall goal of this project was to investigate why social cognitive difficulties, specifically difficulties in facial affect recognition, exist in individuals with TBI. Experiment 1 investigated the relationship between attention and facial affect recognition abilities. In order to investigate this relationship, we conducted correlations between a measure of facial affect recognition ability and two measures of attention. We found significant positive correlations between the measure of facial affect recognition ability and the two measures of attention. In other words, individuals that performed high on the measure of facial affect recognition ability also performed high on the two measures of attention. Experiment 2 investigated differences in TBI and HC participants' performance on a facial affect recognition task and how participants' gaze patterns differed using eye-tracking. In terms of behavior, we found significant differences on both groups of participants' performance on the facial affect recognition task for Condition 2A (Full Attention Condition) and Condition 2B (Divided Attention Condition). TBI participants were less accurate on the facial affect recognition task compared to HC participants when they had full attention and when their attention was divided on the facial affect recognition task. In terms of eye-tracking, we found that TBI participants made fewer fixations inside of the ROIs and made more fixations outside of the ROIs (viewing the non-ROIs) when they had full attention during the facial affect recognition task compared to HC participants.

Additionally, we found that, compared to HC participants, TBI participants spent more time viewing the non-ROIs (outside of the ROIs) of an emotional face and spent less time viewing the ROIs of an emotional face when they had full attention and when their attention was divided on the facial affect recognition task. We also found differences between the amounts of fixations that TBI participants and HC participants made on specific ROIs (i.e., the eyes nose and mouth ROIs) and found differences in the amount of time TBI participants and HC participants spent viewing specific ROIs. Compared to HC participants, TBI participants made fewer fixations on the eyes, nose, and mouth ROIs when they had full attention on the facial affect recognition task but made more fixations on the nose and mouth ROIs when their attention was divided during the facial affect recognition task. In Condition 2A, participants with TBI spent less time viewing the eyes, nose, and mouth ROIs on the facial affect recognition task compared to HC participants. In Condition 2B, TBI participants spent more time viewing the nose and mouth ROIs on the facial affect recognition task compared to HC participants.

Correlations Between Attention and Facial Affect Recognition

There was a significant positive correlation between a task of facial affect recognition (TOFER) and a task of attention (the Digit Span) and there was a significant positive correlation between the TOFER and the SDMT (a task of attention and processing speed). These results mean that individuals with TBI that perform well on a measure of facial affect recognition also perform high on measures of attention. This indicates that attention may play a role in facial affect recognition abilities. This is an important link because individuals with TBI have difficulties focusing and paying attention (Bonnelle et al., 2011). These findings are consistent with prior research as individuals that have impaired Theory of Mind (ToM) abilities/impaired social cognitive abilities also have impairments in executive functioning, working memory, verbal memory, and visual memory (Kim et al., 2011). In the current study, the TOFER can be considered a measure of facial affect recognition/social cognitive ability as it requires participants to identify emotions (Goeleven et al., 2008). The Digit Span and the SDMT are measures of attention and processing speed but they are also related to executive functioning, working memory, and verbal memory (Wechsler, 1997; Smith, 1982). This is important because if an individual with TBI can not pay attention to an emotional face, then they may misidentify the emotion on that face. Due to the strong positive relationships that Experiment 1 showed, it may be possible to develop therapies and interventions that first focus on improving skills in executive functioning, working memory, and verbal memory, which may in time, improve facial affect recognition abilities.

Behavioral

For the behavioral data, TBI participants were less accurate on the facial affect recognition task compared to HC participants when they had full attention and when their attention was divided. TBI participants were less accurate identifying emotions on the facial affect recognition task (compared to HC participants) when they had full attention because TBI participants have impaired facial affect recognition abilities (Babbage et al., 2011; Croker & McDonald, 2005). TBI participants were less accurate identifying emotions on the facial affect recognition task (compared to HC participants) when their attention was divided because individuals with TBI experience difficulties in focusing/attending to something when their attention is divided (Azouvi et al., 2004). The behavioral data findings are consistent with prior research by Azouvi et al., (2004) and Park et al., (1999), which found that individuals with TBI experiences difficulties in task-switching and score less highly (compared to HC participants) on measures of working memory when their attention was divided.

When each emotion was examined separately, we found that TBI and HC participants also differed on accuracy rates for each emotion for the full and divided attention conditions. In Condition 2A, TBI participants experienced the most difficulty correctly identifying the emotions fear (17% correct), anger (33% correct), and sadness (50% correct) compared to HC participants. In Condition 2B, TBI participants experienced the most difficulty correctly identifying the emotions fear (45% correct), anger (25% correct), disgust (33% correct) and sadness (33% correct). Both groups of participants in both conditions experienced little difficulties in correctly identifying the emotion surprise. These findings are consistent with previous research as individuals with TBI experience difficulties in correctly identifying negative emotions such as fear, anger, and sadness (Croker & McDonald, 2005; Genova et al., 2017). It may be possible that individuals with TBI experience difficulties in correctly identifying these emotions because their friends/family/caregivers may not want to expose them to these negative emotions. Receiving a TBI can be a life changing experience and many individuals close to someone with a TBI may not want their loved one to experience any negativity or hostility after such a traumatic event. In doing so, friends/family/caregivers of individuals with TBI might do their best to not express negative emotions around an individual with TBI.

This study is innovative because it is the first study to examine how divided attention affects facial affect recognition. This is important because individuals with TBI may experience situations in which their attention is divided quite frequently. An individual with TBI may have to divide their attention while talking to/interacting with a family member or a caretaker while simultaneously focusing on the environment around them (i.e., in the home, at a grocery store, at a party, etc.). If an individual with TBI can not successfully divided their attention in a situation like this, then they may risk incorrectly identifying the emotion displayed on their family member's/friend's/caretaker's face and may trigger the individual with TBI to respond in a way that is not congruent with the emotion displayed (i.e., responding to a happy emotional expression with an angry or sad response). This may lead to negative social engagements, which could lead to social isolation in individuals with TBI.

Other factors may have influenced the findings of the current study. For example, cognitive fatigue (i.e., a lack of mental energy that is perceived by the individual during common and usual activities) may have played a role in why TBI participants performed worse than HC participants on the task of facial affect recognition when their attention was divided. In a study conducted by Kohl et al., (2009), functional magnetic resonance imaging (fMRI) was used to assess cognitive fatigue in individuals with TBI. TBI participants and HC participants completed a modified SDMT while having their brain activity monitored by fMRI. They found that TBI participants exhibited increased brain activity, which represented increased cerebral effort. This increased cerebral effort may have manifested as cognitive fatigue. Our findings relate to Kohl et al., (2009) because TBI participants may have experienced an increase in brain activity during Condition 2B (Divided Attention Condition) as they had to identify the emotion on the face presented while simultaneously identifying the tone being played. These two tasks combined may have resulted in an increase in brain activity for TBI participants and may have led them to become cognitively fatigued in Condition 2B (Divided Attention Condition) and may have made it extremely difficult to focus and correctly identify the emotions displayed on the faces during the facial affect recognition task.

Eye – Tracking

TBI participants made fewer fixations inside of the ROIs and made more fixations outside of the ROIs (viewing the non-ROIs) when they had full attention during the facial affect recognition task compared to HC participants. Also, compared to HC participants, TBI participants spent more time viewing the non-ROIs (outside of the ROIs) of an emotional face and spent less time viewing the ROIs of an emotional face when they had full attention and when their attention was divided on the facial affect recognition task. These findings are consistent with another specialized population – Autism Spectrum Disorder (ASD). Individuals with ASD tend to make more fixations and spend more time viewing non-critical regions of the face (ears, forehead, hair, other facial area, etc.) and tend to make fewer fixations and spend less time viewing the critical regions of the face (i.e., eyes, nose, and mouth) compared to HC participants (Boraston & Blakemore, 2007; Dalton et al., 2005).

We found differences between the number of fixations that TBI participants and HC participants made on specific ROIs (i.e., the eyes nose and mouth ROIs) in the full and divided attention conditions and found differences in the amount of time TBI participants and HC participants spent viewing specific ROIs in both the full and divided attention conditions. Both TBI and HC participants in Condition 2A fixated on more frequently and spent more time viewing the eyes ROI compared to the other ROIs (nose and mouth). This result is consistent with other research because HC individuals and TBI individuals tend to view the eyes of others during conversations (Turkstra, 2005). There are other tests that measure social cognitive abilities/facial affect recognition abilities. One test in particular, the Reading the Mind in the Eyes test, is a measure of social cognitive abilities and facial affect recognition abilities. In this test, participants view static images of just the eyes region and identify which emotion a full emotional face would be displaying based on the information provided by the eyes region (Baker et al., 2014). Previous research shows that individuals with TBI perform worse on this test compared to HC participants (Baker et al., 2014). In this study, both TBI and HC participants fixated on the eyes ROI more often and viewed the eyes ROI for a longer period of time compared to the other critical ROIs (i.e., nose and mouth). However, TBI participants fixated on the eyes ROI less often and viewed the eyes ROI for a lesser amount of time compared to HC participants. This suggests that the eyes may contain key information that is useful when attempting to correctly identify an emotional face, but TBI participants may not retain/utilize this key information as well as HC participants do while attempting to correctly identify an emotion displayed on a face.

These results are important because, until this study was conducted, we did not know exactly where and for how long participants with TBI fixated on an emotional face. Many studies that investigate facial affect recognition only informed us that participants with TBI have difficulties correctly identifying emotions. This study is the first of its kind to investigate exactly where (i.e., eyes, nose, mouth, or non-ROIs) and for how long that TBI participants fixated on an emotional face when they had full attention on a facial affect recognition task and when their attention was divided on a facial affect recognition task. The information gained from this study can be used to inform/develop treatments and interventions for individuals with TBI that suffer from poor facial affect recognition abilities. By using eye-tracking, we can understand where and for how long an individual with TBI is fixating on an emotional face, and then try to correctly alter TBI individuals' gaze patterns. For example, if an individual with TBI is fixating on a non-critical ROI (ears, hair, forehead, other facial area, etc.) for too long of a time period, then we can inform the individual of this and attempt to switch their focus to a critical ROI on the face (eyes, nose, mouth). By consistently "training" individuals with TBI to change their fixation patterns from non-critical ROIS to critical ROIs, we may be able to improve facial affect recognition abilities in TBI individuals.

One finding that stood out was how participants' number of fixations on the ROIs and outside the ROIs (viewing the non-ROIs) did not significantly differ in Condition 2B (Divided Attention Condition) but their total dwell time significantly differed in Condition 2B (Divided Attention Condition). This could be explained by the idea that dwelling on an emotional face (i.e., viewing it) may be different than fixating (i.e., concentrated viewing) on an emotional face. This difference could also be explained through attention. TBI participants may have been able to dwell on the ROIs of an emotional face but having their attention divided made it more difficult for them to actually fixate and concentrate on the specific ROIs and the information gained from viewing them. For example, an individual with TBI may have been able to view the ROIs of an emotional face but they may not have been able to gain information from the ROIs (i.e., they may have looked at a face's open mouth but not associated it with the emotion surprise). This suggests that there may be some area in the brain/process that occurs in the brain that enables individuals to switch from just viewing an area on the face, to fixating on that area and gaining information from it. In individuals with TBI, this brain area/brain process may be damaged or may not function as efficiently as a healthy individual's area/process. This also suggests that this area/process is interfered with when attention is divided, even more with an individual with TBI.

Another interesting finding was that, in Condition 2B, TBI participants fixated more frequently and spent more time viewing the nose and mouth ROIs on the facial affect recognition task compared to HC participants. This might have occurred because the division of attention in Condition 2B led TBI participants to focus on an ROI that may not have contained the most informative facial information. For example, the eyes ROI may have contained the best facial information for participants to view and utilize in order to correctly identify an emotion on a face. With divided attention, TBI participants may have lost/shifted their focus from the eyes (which may have contained the most important facial information to correctly identify an emotion on a face) to the nose and mouth (which may have contained less useful facial information to correctly identify an emotion on a face).

Limitations

Experiment 2 had a small sample size (6 participants for behavioral and 5 participants for eye-tracking). We still believe that the results are valid but it is important to understand that the results, especially significance, may be due to a lack of participants. The lack of participants was due to difficulties in recruiting as many potential participants were over the age range (over 50 years old). The sample also consisted of 2 males with TBI and 4 female HC participants. Gender may have been a reason there were significant differences but we did not expect men and women to differ on a test of facial affect recognition abilities as previous research states that there are no differences (Hoffmann et al., 2010). Another limitation is the stimuli in this study may have lacked ecological validity. The stimuli in this study were static images of faces displaying different emotions. In more real-world situations, an individual is usually talking to or interacting with another person while trying to correctly identify the emotion they are displaying on their face. The static images we used in this study may not have best represented this situation.

Future Directions

This experiment will be conducted again with an adequate sample size, with participants matched across gender, and with the addition of participants with Multiple Sclerosis (MS). Adding another specialized population to this experiment will inform us on how another specialized population compares to individuals with TBI in terms of eye-tracking and behavior. Adding MS participants will enable us to determine if TBI individuals and MS individuals have the same or different gaze patterns. Additionally, adding MS participants will allow us to understand if they fixate longer/shorter on one area of the face compared to TBI participants. Finally, adding MS participants will enable us to understand what emotions they misidentify compared the TBI participants. This experiment will also add Theory of Mind (ToM) measures in order to investigate if participants that are impaired on facial affect recognition also have impaired ToM abilities.

Future experiments will utilize measures with greater ecological validity than static images of faces displaying emotions. In order to increase the ecological validity of the study we will use Virtual Reality Technology (VR). VR is a computer-generated scenario that simulates a realistic experience. VR will be used to simulate talking to and interacting with someone while simultaneously trying to correctly identify what emotion the individual is displaying on his or her face. We will also add different levels of distraction (low distraction, medium distraction, and high distraction) in order to determine what level of distraction and when the level of distraction negatively influences a participant's performance on the facial affect recognition task. This will enable us to understand if one group of participants has more difficulty identifying emotions compared to another group of participants on a certain level of distraction (i.e., TBI participants may perform worse than MS participants on the facial affect recognition task during the medium distraction condition but MS participants may perform better than TBI participants on the facial affect recognition task during the low distraction condition).

References

Arizpe, J., Kravitz, D. J., Walsh, V., Yovel, G., & Baker, C. I. (2016). Differences in looking at own-and other-race faces are subtle and analysis-dependent: An account of discrepant reports. *PLoS One*, *11*(2), e0148253.

Azouvi, P., Couillet, J., Leclercq, M., Martin, Y., Asloun, S., & Rousseaux, M. (2004). Divided attention and mental effort after severe traumatic brain injury. *Neuropsychologia*, *42*(9), 1260-1268.

Babbage, D. R., Yim, J., Zupan, B., Neumann, D., Tomita, M. R., & Willer, B. (2011). Meta-analysis of facial affect recognition difficulties after traumatic brain injury.

Baker, C. A., Peterson, E., Pulos, S., & Kirkland, R. A. (2014). Eyes and IQ: A meta-analysis of the relationship between intelligence and “Reading the Mind in the Eyes”. *Intelligence*, *44*, 78-92.

Basford, J. R., Chou, L. S., Kaufman, K. R., Brey, R. H., Walker, A., Malec, J. F., ... & Brown, A. W. (2003). An assessment of gait and balance deficits after traumatic brain injury. *Archives of physical medicine and rehabilitation*, *84*(3), 343-349.

Bergfeldt, U., Borg, K., Kullander, K., & Julin, P. (2006). Focal spasticity therapy with botulinum toxin: effects on function, activities of daily living and pain in 100 adult patients. *Journal of Rehabilitation Medicine*, *38*(3), 166-171.

Bonnelle, V., Leech, R., Kinnunen, K. M., Ham, T. E., Beckmann, C. F., De Boissezon, X., ... & Sharp, D. J. (2011). Default mode network connectivity predicts sustained attention deficits after traumatic brain injury. *Journal of Neuroscience*, *31*(38), 13442-13451.

Boraston, Z., & Blakemore, S. J. (2007). The application of eye‐tracking technology in the study of autism. *The Journal of physiology*, *581*(3), 893-898.

Bruns, J., & Hauser, W. A. (2003). The epidemiology of traumatic brain injury: a review. *Epilepsia*, *44*(s10), 2-10.

Cicerone, K., Levin, H., Malec, J., Stuss, D., & Whyte, J. (2006). Cognitive rehabilitation interventions for executive function: moving from bench to bedside in patients with traumatic brain injury. *Journal of cognitive neuroscience*, *18*(7), 1212-1222.

Croker, V., & McDonald, S. (2005). Recognition of emotion from facial expression following traumatic brain injury. *Brain Injury*, *19*(10), 787-799.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., ... & Davidson, R. J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature neuroscience*, *8*(4), 519.

Dimoska, A., McDonald, S., Pell, M. C., Tate, R. L., & James, C. M. (2010). Recognizing vocal expressions of emotion in patients with social skills deficits following traumatic brain injury. *Journal of the international neuropsychological Society*, *16*(2), 369-382.

Ekman, P., & Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of personality and social psychology*, *17*(2), 124.

Genova, H. M., Genualdi, A., Goverover, Y., Chiaravalloti, N. D., Marino, C., & Lengenfelder, J. (2017). An investigation of the impact of facial affect recognition impairments in moderate to severe TBI on fatigue, depression, and quality of life. *Social neuroscience*, *12*(3), 303-307.

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The Karolinska directed emotional faces: a validation study. *Cognition and emotion*, *22*(6), 1094-1118.

Henry, J. D., Cowan, D. G., Lee, T., & Sachdev, P. S. (2015). Recent trends in testing social cognition. *Current opinion in psychiatry*, *28*(2), 133-140.

Hoffmann, H., Kessler, H., Eppel, T., Rukavina, S., & Traue, H. C. (2010). Expression intensity, gender and facial emotion recognition: Women recognize only subtle facial emotions better than men. *Acta psychologica*, *135*(3), 278-283.

Honan, C. A., McDonald, S., Sufani, C., Hine, D. W., & Kumfor, F. (2016). The awareness of social inference test: Development of a shortened version for use in adults with acquired brain injury. *Clinical Neuropsychologist*, *30*(2), 243–264.

Johnson, V. E., Stewart, W., & Smith, D. H. (2010). Traumatic brain injury and amyloid-β pathology: a link to Alzheimer's disease? *Nature Reviews Neuroscience*, *11*(5), 361-370.

Kim, H. S., Shin, N. Y., Jang, J. H., Kim, E., Shim, G., Park, H. Y., ... & Kwon, J. S. (2011). Social cognition and neurocognition as predictors of conversion to psychosis in individuals at ultra-high risk. *Schizophrenia research*, *130*(1), 170-175.

Kohl, A. D., Wylie, G. R., Genova, H. M., Hillary, F. G., & Deluca, J. (2009). The neural correlates of cognitive fatigue in traumatic brain injury using functional MRI. *Brain injury*, *23*(5), 420-432.

Lyeth, B. G., Jenkins, L. W., Hamm, R. J., Dixon, C. E., Phillips, L. L., Clifton, G. L., ... & Hayes, R. L. (1990). Prolonged memory impairment in the absence of hippocampal cell death following traumatic brain injury in the rat. *Brain research*, *526*(2), 249-258.

McDonald, S., Flanagan, S., Rollins, J., & Kinch, J. (2003). TASIT: A new clinical tool for assessing social perception after traumatic brain injury. *The Journal of head trauma rehabilitation*, *18*(3), 219-238.

Park, N. W., Moscovitch, M., & Robertson, I. H. (1999). Divided attention impairments after traumatic brain injury. *Neuropsychologia*, *37*(10), 1119-1133.

Rodriguez-Paez, A. C., Brunschwig, J. P., & Bramlett, H. M. (2005). Light and electron microscopic assessment of progressive atrophy following moderate traumatic brain injury in the rat. *Acta neuropathologica*, *109*(6), 603-616.

Roozenbeek, B., Maas, A. I., & Menon, D. K. (2013). Changing patterns in the epidemiology of traumatic brain injury. *Nature Reviews Neurology*, *9*(4), 231-236.

Rosenfeld, J. V., Maas, A. I., Bragge, P., Morganti-Kossmann, M. C., Manley, G. T., & Gruen, R. L. (2012). Early management of severe traumatic brain injury. *The Lancet*, *380*(9847), 1088-1098.

Smith A; *Symbol Digit Modalities Test Manual*. Los Angeles, CA: Western Psychological Services; 1982.

Stocchetti, N., & Zanier, E. R. (2016). Chronic impact of traumatic brain injury on outcome and quality of life: a narrative review. *Critical Care*, *20*(1), 148.

Struchen, M. A., Pappadis, M. R., Sander, A. M., Burrows, C. S., & Myszka, K. A. (2011). Examining the contribution of social communication abilities and affective/behavioral functioning to social integration outcomes for adults with traumatic brain injury. *The Journal of head trauma rehabilitation*, *26*(1), 30-42.

Teasdale, G., Murray, G., Parker, L., & Jennett, B. (1979). Adding up the Glasgow coma score. In *Proceedings of the 6th European Congress of Neurosurgery* (pp. 13-16). Springer Vienna

Thurman, D. J., Alverson, C., Dunn, K. A., Guerrero, J., & Sniezek, J. E. (1999). Traumatic brain injury in the United States: a public health perspective. *The Journal of head trauma rehabilitation*, *14*(6), 602-615.

Turkstra, L. S. (2005). Looking while listening and speaking: Eye-to-face gaze in adolescents with and without traumatic brain injury. *Journal of Speech, Language, and Hearing Research*, *48*(6), 1429-1441.

Wechsler D; *Wechsler Memory Scale - Third Edition*. San Antonio, TX: The Psychological Corporation; 1997.

Wells, L. J., Gillespie, S. M., & Rotshtein, P. (2016). Identification of emotional facial expressions: effects of expression, intensity, and sex on eye gaze. *PloS one*, *11*(12), e0168307.

Zgaljardic, D. J., Seale, G. S., Schaefer, L. A., Temple, R. O., Foreman, J., & Elliott, T. R. (2015). Psychiatric disease and post-acute traumatic brain injury. *Journal of neurotrauma*, *32*(23), 1911-1925.

Supplemental Figures & Illustrations

Test		TOFER Total	Digit Span (Forward)	Digit Span (Backward)	Digit Span Total	SDMT Total
TOFER	Pearson Correlation	1	.44*	.36*	.41*	.57**
Total	Sig. (1-tailed)		.011	.034	.017	.001
	N	28	26	26	26	28
Digit Span	Pearson Correlation	.44*	1	.70**	.69**	.22
(Forward)	Sig. (1-tailed)	.011		.00	.00	.13
	N	26	26	26	26	26
Digit Span	Pearson Correlation	.36*	.70**	1	.87**	.47**
(Backward)	Sig. (1-tailed)	.034	.00		.00	.007
	N	26	26	26	26	26
Digit Span	Pearson Correlation	.41*	.69*	.87**	1	.50**
Total	Sig. (1-tailed)	.017	.00	.00		.004
	N	26	26	26	26	26
SDMT	Pearson Correlation	.57**	.22	.47**	.50**	1
Total	Sig. (1-tailed)	.001	.13	.007	.004	
	N	28	26	26	26	28

Illustration 1. Bivariate correlation matrix between the TOFER, Digit Span, and SDMT. * = Correlation is significant at the 0.05 level (1-tailed).
** = Correlation is significant at the 0.01 level (1-tailed).