VISUAL SCANNING AND ITS RELATIONSHIP TO FACIAL EMOTION RECOGNITION IN INDIVIDUALS WITH TRAUMATIC BRAIN INJURIES

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Abstract

Objective: Mounting research evidences a relationship between decreased social integration and reduced facial emotion perception (FEP) after traumatic brain injury (TBI). More research is needed regarding the components that contribute to efficient FEP. Given the relationship between FEP, and the visual scanning of emotional faces in other patient populations, a relationship between visual scanning and the accurate and fast identification of facial emotions was hypothesized. Two FEP studies were undertaken to test this overall hypothesis. Study 1 aimed to examine the visual scanning of emotional faces under non-speeded and speeded conditions in a sample of typically developing undergraduate students. The goal of Study 2 was to examine the visual scanning of emotional faces in a convenience sample of patients with TBI in comparison to that of a subset of control participants from Study 1. Scan patterns and their relationship with each of reaction time and accuracy were examined.

Participants and Methods: Study 1 included a sample of 33 (9 males) undergraduate students. Study 2 included 17 typically developing controls (9 males) and 10 patients with TBI (7 males). Both studies employed a novel voice-key eye tracking paradigm that included a large number of faces modeling neutral or one of the six basic emotions (i.e., angry, disgusted, fearful, happy, sad, surprised). Participants responded verbally, labeling the emotion in each trial and reaction time data were collected. Eye tracking measures were obtained to examine how the emotional faces were scanned, including the amount of time spent on features of the face (i.e., eye region, nose region, mouth region) and less salient features of the face (i.e., the remainder of the face).

Results: Consistent with previous studies, Study 1 illustrates that typically developing adults attend to the eyes of emotional faces more than the nose or the mouth. On the speeded task, mean response times among the typically developing undergraduates were 1-3 seconds faster than the

reaction times previously reported in button-press studies. The results of Study 1 illustrate that number of fixations made to the eyes and nose of emotional faces was related to reaction time among the typically developing control group. Emotion had a significant effect on visual scanning, reaction time and accuracy in Study 1 and Study 2. In Study 2, patients with TBI attended proportionately less to the eyes and proportionally more to less salient features of emotional faces relative to controls (between-group effects, $p < .05$). The TBI group was significantly slower to label emotional faces than the control group and significantly less accurate, overall (between-group effect, $p < .05$). Attending to the lower part of the face was negatively related to accuracy in both groups. The results of Study 2 also demonstrate that time of first fixation to the eyes was positively related to reaction time among the group with TBI.

Conclusions: Overall, the findings demonstrate that typically developing adults' scanning of emotional faces is emotion-specific. Although additional research is needed, this dissertation provides initial evidence that the TBI convenience sample scanned the emotional faces differently than the typically developing group, particularly during the speeded task. Further, the results suggest that visual scanning is related to FEP accuracy and the speed at which typically developing adults and those with TBI label emotional faces. These findings may provide new avenues for FEP assessment and treatment research.

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Chapter 1

General Introduction and Literature Review

An estimated one to two million North Americans sustain a traumatic brain injury (TBI) each year (Frost, Farrer, Primosch, & Hedges, 2013). Nonetheless, the availability of treatments to address disability is limited. This may be due in part to a lack of understanding of the mechanisms that underlie the impairments that contribute to disability. Decreased facial emotion perception (FEP) accuracy is one well-documented impairment following moderate-severe TBI. It has been associated with reduced every-day function and quality of life. Recent research suggests that visual scanning deficits may play a causal role in FEP deficits. In order to harness this mechanistic understanding in the design of novel interventions, it is critical to gain a better understanding of the visual scanning mechanisms of facial emotion perception in typically developing adults. Such an understanding can then be harnessed to develop treatments for TBI-related FEP deficits. The overarching aims of this dissertation were (i) to gain a better understanding of how typically developing adults scan emotional faces, and (ii) to explore the visual scanning of emotional faces in a convenience sample of patients with moderate-severe TBIs in order to generate hypotheses for future TBI research on this topic. The intended application of this research is to support the development of novel treatment approaches that enhance FEP and social function, in part through the development of efficient visual scanning of emotional faces.

Before discussing the specific objectives and hypotheses of the dissertation, this chapter provides a summary of the relevant literature. This will include a brief overview of the following topics: TBI severity and outcomes, social functioning and FEP after TBI,

two models of emotional recognition, FEP research and paradigms including findings from typically developing samples, and FEP findings from patients with TBI and other neurological conditions. Through this review, relevant gaps in the literature are identified.

Traumatic Brain Injury: Severity and Outcomes

TBI is broadly defined as a brain injury due to externally inflicted trauma (National Institute of Health (NIH) Consensus Development Panel, 1999). Recently, the International and Interagency Initiative toward Common Data Elements for Research on Traumatic Brain Injury (Menon, Schwab, Wright, Maas et al., 2010) provided the following definition: (a) an alteration in brain function, or other evidence of brain pathology, (b) caused by an external force. This definition states that an alteration in brain function includes the following clinical evidence: any period of loss of consciousness (i.e., LOC), or decreased consciousness, any loss of memory for events immediately before (i.e., retrograde amnesia), or after the injury (i.e., post-traumatic amnesia; PTA), neurologic deficits (weakness, loss of balance, change in vision, dyspraxia paresis/paralysis, sensory loss, aphasia, etc.), or any alteration in mental state at the time of the injury (e.g., confusion, disorientation, slowed thinking, etc.).

According to Menon et al.'s (2010) definition, and with regard to the criteria listed above, evidence of brain pathology may include "neuroradiologic, or laboratory confirmation" of brain damage, and an external force may include: the head being struck by an object, the head striking an object, the brain undergoing an acceleration / deceleration movement without direct external trauma to the head, a foreign body penetrating the brain, forces generated from events such as a blast or explosion, or another to-be-defined force. The acceleration-deceleration forces that accompany a

traumatic event (e.g., motor vehicle accident, fall) cause the brain to compress and rebound against the surface of the skull. This makes regions of the brain in close proximity to bony protrusions of the skull, namely in the frontal and anterior temporal regions, especially vulnerable to injury (Bigler, 2001; Bigler et al., 2007; Blumenfeld, 2002; 2010, Roosenbeek, Maas, & Menon, 2013).

TBI can result in not only focal, localized injuries (e.g., hemorrhagic lesions, contusions), but also diffuse damage that disrupts neuronal connections throughout the brain (Bigler et al., 2001; Cicerone et al., 2006; Levine et al., 2008; Meythaler, Peduzzi, Eleftheriou, & Novack, 2001). Shearing forces can lead to diffuse axonal injury (DAI) and cause widespread and variable white matter damage. Rapid, brief acceleration/deceleration forces that occur at the time of impact (e.g., motor vehicle accidents) cause axons to rupture, often at the white-grey matter juncture (i.e., boundary; Hayes et al., 2016; Meythaler et al., 2001). This is often accompanied by petechial hemorrhaging (i.e., traumatic microbleeds) within the white matter (Blumenfeld, 2010; Schield et al., 2006).

As indicated in Menon et al.'s (2010) definition, TBI diagnosis is established using multiple indicators. These include the Glasgow Coma Scale (GCS: Teasdale and Jennett, 1974), length of coma (Lezak, Howieson, Loring, Hannay, & Fischer, 2004), length of PTA (Russell, 1932; Levin et al., 1979), and presence or absence of consciousness at the time of injury (Frost et al., 2013). The Glasgow Coma Scale ranges from 3 to 15, with scores of 3-5 representing very severe TBI, scores of 6-8 representing severe TBI, scores of 9-12 representing moderate TBI and scores of 13-15 representing mild TBI. The score is composed of the following three subscores including: eye-

opening, best verbal response, and best motor response. In addition to the criteria illustrated on Figure 1, the best motor response category currently includes Flexing-abnormal and Flexing-withdrawal, for a total of six possible "points". A TBI with a GCS of 13-15 with positive imaging is classified as a "complicated mild TBI" (Hayes et al., 2016). Patients with mild, or mild-complicated TBI were excluded from this dissertation study.

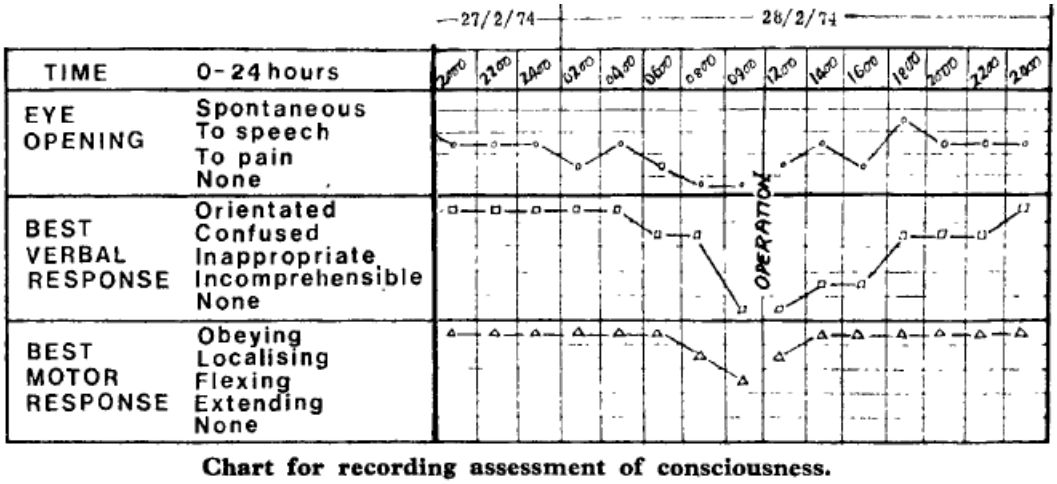

Figure 1. An example of an assessment of consciousness for a patient with TBI based on the Glasgow Coma Scale (Teasdale & Jennett, 1974).

There are both benefits and drawbacks associated with length of PTA as an indicator of severity. One of its main benefits is that duration of PTA has been shown to be predictive of neuropsychological outcome, independent living status, and return to work after TBI (Lezak et al., 2004). However, relative to GCS and the presence / absence of consciousness, it is limited in that patients need to be responsive before it can be evaluated. Therefore, one disadvantage is that self-reported PTA may be affected by LOC (Menon et al., 2010). Accuracy of PTA estimates can also be affected by fluctuations in communication (e.g., aphasia, Table 5, participant # 03p). PTA of 1-24

hours falls into the moderate range while PTA of 1-7 days falls into the severe range and PTA > 7 days falls into the very severe range (Lezak et al., 2004).

Coma is a state of unconsciousness. Lezak et al. (2004) define coma as not obeying commands, not uttering words, and not opening eyes. The longer the coma, the greater the severity, with mild coma being $\leq$ 20 minutes, moderate coma being >20 minutes and $\leq$ 6 hours, and severe coma being $\geq$ 6 hours. Duration of loss of consciousness has several benefits, first and namely, it is relatively simple and reliable for both emergency and acute care medical staff to use and can be used repeatedly. It is also a good predictor of outcome. Nonetheless, it is not without drawbacks, including its vulnerability to intoxication, medication and other injuries.

With respect to overall prevalence, by 2020, TBI is forecast to be the 3rd leading cause of disability and death worldwide (Hyder, Wunderlich, Puvanachandra, Gururajc, Kobusingyed, 2007; Murray & Lopez, 1997). TBI has an annual incidence of approximately 50,000 new cases per year in Canada (Statistics Canada, 1996). The incidence is approximately 1.4-2 million new cases annually in the United States (Frost et al., 2013, Katz et al., 2007; NIH Consensus Conference, 1999; Povlishock & Katz, 2005). Zaloshnja, Miller, Langlois, and Selassie (2008)'s analysis suggests that the prevalence of individuals living with long-term TBI-related disability is approximately 1.1%. This suggests that approximately 386,760 Canadians are living with the effects of moderate to severe TBI. This is approximately equal to prevalence of stroke in Canada (Public Health Agency of Canada, 2009). However, unlike stroke and several other conditions that impact older adults, TBI is a leading cause of death and disability in adults 45 years of age and younger. The incidence of TBI is highest among individuals aged 15-24 and

those older than 75 years of age (Kraus & Chu, 2005). Frost et al.'s (2013) recent meta analysis confirms that men have twice the odds of sustaining a TBI relative to women.

The costs associated with TBI are substantial. In Canada, TBI is estimated to cost society and individuals approximately $3-4 billion, annually. In the United States, it is estimated to cost approximately $37 billion annually, including $60 million in direct medical costs and indirect loss-of-productivity costs. The lifetime cost per patient is estimated to be $ 600,000-$1,875,000 (Finkelstein et al., 2006). Approximately 43% of those hospitalized with TBI experience long-term disability.

Social Functioning and Facial Emotion Perception after TBI: The Clinical Problem

Evidence indicates that although many individuals with TBI regain physical, cognitive, and basic language functioning, impaired social skills often impede effective participation at home, work, and school. This impacts relationships with family, colleagues and friends (Spell & Frank, 2000). Importantly, social isolation has been reported to be the single biggest problem 10-15 years post injury (Thomsen, 1984; Koskinen, 1998). Social integration is an important predictor of life satisfaction and quality of life among individuals with TBI (Corrigan, Bogner, Mysiw, Clinchot, & Fugate, 2001, Spell & Frank, 2000). In addition to improving quality of life, social support acts as a protective factor against the development of depression and anxiety. It also promotes effective adaptation during periods of transition (Arnold Oatley & Wintre, 2006).

FEP is one of the essential components of inter-personal communication (Spell & Frank, 2000), and a predictor of social skills in several populations (e.g., Leppanen &

Hietanen, 2001; Mostow, Izard, Fine, & Trentacosta, 2002). FEP refers to the ability to accurately perceive and appreciate affective information from facial expressions (Adolphs, 2002a). Findings among typically developing children (Leppanen & Hietanen, 2001; Mostow, Izard, Fine, & Trentacosta 2002), individuals with acquired brain injuries (Knox & Douglas, 2009; Hornak, Rolls, & Wade, 1996; Mancuso, Magnani, Cantagallo, Rossi, Capitani, Galletti, …Robertson, 2015), adults with Asperger's syndrome (Corden, Chivers & Skuse, 2008), and people with neuro-behavioural conditions (Kats-Gold, Besser, & Priel, 2007; Muesser, Doonan, Penn, Blanchard, Bellack, Nishith et al, 1996) show a relationship between the ability to recognize facial emotions in others and indices of social functioning (e.g., peer acceptance; social competence, social anxiety). Further, Mostow et al. (2002) found that early emotion recognition abilities predict subsequent social skills.

FEP is frequently compromised in people with TBI (Green, Turner & Thompson, 2004; McDonald et al. 2008). A large body of research indicates that TBI compromises people's ability to identify facial emotions accurately (e.g., Bornhofen & McDonald, 2008a; Prigatano & Pribram, 1982; Radice-Neumann, Zupan, Babbage & Willer, 2007; Rosenberg, McDonald, Dethier, Kessels, & Westbrook, 2014). Prigatano and Pibram (1982) provided one of the seminal papers on brain injury and FEP. This study includes a heterogeneous sample of participants with closed head injury and more focal injuries (i.e., tumor, cardiovascular injuries) and indicates that patients with closed head injuries, including DAI, frequently exhibit more severe impairments in FEP accuracy than patients with focal injuries.

Since this seminal paper, mounting evidence indicates that individuals with TBI are at increased risk for FEP impairments in both the subacute (Green, et al., 2004; Ietswaart et al., 2008) and chronic stages of injury (McDonald, Bornhofen & Hunt, 2009; McDonald, 2013). Consistent with findings from several neurological conditions (e.g., autism spectrum disorder; Corden et al., 2008; Pelphrey et al., 2002), the perception of negative emotions (e.g., anger, disgust, fear, sadness) is frequently more impaired following TBI than the perception of positive emotion (e.g., happiness; Hornak et al., 2003; Bornhofen & McDonald, 2008a; McDonald et al., 2009). For example, Hopkins et al. (2002) found that participants with TBI had the most difficulty identifying fear, anger and disgust relative to controls, while Croker and McDonald (2005) found that they were relatively more impaired at identifying sadness, fear, and disgust. As in other clinical populations, neutral and the six basic or universal emotions (i.e., anger, disgust, fear, happiness, sadness, surprised; Ekman, 1993) are the most widely studied emotional expressions (Bornhofen & McDonald, 2008a). As most studies of FEP have employed only one positive vs. multiple negative emotions, it is important to note that the relative difficulty in identifying negative facial emotions may be attributable to this methodological confound (Ebner, He, & Johnson, 2011).

Given the complex nature of emotional face processing in normative situations, and the diffuse nature of TBI (Hayes et al., 2016), several TBI-related cognitive impairments have been found to impact FEP following TBI (e.g., memory, executive functioning, processing speed; Allerdings & Alfano, 2006; Bornhofen & McDonald, 2008a; Ietswaart et al., 2008). Of particular relevance to the current project's research objectives, MacDonald (2013) explains that reduced processing speed commonly

contributes to reduced FEP accuracy in this population. Ietswaart, Milders, Crawford, Currie, and Scott's (2008) behavioural study of patients with TBI is one of the few to measure FEP accuracy under speeded conditions. In their study, controlling for processing speed differences (i.e., using WAIS digit-symbol score as a covariate) eliminated TBI-orthopedic injury control group differences in FEP accuracy, but not group differences in emotional face labeling reaction time. This underscores the influence of processing speed on FEP.

Approximately 87% of individuals with TBI experience impairments in the ability to rapidly process mental information (Meythaler et al., 2001). Several studies document the relationship between processing impairments, and diffuse axonal injury, making reduced processing speed one of the cardinal features of TBI (Farbota, Bendlin et al., 2012; Meythaler et al., 2001). At 1-year post-injury, participants with TBI exhibit processing speed scores that are 1-1.5 standard deviations below average (Christensen et al., 2008). In addition to the effects of diffuse axonal injury, Stuss's (2011) review indicates that frontal lobe damage is often related to processing speed impairments, many of which persist for several years post-injury. Levine et al. (2008) report that white matter loss is apparent throughout the brain following TBI: however, white matter volume loss is greater in the right hemisphere than the left hemisphere. Lesion studies suggest that right-hemisphere damage impacts FEP more than left hemisphere damage (Adolphs et al., 2000). Taken together, evidence of pervasive speed of processing impairments and the importance of speed of processing to FEP accuracy (Bornrrhofen & McDonald, 2008a; Ietswaart et al., 2008; McDonald, 2013) suggests that it is important to assess FEP under both non-speeded and speeded conditions. Therefore, an understanding of FEP

under both non-speeded and speeded conditions following TBI may lead to treatments to obviate psychosocial dysfunction.

To date, the underlying mechanisms of FEP are not fully understood. Such an understanding could lead to treatments that reduce FEP impairments, and thereby improve the quality of life of people with TBI. Adolphs, Gosselin, Buchanan, Tranel, Schyns, and Damasio's (2005) seminal case study of a woman with bilateral amygdala damage demonstrated that visual scanning of emotional faces is one potential mechanism underlying accurate and efficient FEP. Further, as detailed below, several studies in non-TBI patient samples suggest that visual scanning of emotional faces is often compromised in patients with a variety of neurological conditions that experience FEP accuracy deficits. Thus, this dissertation focuses on gaining a better understanding of the visual scanning of emotional faces in typically developing adults and determining whether aberrant visual scanning of emotional faces may contribute to FEP impairments following TBI.

Two Models of Emotional Recognition

Frontotemporal injuries are likely major contributors to the emotional impairments that often accompany TBI because many of the neural structures involved in emotional processing are located in the frontotemporal regions of the brain, including the amygdala, insula and orbitofrontal cortex (Adolphs, 2002, 2009; Bornhofen & McDonald, 2008; Fisher et al., 2015). The frontotemporal regions are especially vulnerable after TBI (Bigler, 2011; Bigler & Maxwell, 2011). Importantly, it has been demonstrated that disruptions to connections between orbitofrontal regions and sub-cortical structures of the temporal lobe can lead to impaired affect and impaired emotion

processing (Cha, Greenberg, Carlson, DeDora, Hajcak & Mujica-Parodi, 2014). Tonks, Slater, Frampton, Wall, Yates and Williams (2009) integrated much of the evidence regarding emotion processing and TBI into a model of emotion recognition (see Figure 2). This model will be used as a basis for the current study because it is consistent with Adolphs's (2002a, b; Pessoa & Adolphs, 2010) neuroanatomical model of emotion processing (see Figure 3). Adolphs (2002a) explains that the neural structures and systems involved in FEP work in parallel through multiple bidirectional tracks.

Tonks et al.'s (2009) model outlines three inter-related levels of emotion processing that can be disrupted following TBI. The *intrinsic emotional arousal and control system* is made up of the amygdala and the hippocampus. The amygdala has been shown to be especially important in directing the observer to attend to, and make use of information in the eye region, which is essential for emotion perception (Adolphs et al., 2005; Pessoa & Adolphs, 2010). Consistent with its role in memory formation, the hippocampus provides the contextual information associated with specific emotional expressions (Adolphs, 2002a). Several sensory and spatial information processes converge on the amygdala forming the second level of the model, the *sensory/spatial analysis system*. The third level of the model, the *executive system synthesis*, includes the integration of emotion and cognition, which allows emotions to impact conscious thought and emotion regulation. The executive system performs many functions including concept formation, inhibition, attention, and cognitive flexibility. These functions are mediated by the prefrontal and orbitofrontal cortices, areas of the frontal lobe that are especially vulnerable to TBI (Tonks, Williams, Frampton, Yates and Slater, 2007).

Notably, the models of emotion recognition of both Tonks et al. (2009) and Pessoa and Adolphs (2010) illustrate the need to integrate information mediated by several different neural structures (e.g., amygdala, hippocampus, prefrontal cortex) and systems. Therefore, they highlight that both focal (e.g., to a particular structure) and diffuse (e.g., to interconnecting pathways) TBI can impact FEP. They also highlight cognitive activity (e.g., executive functioning and social reasoning; attention, & memory; Adolphs, 2003) that may be especially critical to understanding socially relevant information (e.g., details in eye region of a face) and FEP in particular (Adolphs, 2009).

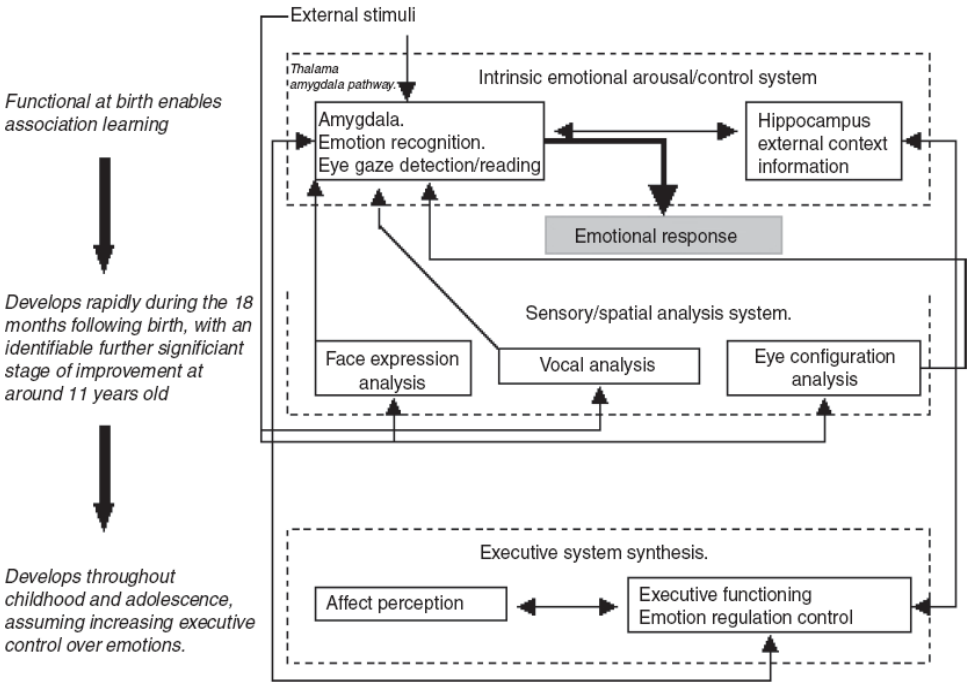

Figure 2. Tonks et al.'s (2009) Model of Emotion Recognition/Processing

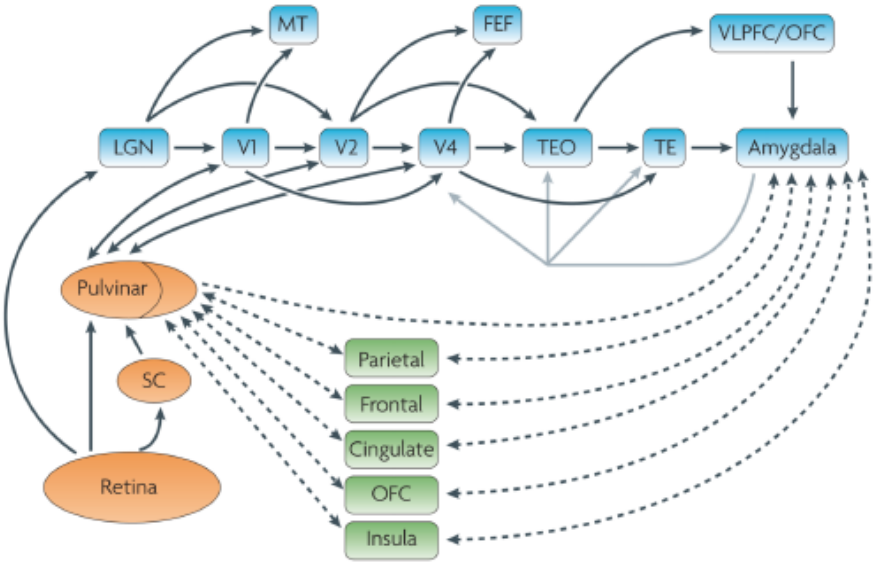

Figure 3. Pessoa & Adolphs' (2010) Multiple Waves Model of Emotion Perception. SC = superior colliculus; LGN = lateral geniculate nucleus; MT = medial temporal area / V5; V = visual cortex ; FEF = frontal eye fields; TEO / TE = inferior temporal area; VLPFC = ventral lateral prefrontal cortex; OFC= orbitofrontal cortex

As indicated above, a primary focus of the current project is to determine whether aberrant visual scanning is one of the mechanisms through which FEP becomes disrupted following TBI. The model of Tonks et al. (2009) suggests that integrating visual scanning information, and information regarding other TBI-related impairments (e.g., attention, arousal, memory) that affect FEP (Adolphs, 2003), would facilitate the development of one of the first mechanism-based FEP treatments. To date, only a handful of emotion perception interventions have been published, and few of these have been designed specifically for people with TBI (Bornhofen & McDonald, 2008b; McCabe, Lippert, Weiser, Hilditch, Hartridge, & Villamere, 2007; Spell & Frank, 2000). Given that TBI causes FEP deficits – a consequential impairment in and of itself – and, moreover, that these deficits may play a causal role in social integration problems

following TBI (Knox & Douglas, 2009), treatment for these deficits is needed to improve clinical outcomes (Radice-Neumann et al., 2007).

Facial Emotion Perception Research and Paradigms: Findings from Typically Developing Samples

Although there is a dearth of comprehensive behvioural FEP studies in typically developing adults, knowledge of FEP in typically developing samples is essential to inform FEP research among those with TBI and other neurological conditions (Schurgin, Nelson, Iida, Ohira, Chiao & Franconeri, 2014). Williams et al.'s online studies (Mathersul, Palmer, Gur, Gur, Cooper, Gordon..., 2009; Williams, Mathersul, Palmer, Gur, Gur, & Gordon, 2009) are an important exception. Like several group studies of patients and controls (Adolphs, 2002, 2009), these online studies of approximately 1000 individuals, age 6 to 91, illustrate that typically adults identify happy faces more accurately than negatively-valenced faces (e.g., sad or fearful). Information contained in the eye region has been shown to be especially important for the accurate identification of fearful and sad faces (Adolphs et al., 2005; Fusar-Poli, Placentino, Carletti, Landi, Allen, Surguladze et al., et al., 2009). In the studies of Williams and colleagues, reaction times were shortest for happy faces and longest for fearful faces. Further, reaction times were fastest among the participants age 10-19, 20-29, and 30-39 and slowest among participants age 70-79, and 80-91 (Williams et al., 2009). Corden, Critchley, Skuse, & Dolan (2006) conducted a web-based study of over 350 typically developing university-recruited men (mean age was 29.9 years, SD = 8.95) and found participants who were less accurate at labeling fearful faces were also somewhat less accurate at labeling sad and angry faces.

Several FEP studies have also been conducted in typically developing children and adolescents (e.g., Gee, Humphreys, Flannery, Goff, Telzer, Shapiro... Tottenham, 2013; Herba et al., 2006; for a review, see Herba & Phillips, 2004; Wiggins, Adleman, Kim, Oakes, Hsu, Reynolds,…Leibenluft, 2016). Neuroimaging studies concur with the behavioural studies of Williams et al. (2009) and demonstrate that FEP accuracy increases throughout childhood. However, fMRI studies also demonstrate that there are significant differences in the activation of some brain regions during FEP in adulthood versus adolescence. For example, areas of the ventral lateral PFC and temporal cortex have also been shown to be more responsive to the intensity of fearful and happy faces in adults, relative to adolescents (Wiggins et al., 2016). Gee et al. (2013) found that the amygdala reactivity decreases throughout childhood and that amygdala-medial PFC activation is negatively correlated in 17- to 22-year-olds and significantly different from that of younger children and adolescents. Decreased amygdala activation begins to be associated with increased medial PFC activation after age 10. Overall, pediatric FEP research informs adult FEP research and the current dissertation by demonstrating that activation and connectivity within emotion perception networks (i.e., amygdala-PFC) change across development. Development provides a normative example of the brain's plasticity and ability to respond to a task in multiple ways to achieve a similar outcome (e.g., level of accuracy). This suggests that there is redundancy and resiliency within the brain's emotion neural networks that may allow it to adapt to not only development, but also injury (i.e., to amygdala-PFC connections). An understanding of the visual scanning of emotional faces in typically developing adults and those who have sustained a TBI may help evidence-based FEP treatments to harness the brain's residual function.

Several different paradigms have been employed to examine FEP in both typically developing and patient populations. Explicit FEP (e.g., emotional labelling; emotional matching, same-different emotion tasks) require participants to consciously direct attention toward the facial emotion (Green et al., 2004; Habel, Windischberger, Derntl, Robinson, Kryspin-Exner, Gur & Moser, 2007; Herba et al., 2006). Conversely, implicit FEP tasks involve indirect or incidental FEP, during which attention is directed toward another aspect of the stimulus; Critchley, Daly, Phillips et al., 2000; Habel et al., 2007). Some research suggests that explicit processing requires greater bilateral brain activation, while implicit paradigms are mediated more by the right hemisphere (Habel et al., 2007), and subcortical structures (Herba et al., 2006).

An explicit paradigm was selected for this dissertation given that initial studies documenting a relationship between FEP and social functioning in patients with TBI and other neurological conditions have employed an explicit labeling paradigm (Corden et al., 2006; Knox & Douglas, 2009). Further, there is some evidence to suggest that implicit emotional perception is less impaired following TBI (McDonald, Saad, & James, 2011). Therefore, it follows that an explicit paradigm might best identify individuals at risk for FEP deficits and decreased social integration.

Furthermore, McDonald, Hunt, Henry, Dimoska and Bornhofen (2010) demonstrate that participants with TBI who report heightened anxiety after viewing emotional films also exhibit decreased executive functioning and cognitive inhibition on standardized tests (e.g., speeded letter letter-number alteration; Trail-Making Test B). Lieberman et al.'s widely cited fMRI studies (Creswell et al., 2007; Liberman, Eisenberger, Crockett, Tom, Pfeifer, & Way, 2007) and those of other research groups

indicate (Wiggins et al., 2016) that FEP labeling activates brain regions involved in language-related aspects of executive function and inhibition (i.e., ventral lateral prefrontal cortex; VLPFC) and related areas (i.e., medial prefrontal cortex) that are frequently impacted by TBI (Bigler, 2001; Bigler & Maxwell, 2011). Lieberman et al. (2007) demonstrate that emotion labeling paradigms, but not emotional matching (i.e., discrimination, language free) or sex labeling of emotional faces (i.e., implicit FEP paradigms), activate the VLPFC. Activation of the VLPFC has been shown to down-regulate the amygdala. Therefore, emotional labeling is important for emotional regulation and modulation (Creswell et al., 2007). This may be one of the pathways activated through psychotherapy (Lieberman et al., 2007), and potentially FEP-based treatments for those with neurological conditions might be effective. As explained above, recent pediatric literature suggests that subcortical-cortical connections are especially important to FEP during typical development.

Norton and Stark (1971) and Walker-Smith, Gale and Findlay's (1977) inaugural eye tracking studies employed line drawings of neutral faces and demonstrated that typically developing adults typically focus on the salient features of a face (i.e., eyes, nose, mouth) rather than less salient features of the face (e.g., forehead, cheeks) and exhibit a relatively stable triangular pattern of visual scanning. These studies determined that adults allocate a similar proportion of attention to the eyes, nose and mouth, irrespective of the size of the image. Nonetheless, few studies have provided a detailed examination of how typically developing adults scan emotional faces, particularly under both non-speeded and speeded conditions.

To date, the majority of available data on typically developing individuals is embedded in patient (e.g., Corden et al., 2009), or condition-specific (e.g., psychopathy; Gillespie et al., 2015) studies (but see Corden et al., 2006). Further, the majority of patient eye-tracking studies have utilized a fixed-duration presentation time (e.g., Adolphs et al., 2005; Corden et al., 2009, Marsh et al., 2012). Although this accounts for the potential processing-speed impairments and concomitant reaction-time variability that characterize patient samples (Green et al., 2008), non-speeded tasks do not map onto the short processing times evidenced in everyday social interaction (Adolphs, 2003) and, therefore, lack generalizability.

Vassallo et al.'s (2009) study is one of the only reports to provide a detailed analysis of how typically developing adults scan emotional faces. However, it did not include a non-speeded task, making it difficult to compare their data to existing patient studies. The similarities and differences between speeded and non-speeded tasks and their potential utility during FEP treatments remain unclear. The response list employed as part of Vassallo et al.'s (2009) speeded task was presented following the facial emotion stimuli. This design is not optimal for patient studies (i.e., among those with TBI) as it increases the memory demands of the task and may artificially influence FEP results (i.e., reaction time). Further, unlike the current dissertation study, Vassallo et al.'s (2009) study did not include neutral faces.

Participants in Vassallo et al. (2009)'s study were fastest to identify happy faces, relative to surprised faces, and negatively-valenced faces. Like happy faces, surprised faces were also identified faster than negatively valenced emotions. Unlike the majority of patient studies (e.g., Corden et al., 2008), Vassalllo et al. (2009) reported only raw

fixation data. Proportional data were not reported. Consistent with the behaviour literature regarding typically developing adults (Mathersul et al., 2009), and several non-eye-tracking facial emotion perception patient studies (Corden et al., 2008; Green et al., 2004), accuracy was significantly greater for positive-valenced (e.g., surprised, happy) emotions than negative emotions. Vassallo et al.'s (2009) young adult sample identified surprised faces most accurately and fearful faces least accurately. Despite the contributions of Vassallo et al.'s study, in addition to separating stimulus and response-list onset, and excluding neutral faces, it included a small number of stimuli per emotion. Consequently, emotion-specific analyses were not reported.

The FEP labeling eye-tracking studies of Vaidya, Jin, and Fellows (2014), and Schurgin et al. (2014) provide two of the first inter-emotion analyses in typically developing young adults. The eye-tracking study of Vaidya et al. (2014) found that although nose and mouth fixations can aid in the identification of overt emotional expressions and subtle expressions of happiness, they contribute little-to-no predictive value to the identification of other subtle emotions. In their study, eye fixations were essential for the identification of subtle expressions of fear, disgust and surprise. Angry and sad faces were not included.

Vaidya et al. (2014) included both an emotion-labeling task and an emotion rating task, with subjects asked to rate the extent to which each face is angry, disgusted, fearful, or surprised. Fixation patterns were relatively similar regardless of whether participants were asked to label or rate a face, suggesting that fixation patterns are more stimulus-driven than instruction-driven. Walker-Smith et al.'s (1977) examination of the scanning of neutral faces also suggests that participants exhibit similar fixation patterns

irrespective of the paradigm employed (i.e., side-by-side same-different paradigm versus single-face matching paradigm).

Schurgin et al.'s (2014) study included five of the six basic emotions (angry, disgusted, fearful, happy, sad; Ekman, 1993), one "social" or self-referential emotion (shame; Adolphs, 2002), and neutral. Rather than presenting all emotions in a single block, as in the current dissertation project (see procedure for details), one emotion was presented per block, with neutral faces randomly interspersed throughout the block. Participants completed a yes-no task during which they were asked to indicate whether each stimulus was an emotional face. Using this task, Schurgin et al. (2014) determined that typically developing young adults look at the eyes of fearful, angry, sad and shameful eyes more than the average, across all types of emotions. Further, they also look at the upper lip of happy and disgusted faces more relative to the mean (i.e., average, collapsed across emotion) and less at the upper lip of angry and sad faces in comparison to the mean. They found that participants' fixation patterns could be used to predict the emotion being displayed in each stimulus. Although this study employed a multicultural stimulus set (i.e., including African Americans, Asians and Caucasians in the "Montreal Set of Facial Displays of Emotion" battery, Beaupre & Hess, 2005), each model (i.e., person demonstrating the emotion) was repeated multiple times throughout the experiment, unlike in the current dissertation study.

Taken together, although relatively few studies have focused on FEP in typically developing adults, the available research indicates that there are inter-emotion differences in accuracy and reaction time. Although recent eye-tracking studies indicate that the emotion in stimulus faces affects visual scanning of the eyes and mouth in typically

developing young adults, this research uses a relatively small number of models demonstrating the emotions, and suggests that additional research in this population would be beneficial to future patient studies. Labeling paradigms may be valuable for the study of FEP following TBI given the reported relationship between FEP labeling and social functioning in this group (Knox & Douglas, 2009). As indicated above, there is also widely cited evidence that FEP labeling activates the PFC, a region of the brain that is especially vulnerable to TBI and becomes more sensitive to facial emotions throughout adolescence and young adulthood.

Facial Emotion Perception Findings from Patients with TBI and other Neurological Conditions

To date, there are few published studies of the visual scanning of emotional faces in individuals with TBI (Mancuso, Magnani, Cantagallo, Rossi, Capitani, Galletti,…Robertson, 2015). However, as indicated above, mounting non-eye-tracking evidence suggests that individuals with TBI make proportionally more errors perceiving negative emotions than they do positive ones (Jackson & Moffat, 1987), with the perception of fearful and other negatively valenced faces being among the most challenging (Croker & McDonald, 2005; Hopkins et al., 2002). The extent to which the relative difficulty of accurately identifying negatively- versus positively-valenced emotions is confounded by the inclusion of more negatively valenced stimuli than positively valenced stimuli is beyond the scope of this dissertation. Nonetheless, it is a possible factor that may influence patient accuracy (Green et al., 2004; Ietswaart et al., 2008; Rosenberg, McDonald, Dethier, Kessels, & Westbrook, 2014) and it warrants further study. Decreased social integration is a commonly reported but frequently

untreated impediment following brain injury (Corrigan et al., 2001; Green et al, 2004; McDonald et al., 2009). Moreover, decreased FEP accuracy is a common characteristic of several neurodevelopmental and neuropsychiatric conditions (e.g., autism spectrum disorder, Corden, Chilvers & Skuse, 2008; Pelphrey, Sasson, Reznick, Paul, Goldman, & Piven, 2002; obsessive compulsive disorder, Daros, Zakzanis, & Rector, 2014; schizophrenia, Loughland, Williams, Gordon, 2002; Huntington's disease, Johnson et al., 2007; Parkinson's disease, Clark, Neargarder, & Cronin-Golomb, 2010). The range of neurological conditions with co-occuring FEP impairments underscores the complexity of FEP and its vulnerability in the context of brain functioning. Furthermore, although neurological conditions frequently impact the identification of negative emotions, there is evidence of some condition specificity with respect to FEP labeling impairments. For example, some research suggests that individuals with conditions that affect the basal ganglia have more difficulty accurately labeling disgust and anger (Daros et al., 2014; Johnson et al., 2007).

Given the paucity of eye-tracking FEP studies of participants with TBI, findings from participants with other neurological conditions will be reviewed. As outlined above, a recent case report of a woman with bilateral amygdala damage suggests a promising line of clinical intervention. Adolphs et al., (2005) found that this individual's facial emotion recognition skills could be dramatically improved by determining how her visual scanning of facial expressions differed from that of control participants. Their patient neglected to look at the eyes of emotional faces and was therefore unable to recognize fearful faces. When simply instructed to attend to the eyes, her accuracy increased to a level comparable to that of controls. This suggests that targeted instruction can

significantly improve emotion recognition, at least for this mechanism of underlying impairment (i.e., reduced scanning of the eyes). Nonetheless, to date, our understanding of visual scanning in typically developing (i.e., control) participants, and in individuals with TBI is limited. It is for this reason that the present dissertation aimed to assess the visual scanning of emotional faces in these populations, with the long-term aim of contributing to visual-scanning-based research and intervention techniques similar to those employed by Adolphs et al. (2005), and more recently McDonald and colleagues (e.g., McDonald, Tate, Togher, Bornhofen, Long, Gertler,…Bowen, 2008) .

In addition to the above case study of the individual with bilateral amygdala damage (Adolphs et al., 2005), studies of individuals with autism spectrum disorder (e.g., Corden, Chivers & Skuse, 2008; Pelphrey, Sasson, Reznick, Paul, Goldman & Piven, 2002, Spezio, Adolphs, Hurley, & Piven, 2007) and schizophrenia and attention deficit hyperactivity disorder (Marsh & Williams, 2006; Williams, Loughland, Gordon, & Davidson, 1999) indicate that maladaptive visual scanning is common among individuals with neurological conditions who experience FEP difficulties.

Like Adolphs et al.'s (2005) study, Pelphrey et al.'s (2002) examination of participants with high-functioning autism found that individuals with autism spent less time looking at the eye region of emotional faces than control participants, and that this affected their FEP, particularly with respect to fear recognition. Pelphrey et al. (2002) reported that their participants with autism spent a smaller percentage of time scanning features of the face relative to less salient features. Their control group spent significantly more time looking at the eyes and the nose relative to the autism group. There was no group difference in mouth viewing time.

Corden et al.'s (2008) overall analyses of between-group differences comparing adults with Asperger's syndrome and controls revealed results that were similar to those of Pelphrey et al., (2002). Although a smaller number of emotions were investigated, Hernandez et al. (2009) found that their autism group spent less time fixating on facial features than their control group. Corden et al. (2008) also revealed a trend toward participants with Asperger's fixating on the mouth (i.e., not the eyes) significantly more than controls. Their inter-emotion analyses suggest that both controls and participants with Asperger's syndrome spend less time fixating on the eyes of disgusted and angry faces relative to other emotions. Also, both groups spend more time fixating the eyes of surprised faces relative to those of happy faces.

Regarding the relationship between visual scanning and accuracy, Corden et al. (2008) found a positive correlation between fixations to the eyes and fear accuracy in their Asperger's group. These results converge with those of Adolphs et al. (2005)'s case study of the woman with bilateral amygdala damage (i.e., "SM"). Fixation-accuracy relationships did not manifest in controls, most likely because of ceiling effects and the restricted range of the accuracy data.

The above data from neurological populations other than TBI are especially relevant given that this is one of the first eye-tracking studies to examine the FEP of individuals with TBI. However, it is important to emphasize that the neuroanatomical and cognitive sequelae specific to TBI are likely to affect FEP in distinct ways that have unique implications for eye-tracking-based research and interventions. For example, although individuals with autism spectrum disorder and TBI both experience deficits in FEP, evidence suggests that TBI often results in reduced amygdala volume (Fisher,

Rushby, McDonald, Parks, & Piguet, 2015; Wilde, Bigler, Hunter, Fearing, Scheibel, Newsome et al., 2007). In contrast, research suggests that, during childhood, the amygdalae of children with autism and Asperger's syndrome are enlarged by an average of 16% and 9%, respectively (Mills, Schumann, Hamstra, Goodlin-Jones, Lotspeich, Kwon, Buonocore, …Amaral, 2004).

Sasson et al. (2007) discuss the importance of examining facial emotion perception in a variety of clinical groups to elucidate differences in functioning and underlying neural circuitry. This study of the visual scanning of emotional faces following TBI was undertaken to provide novel information not only about the consequences of TBI, but also about facial emotion perception, more generally. It is hoped that both the TBI- and control-group data provided in this dissertation will contribute to the development of future FEP and social integration treatments.

Identified Research Needs: Visual Scanning Deficits as a Possible Mechanism Underlying FEP Impairments following TBI

Given existing and emerging research, the following research needs have been identified. First, several researchers (Babbage et al., 2011; Sasson, Tsuchiya, Hurley, Couture, Penn, Adolphs, et al., 2007; Schurgin et al., 2014; Vaidya et al., 2014; Vassallo et al., 2009) have proposed that additional eye-tracking studies would help to characterize the relationship between visual scanning and FEP accuracy in patient populations and typically developing samples. Typically developing data may be critical to the development of evidence-based FEP interventions and our understanding of FEP, more generally. Based on a the above review of the literature, more research is needed regarding how the visual scanning of emotional faces under speeded conditions compares

to the visual scanning of emotional faces under non-speeded conditions. Moreover, few studies examine inter-emotion (Schurgin et al., 2014; Vaidya et al., 2014) scanning differences in a typically developing sample.

Second, to date, there is only one known study examining how TBI affects the visual scanning of emotional faces. Mancuso et al.'s (2015) relatively recent study only included a non-speeded task (i.e., with a 5-second fixed presentation) and did examine inter-emotion differences. Determining whether individuals with TBI scan emotional faces differently from typically developing individuals, and whether any observed differences are related to accuracy under both non-speeded and speeded conditions may be critical to future treatment studies. This may be especially important given evidence of the relationship between reduced processing speed and impaired FEP following TBI (Ietswaart et al., 2008).

Purpose

The primary purpose of the present study was to analyze the visual scanning of typically developing controls and participants with TBI while they were performing a facial emotion perception labeling task under non-speeded and speeded conditions. First, potential inter-emotion visual scanning, reaction time, and accuracy differences were identified among typically developing controls. Fixations and proportion of fixations are the main visual scanning dependent variables reported in Study 1, in line with the data reported in prior studies (e.g., Corden et al., 2008; Shurgin et al., 2014).

Second, potential inter-emotion visual scanning, reaction-time, and accuracy differences were identified among participants with TBI and compared to those of controls in Study 2. Upon completion of study 1, ongoing review of the literature

determined that patients with executive functioning deficits (Clark, Neargarder, & Cronin-Golomb, 2010), similar to those which are commonly experienced by patients with TBI (Stuss, 2011; Bornhofen & McDonald, 2008), often exhibit longer fixations than typically developing control participants. Therefore, dwell time and proportional dwell time were the main visual scanning dependent variables employed in Study 2. As Tonks et al. (2009) and Pessoa and Adolphs' (2010) models of FEP would support, a third goal of the study was to explore the relationship between the visual scanning of emotional faces with FEP accuracy and with labelling speed (i.e., reaction time) following TBI.

Dissertation Structure

This dissertation consists of two main empirical chapters, Chapters 2 and 3. Chapter 2 presents the visual scanning of emotional faces with respect to (1) overall scanning patterns and (2) inter-emotion scanning differences in typically developing controls employing accuracy and reaction time as outcome measures. Chapter 3 addresses the aforementioned visual scanning relationships in participants with TBI and compares them to those of controls. Overall implications of both studies will be considered in Chapter 4, the General Discussion.

Chapter 2

Gaining a Better Understanding of How Typically Developing Adults Scan Emotional Faces: Implications for Treating Visual Scanning Deficits in TBI

Impairments in FEP following TBI are now well documented (Babbage et al., 2011; Green et al., 2004; Ietswaart et al., 2008, McDonald et al., 2014).There is growing evidence that visual scanning of emotional faces is often compromised in people with neurological conditions (Adolphs et al., 2005; Clark et al., 2010; Corden et al, 2008). FEP visual scanning based research among individuals with TBI is still in its infancy (e.g., Mancuso et al, 2015). Evidence of relationships between visual scanning and FEP (e.g., accuracy, speed) would open new avenues of intervention research, for example, the treatment of visual scanning deficits to improve FEP abilities. Critically needed, however, is a fuller understanding of visual scanning of emotional faces in typically developing adults (Schurgin et al., 2014; Vaidya et al., 2014). In particular, the nature of the emotion content, and how this relates to eye movements is relatively understudied (Schurgin et al., 2014; Vassallo et al., 2009). Therefore, the objectives of Study 1 were as follows: To further document the extent to which typically developing adults attend to the eye, nose, and mouth regions of emotional faces; to determine how typically developing adults' visual scanning of emotional faces varies by emotion; to assess the effect of speed demands on the visual scanning of emotional faces, and; to determine if visual scanning is related to emotion labeling speed and accuracy.

Study 1: Objectives and Hypotheses

Objective 1: Effect of Areas of Interest (AOI)

To replicate and extend Vassallo et al.'s (2009) study by quantifying the characteristics of typically developing adults' visual scanning patterns. This was accomplished by measuring i) the number of fixations to the eyes, nose and mouth, and ii) the proportion of fixation to the eyes, nose and mouth in a sample of typically developing adults.

Hypothesis 1. On the basis of Vassallo et al. (2009), it was hypothesized that typically developing adults would spend proportionately more time fixating on the eyes, followed by the mouth, followed by the nose.

Objective 2: Effect of Emotion

To determine if visual scanning characteristics (i.e., fixations, proportion of fixations) vary across different emotions. Fixation data were initially analyzed by collapsing across AOI.

Hypothesis 2. It was hypothesized that participants would allocate more time, and make more fixations to some emotions than others, and the eyes of some emotional faces in particular. If inter-emotion differences emerged, it was hypothesized that they would be strongest for emotions such as fear and sadness (i.e., relative to other emotions), as the eyes have been shown to be especially important for identifying these negative emotions in the face. Further, it was hypothesized that inter-emotion differences would be especially evident on the speeded task.

Objective 3: Effect of Task

To examine how typically developing adults effectively attend to the features of emotional faces under i) non-speeded and ii) speeded task conditions.

Hypothesis 3. It was hypothesized that here would be a significant effect of task. We predicted that participants would exhibit more strategic visual scanning during the speeded task relative to the non-speeded task. Further, it was hypothesized that larger inter-emotion effects would be observed on the speeded task.

Objective 4: Reaction Time

To examine the effect of emotion on reaction time, and explore the relationship between visual scanning and reaction time.

Hypothesis 4a. Based on the existing literature, a significant effect of emotion on reaction time was anticipated. It was hypothesized that happy faces would be labeled more quickly than all other emotions.

Hypothesis 4b. It was hypothesized that participants who spend the most time on the 'emotionally uninformative' AOI (i.e., the nose) would take the longest amount of time to complete the task. It was predicted that proportion of nose fixations would correlate positively with reaction time.

Objective 5: Accuracy

To examine the effect of emotion on accuracy, and explore the relationship between visual scanning and accuracy.

Hypothesis 5a. Based on the existing literature reviewed above, a significant effect of emotion on emotion labeling accuracy was anticipated. Further, it was hypothesized that happy faces would be labeled more accurately than all other emotions.

Hypothesis 5b. Hypotheses were not proposed regarding the relationships between visual scanning and accuracy, as this this analysis was considered exploratory.

Method

Participants

Forty participants (11 males) were recruited through the York University Undergraduate Participant Pool. Inclusion criteria were as follows: normal or corrected-to-normal visual face recognition (i.e., based on the Benton Face Recognition Test, as in previous studies; Ietswaart et al., 2008). Soft contacts but not glasses were permitted. Exclusion criteria were as follows: history of psychiatric illness, neurological condition or concussion requiring hospitalization, substance abuse, clinical depression or anxiety disorder (based on self-report), developmental disability or ophthalmological condition. One participant was excluded due to self-reported anxiety or depression. Two people reported having sustained multiple concussions and two participants wore glasses, or had uncorrected vision problems. Two additional participants were unable to achieve an average spatial accuracy of 0.5 degrees during the eye tracker calibration and validation procedure at the beginning of the experiment (see below). Therefore, they could not complete the experiment. This resulted in a sample of sample of 33 (9 males) participants. Participants had a mean age of 19.83 (SD=2.89) and a mean of 13.33 (SD = 2.12) years of education. On average, they had spent 70% of their lives in a large, urban city. Additional demographic data are presented in Table 1.

Table 1

Study 1: Participant Demographics.

Group	Age	Years of Education	BFRT	Years in Metropolitan City (%)	Years in N. America (%)
Men					
9	20.56 (3.75)	12.83 (0.82)	46.33 (2.71)	72.95 (27.12)	82.33 (18.8)
Women					
24	19.64 (2.60)	13.46 (2.35)	49.13 (3.35)	68.69 (36.55)	90.21 (19.8)
Total					
33	19.83 (2.89)	13.33 (2.12)	48.36 (3.11)	69.85 (33.88)	88.12 (19.5)

Note. There were no significant differences between the groups on any of the demographic variables, BFRT = Benton Face Recognition Test
Mean *(SD)*

Materials

Test of facial recognition. The Benton Face Recognition Test (BFRT; Benton et al., 1983; Levin, Hamsher, & Benton, 1975) was used to assess participants' ability to identify and match non-emotional faces based on their facial features. During each trial, participants looked at a target face and compared it to six test faces. Their task was to identify the test face(s) that matches the target face in various views and lighting conditions. The BFRT has been used in several studies of patients with neurological conditions to screen for the inability to recognize faces (Strauss, Sherman, & Spreen, 2006), including studies of FEP (Gomez-Ibanez, Urrestarazu, &Viteri, 2014). It has been shown to have strong test-retest reliability, with no changes in participants' average scores over a one-year period. In terms of its construct validity, the BFRT has also been reported to be associated with the Wechsler Adult Intelligence Scale perceptual reasoning index, and the Hooper Visual Organization Test. This suggests that it relates to both general object recognition and general visuospatial skills. Patients with intact vision have also been found to have significantly better scores (Strauss et al., 2006).

Eye-tracking stimulus sets. Two equivalent sets of stimuli were created for the eye-tracking tasks, Set A and B. Each set consisted of a combination of 56 stimuli, 8 neutral faces and 8 of each of the 6 basic emotions (angry, disgusted, fearful, happy, sad, and surprised). Eighty-five Caucasian faces and 27 non-Caucasian faces were included. Caucasian stimuli were equally distributed across emotion and stimulus set for all but the surprised category, which contained one additional Caucasian stimulus in lieu of a non-Caucasian stimulus. Sex was approximately equal across sets (Set A= 31 women, 25 men; Set B=32 women, 24 men). The pictures were taken from an in-house battery, the Pictures of Facial Affect Battery (Ekman & Friesen, 1979), and the Japanese and Caucasian Facial Expressions of Emotion Test (JACFEE; Matsumoto & Ekman, 1989). Stimuli from the JACFEE and in-house batteries were converted to black and white using Adobe Photoshop. A small convergence study (*N*= 10) conducted prior to testing determined that all stimuli were accurately identified by at least 80% of the participants.

Static as opposed to dynamic faces were employed for several reasons. Firstly, research documenting the relationship between FEP and social functioning is still in its infancy and evidence of this relationship has predominantly been documented using static stimuli (e.g., Corden et al., 2009, Knox & Douglas, 2009). Secondly, static photographs are the most commonly and widely used, with Ekman's seminal Pictures of Facial Affect (POFA; Ekman & Friesen, 1979) being one of the most prevalent and evidence-based FEP batteries. Therefore, using static photographs provided a large corpus of research from other patient populations[1].

[1] One major shortcoming of the majority of static FEP batteries with respect to ecological validity and transferablity in multicultural cities like Toronto, Canada (i.e., where this dissertation study was conducted) is that they are primarily unicultural. Evidence indicates that adults distinguish the facial emotions of individuals within their own cultural group more accurately than those of individuals from anther cultural

In addition to the evidence demonstrating a relationship between static FEP labeling photographs and social functioning following TBI (Knox & Douglas, 2009; Milders et al., 2003), static photographs were chosen for this dissertation study given their compatibility with the eye-tracking technology available when the study was designed. Marsh and Williams (2006) explain that eye-tracking is optimal for examining FEP among patients with neurological conditions that frequently affect attention. It has been argued that eye-movements provide a physiological measure of participants' visual attention and visual information processing (Norton & Stark; 1971; Marsh & Williams, 2006). As noted above, impairments in attention are common after TBI (Ruttan, Martin, Liu, Colella, & Green, 2008). The measurement of a participant's visual scanning of facial expressions is achieved by examining "scanpaths" - an outline of the direction, amount of eye movement, and degree of fixation that occurs while an individual is viewing a complex visual stimulus, such as a face (Hunnius, de Witt, Vrins, & von Hofsten, 2011; Norton & Stark, 1971; Vassallo et al., 2009). Fixations are 'points of attention' in the scanpath in which central vision is focused on a portion of a stimulus for a period of time.

(Elfenbein & Ambady, 2003; Winkline, Bailey & Nowicki, 2009). Although some research has begun to address the need for multicultural stimulus sets (e.g., Beaupre & Hess, 2005, Montreal Set of Facial Displays of Emotion; Matsumoto & Ekman, 1989, Japanese and Caucasian Facial Expressions of Emotion Test, JACFEE), most available FEP batteries offer limited diversity or include a limited number of models. It is for these reasons that the current study employed a combination of stimuli from existing batteries and one developed at Toronto Rehab – University Health Network (UHN).

Design and Procedures

Participants completed a test of facial recognition and visual discrimination (i.e. the BFRT), followed by a two-phase facial emotion labeling experiment comprising a non-speeded task and a speeded task. The non-speeded task preceded the speeded task for all participants. Stimulus set order (A followed by B or vice versa) was counterbalanced across subjects. Stimuli within each set were presented in a randomized order. Seven practice trials (one per emotion) preceded each of the emotion labeling tasks. No feedback was provided during the practice trials. A monocular eye-tracker was used to collect scanpath data during both tasks.

Non-speeded, eye-tracking emotional face labeling task. Participants were presented with one of the two stimulus sets while their eye-movements were recorded. Images were presented for a 4000 ms free-viewing period, after which time the stimulus remained on the screen and the response list (i.e., the emotion labels) appeared at the side of the display. Participants were given unlimited time to view the stimulus and provide a verbal response. Eye-tracking data from the free-viewing period were analyzed.

Speeded eye-tracking emotional face labeling task. Participants were presented with the other of the two stimulus sets. This task was identical to the eye-tracking-only phase of the non-speeded task, with two exceptions: the free-viewing condition was omitted from this phase such that the face stimulus and the response list appeared simultaneously; and, during the reaction-time phase, participants were instructed to respond as quickly and accurately as possible.

Data acquisition. Visual scanning data were acquired at 1000 Hz using an EyeLink 1000 (SR Research) infrared pupil-corneal reflection eye tracker. The EyeLink

1000 allows for a temporal resolution of 1 millisecond, with minimal noise. Participants were seated in a comfortable chair in front of a computer monitor and asked to place their head in a padded head- and chinrest, which minimized head movements and ensured a constant distance of 75 cm between each participant and the display screen. The experiment began with a brief calibration and validation procedure, at which time participants were asked to look at nine points of known position on the screen. Calibration was repeated if the average spatial accuracy of all 9 points was worse than 0.5 degrees. Participants who were unable to meet this criterion were excluded. As indicated above, this resulted in the exclusion of two of the participants. Calibration corrected for individual differences in head position. Participants were recalibrated at the beginning of each task and whenever they removed their heads from the headrest. Following validation, the instructions were presented on the computer screen and read aloud by the experimenter. Each trial began with the 500 ms presentation of a grey screen, which was programmed to have the same luminance value as the face stimuli. Following this, participants were required to fixate a central drift-correction point. Calibration was also repeated if spatial accuracy drifted by more than 0.5 degrees from the initial calibration.

Participants were permitted to take a break at any time. In addition to any self-initiated breaks, participants were invited to a break every 28 trials, such that each phase included two break periods. The EyeLink 1000 has a spatial resolution of .05 degrees and is accurate within .25-.50 degrees when head movement is minimized.

Data Processing. Each trial was individually processed[2]. Fixations identified as blinks by the EyeLink DataViewer software were removed, particularly those that occurred off-screen (i.e., outside the stimulus), at the end of a trial. Trials in which the proportional data summed to less than 1 were also reviewed. List fixations and those that were part of list saccades made to the response list during the speeded task were removed.

Reaction time data for trials in which the voicekey was not activated were obtained by one of three research assistants using Praat speech analysis software. All TBI group voicekey data were reviewed using Praat. These data were subsequently reviewed by an EyeLink consultant and integrated into the EyeLink DataViewer program by the experimenter using Microsoft Excel. Comparison of the reaction time data obtained by via the voicekey and that which was obtained by Praat suggests that Praat reaction times were approximately 10-20 ms shorter than those which were obtained by the voicekey. Although this may have resulted in a slight decrease in TBI-control group reaction time differences, large reaction-time differences emerged, as detailed below.

Statistical Analyses

Consistent with prior studies of typically developing adults (e.g., Vassallo et al., 2009), visual scanning emotion recognition accuracy and reaction time data were analyzed using both 1-way and mixed-design analysis of variance (ANOVA) with (i) facial expression (neutral, angry, disgusted, fearful, happy, sad, surprised), (ii) area of interest (AOI) and (iii) task phase (non-speeded, speeded) as independent variables and

[2] Each trial was viewed by one of two undergraduate research assistants, both of whom are currently completing their masters in clinical psychology, and reviewed by the experimenter, as needed.

(i) raw fixation, (ii) proportion of fixations, (iii) reaction time and (iv) accuracy as dependent variables.

AOIs included features of the face and were defined as the eyes, nose and mouth, and less salient features as areas of the faces outside these areas. Consistent with previous studies, fixations shorter than 100 ms were excluded (Hawelka, Gagl & Wimmer, 2010; Henderson & Pierce, 2008; Norton & Stark, 1971). Therefore, fixations were defined as points of attention in which central vision was focused on a portion of a stimulus for more than 100 ms (Hunnius, de Witt, Vrins, & von Hofsten, 2011; Norton & Stark, 1971; Vassallo et al., 2009). Saccades (i.e., rapid eye movements used to reposition the eye; Duchowski, 2003) were not analyzed as part of the current study. Mancuso et al. (2015) suggest that saccades are not as impacted by TBI as some other neurological conditions (e.g., attention deficit hyperactivity disorder, schizophrenia; Marsh & Williams, 2006).

Pearson correlations were also conducted to analyze the relationship between visual scanning (e.g., time spent on each AOI), and both reaction time and accuracy. The data were reviewed for normality by the experimenter and a statistical consultant at York University. The Greenhouse-Geisser correction was applied when the assumption of sphericity was violated.

Results

Objective 1: Effect of Areas of Interest (AOI)

Analysis of both the non-speeded task a) fixation data, $F(2,68)= 166.85$, $p < .001$, partial $\eta^2 = .831$, and the non-speeded task b) proportional data, $F(2,68)= 172.01$, $p < .001$, partial $\eta^2 = .835$, revealed a significant effect of AOI. Similarly, both the speeded task a) fixation data, $F(2,62)=58.742$, $p < .001$, partial $\eta^2 = .655$, and the speeded task b) proportional fixation data, $F(2,62)= 62.277$, $p < .001$, partial $\eta^2 = .668$, revealed a significant effect of AOI. Pairwise comparisons demonstrated that significantly more fixations were made to the upper region of the face (i.e., eyes and bridge of the nose) when compared to both the nose, $p < .001$, and the mouth, $p < .001$. The number of fixations made to the nose and mouth was not significantly different, $p > .05$.

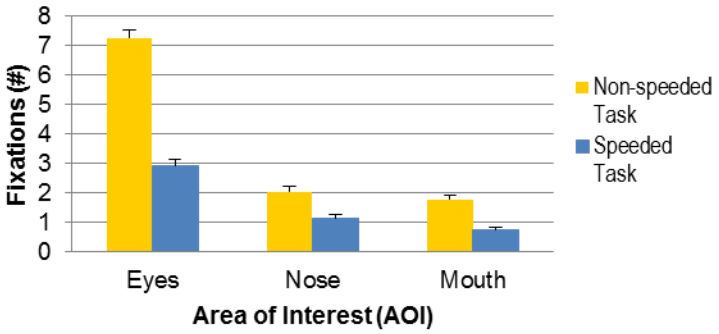

Figure 4. Effect of Area of Interest (AOI) on Number of Fixations to Emotional Face. This graph illustrates the effect of AOI on visual scanning and the average number of fixations made to each AOI during the non-speeded and speeded tasks, collapsed across emotion. Error bars indicate standard error around the mean.

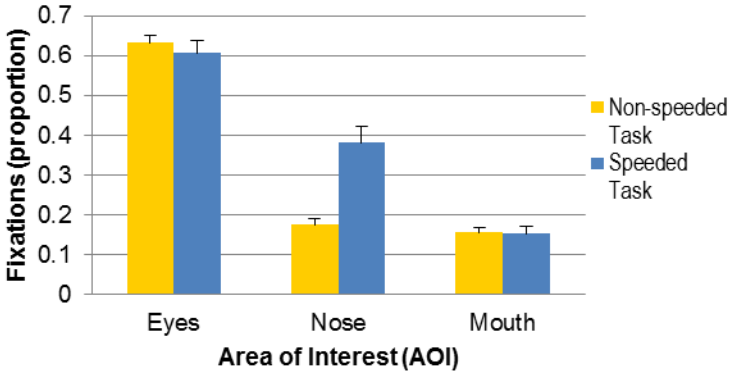

Figure 5. Effect of Area of Interest (AOI) on Proportion of Fixations to Emotional Faces. This graph illustrates the effect of AOI on visual scanning and the proportion of fixations made to each AOI during the non-speeded and speeded tasks, collapsed across emotion. Error bars indicate standard error around the mean

Objective 2: Effect of Emotion

Objective 2 sought to determine the effect of emotion on participants' visual scanning (i.e., fixation patterns). The effect of emotion was analyzed using a series of 3x 7 repeated measures ANOVAs. The raw fixation data evidenced a significant main effect of emotion on visual scanning during the non-speeded task, $F(3.279, 104.925) = 14.927$, $p < .001$, partial $\eta^2 = .318$ and speeded task, $F(6,186) = 10.328$, $p < .001$, partial $\eta^2 = .250$. With respect to the overall fixation pattern by emotion, the proportional fixation data evidenced a significant main effect of emotion during the speeded task, $F(6,186) = 3.639$, $p = .046$, partial $\eta^2 = 105$, but non-speeded task, $F(6,205) = 1.078$, $p = .368$, partial $\eta^2 = .031$. Typically developing adults made an average of 4.86 fixations to the emotional faces during the speeded task. Planned comparisons demonstrated that happy faces were identified with approximately 2 fewer fixations than fearful faces and approximately 1 fewer fixation than all other emotions, $p < .05$. Notably, however, although the number of fixations made to happy and sad faces was significantly different,

p = .002, it differed by only 0.90 fixation on average. Similarly, participants made significantly more fixations overall to fearful faces than happy, disgusted, and sad faces during the speeded task. Interestingly, number of fixations to neutral faces did not differ significantly from the number of fixations made to any emotional faces, except happy, *p* = 0.027, for which there were more fixations for neutral.

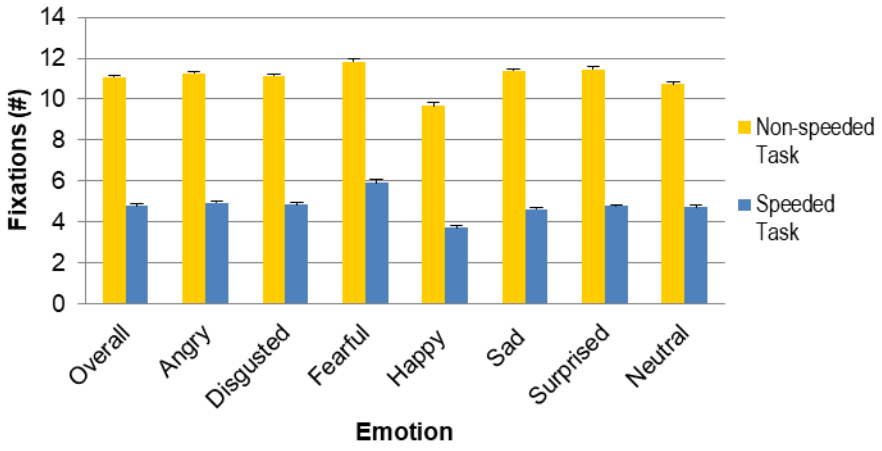

Figure 6. Effect of Emotion on Visual Scanning. This graph illustrates the effect of emotion on number of fixations made to emotional faces by typically developing adults. Error bars indicate standard error around the mean.

Further, significant AOI x emotion interactions were revealed on both the non-speeded task, $F(5.482, 173.701) = 7.629$, $p < .001$, partial $\eta^2 = .193$, $F(6.72, 201.600) = 9.438$, $p < .001$, partial $\eta^2 = .239$ and the speeded task, $F(4.743, 151.77) = 6.499$, $p < .001$, partial $\eta^2 = .169$, $F(6.615, 198.441) = 8.069$, $p < .001$, partial $\eta^2 = .212$, for the proportional fixation and raw fixation data, respectively.

Importantly, follow-up 1-way ANOVAs and pairwise comparisons demonstrated a significant effect of emotion on number of fixations to the eyes during both the non-speeded, $F(3.27,104.639) = 4.779$, $p = .003$, partial $\eta^2 = .13$, and speeded tasks, $F(6, 180) = 12.153$, $p < .001$, partial $\eta^2 = .288$. The number of fixations typically developing

adults made to the eyes of fearful faces during the speeded task was significantly greater than the number of fixations made to happy, surprised, and sad faces, $p < .05$. Although participants made the most fixations to the eyes of fearful faces on average, the number of fixations to the eyes of fearful feces did not differ significantly from those made to the eyes of angry, $p = .483$, and disgusted, $p = .134$, faces. During the speeded task, participants made significantly fewer fixations to the eyes of happy faces than those of all other emotional faces, $p < .05$, except surprised, $p = .388$. During the non-speeded task, the number of fixations participants made to the eyes of fearful faces was only marginally greater than the number of fixations made to happy faces, $p = 0.079$.

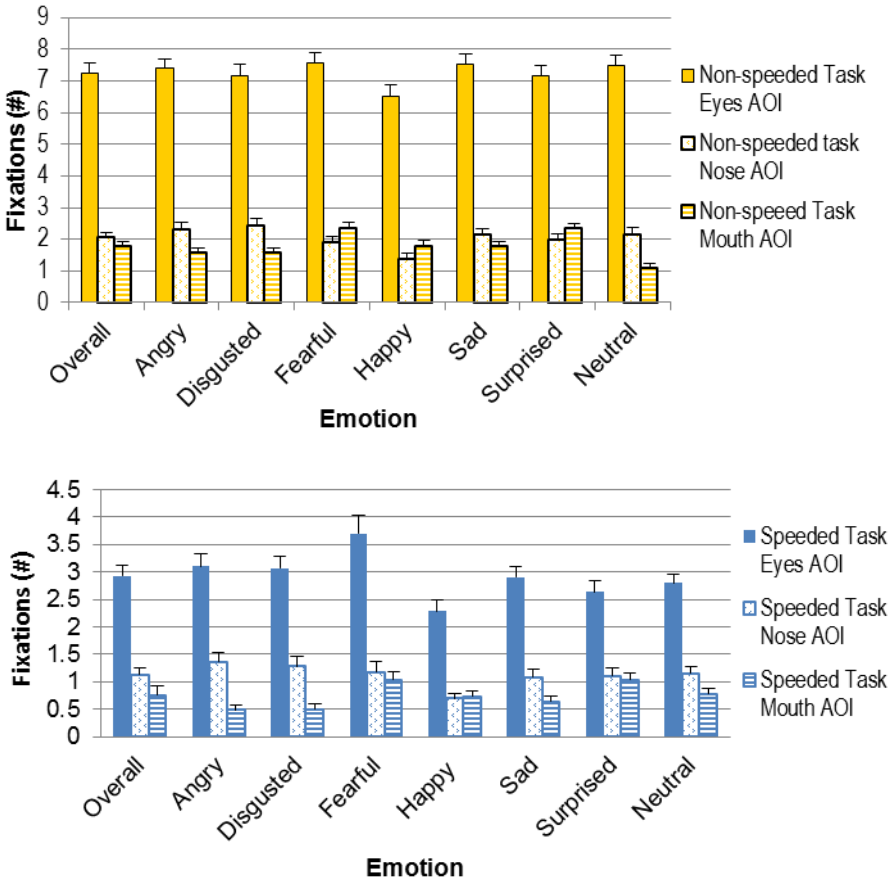

Figure 7. Effect of Emotion by Area of Interest (AOI) on Visual Scanning in Typically Developing Adults. The top graph illustrates the effect of emotion on the number of fixations this typically developing adult sample made to the eyes, nose, and mouth AOIs by emotion during the non-speeded task. The bottom graph illustrates the effect of emotion on the number of fixations this typically developing adult sample made to the eyes, nose, and mouth AOIs by emotion during the speeded task. Error bars indicate standard error around the mean.

Objective 3: Effect of Task

In order to control for the effect of viewing time (i.e., non-speeded versus speeded task), the proportional fixation data were explored to analyze the effect of task. Consistent with hypothesis 3, which predicted a significant effect of task on participants' visual scanning, a significant main effect of task was revealed, $F(1,31) = 7.512$, $p = 0.01$, partial $\eta^2 = .195$, indicative of task-specific scanning differences. A 2 x 3 x 7 repeated measures ANOVA evidenced a significant task x AOI x emotion interaction, $F(12, 372) = 2.502$, $p = 0.016$, partial $\eta^2 = 0.075$ and a significant task x emotion interaction, $F(6,186) = 3.235$, $p = 0.048$, partial $\eta^2 = 0.094$. The task x AOI interaction was not significant.

Consistent with the data described above, planned comparisons demonstrated that visual scanning of happy faces evidenced the most notable task-specific difference. The proportion of fixations made to the eyes of happy faces was marginally greater during the non-speeded task than during the speeded task, $t(32) = 1.995$ $p = .055$. Similarly, the proportion of fixations made to the eyes of surprised faces was marginally greater during the non-speeded task than during the speeded task, $t(32) = 1.889$, $p = .068$. These marginally significant differences suggest that task had a relatively small effect on visual scanning patterns among the typically developing sample.

Hypothesis 3 further predicted that the effect of emotion would be greater on the speeded task than the non-speeded task. As indicated in the emotion section of the results section, and consistent with hypothesis 3, there was a significant main effect of emotion during the speeded task, partial $\eta^2 = .105$ -.250. During the non-speeded task, the effect of emotion had a significant effect on the participants' raw fixation data but not their

proportional fixation data η^2 = .040 – 318. Although the effect of task was small, as predicted, the proportion of fixations made to each AOI differed more by emotion during the speeded task than during the non-speeded task.

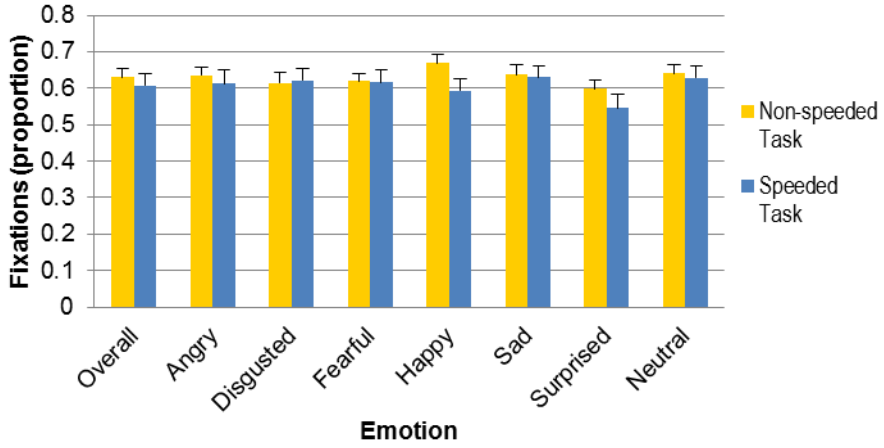

Figure 8. The Effect of Task on the Proportion of Fixations to the Eyes of Emotional Faces. This graph illustrates the effect of task on the proportion of fixations to the eye area of interest (AOI) by emotion. Error bars indicate standard error around the mean.

Objective 4a and 4b: Reaction Time

Objective 4a aimed to examine the effect of emotion on the amount of time needed to label emotional faces (i.e., voice-onset times). A significant effect of emotion on reaction time was revealed, $F(6,198) = 7.941$, $p < .001$, partial $\eta^2 = .194$. Planned comparisons demonstrated that significantly faster response times were recorded for happy expressions in comparison to all other emotions. Fearful faces were also labeled significantly more slowly than sad, $p < .001$, and surprised faces, $p = .002$. Happy face response times did not differ from neutral face response times, $p = 0.279$.

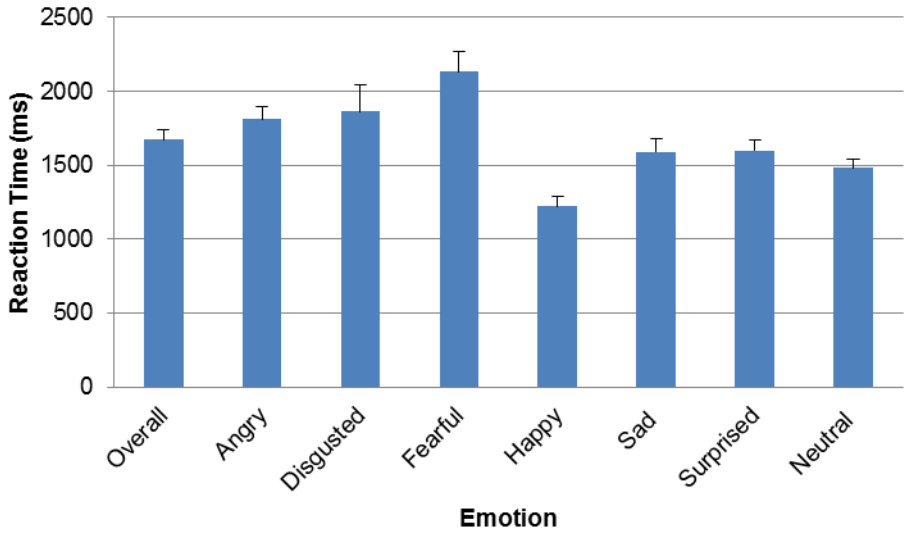

Figure 9. The Effect of Emotion on Labelling (i.e., Reaction) Time. This graph illustrates the effect of emotion on reaction time with happy faces being labelled faster than all other emotional faces (i.e., not including neutral faces). Collapsed across emotion, this sample of typically developing young adults responded in 1672 milliseconds (ms) on average, $p < .05$. Error bars indicate standard error around the mean.

Contrary to Vassallo et al. (2009)'s findings, preliminary follow-up analyses revealed no effect of sex on reaction time, $F(1,32)= 0.002$, $p =.968$, partial $\eta^2 < .001$. Objective 4b sought to explore the relationship between the visual scanning (i.e., fixations to) of emotional faces and the amount of time needed to label the emotion in the face. Consistent with Vassallo et al. (2009), we aimed to determine the effect of AOI on reaction time, irrespective of emotion. Reaction time was significantly related to number of eye, $r(32)=0.487$, $p = 0.005$, and nose fixations, $r(32)=0.374$, $p = 0.035$. More specifically, participants who made more fixations to the eyes and nose had slower reaction times. Exploratory correlation analysis demonstrated a positive correlation between number of nose fixations to surprised faces and surprised reaction times, $r(33)=0.526$, $p < 0.001$. Nose fixations were unrelated to accuracy. Mean number of

fixations made to the features of the face overall was strongly associated with overall reaction time $r(33)=0.773$, $p < 0.001$. Moreover, emotion-specific fixation counts to the features of the face overall were strongly correlated with emotion specific reaction times. For example, the mean number of fixations made to the features of fearful faces accounted for 73% of the variance in fearful face labeling reaction time (e.g., see Figure 10). There were no proportion of fixations x AOI effects on reaction time.

Table 2

Reaction Time (milliseconds) by Emotion

	Overall	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral
Mean	1672.014	1811.52	1862.68	**2133.31***	**1221.18***	1591.31	1601.17	1482.93
SD	(400.71)	(504.75)	(1062.40)	(770.32)	(389.98)	(488.89)	(416.36)	(352.51)

Note. *Mean (SD),* $p < .05$

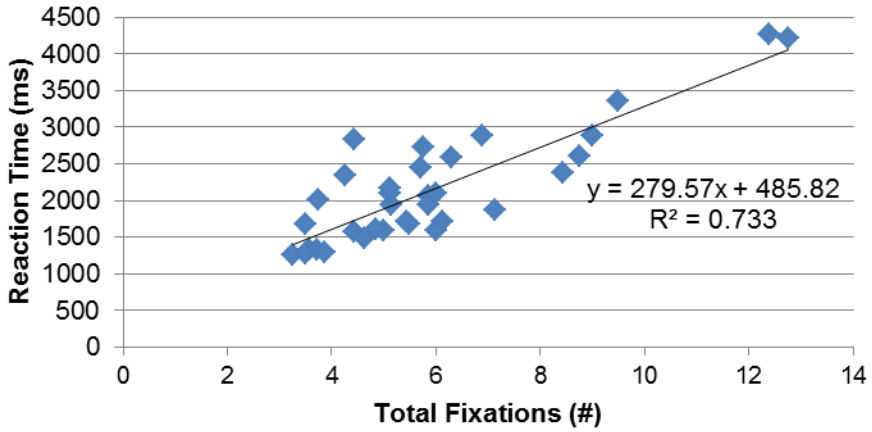

Figure 10. Fearful Face Labeling (i.e., Reaction) Time Versus Number of Fixations to Fearful Faces. This scatter plot illustrates the relationship between the number of fixations made to the fearful faces overall and time to label fearful faces. ms = milliseconds, # = number

Objective 5a and 5b: Accuracy

Overall, the typically developing adults in the current sample achieved an accuracy of 90.4%. Participants were removed from the analysis if their labeling accuracy for any of the 6 emotions or the neutral faces was at least 1 SD below the mean on both tasks and below chance levels (i.e., 50%) on one task. This resulted in the removal of 1 control participant (i.e., 3% of the sample).

In terms of objective 5a, a 2 x 7 repeated measures ANOVA was employed to analyze the effect of emotion on participants' accuracy. A significant main effect was revealed, which accounted for just over 40% of the variance in correct responses, $F(6,192) = 22.301$, $p < 0.001$, partial $\eta^2 = .411$. As predicted, planned comparisons indicated that participants were significantly more accurate when labeling happy faces and significantly less accurate when labeling fearful faces relative to all other faces ($p <$. 001, for all comparisons). Participants identified neutral faces more accurately than all emotions, except happy, $p \leq .02$, for all comparisons. Sad faces were identified *more accurately* than all other negatively valence emotions, $p < 0.001 – 0.063$. Task did not have a significant main effect on accuracy, $F(1,32) = 0.764$, $p = .389$, partial $\eta^2 = 0.023$). Mean non-speeded task accuracy was found to be 90.8% and mean speeded task accuracy was found to be 89.9% (see Table 3).

There was a small but significant emotion x task interaction, $F(6,192) = 2.47$, $p = .049$, partial $\eta^2 = 0.072$. Participants were 8.4% more accurate on fearful faces during the non-speeded task than on the speeded task, $t(33) = 2.12$, $p = 0.042$. Finally, version was not a significant covariate, $F(1,31) = 1.245$, $p = 0.273$, and was not significantly correlated with fearful accuracy, *r* non-speeded task = -0.09, $p = 0.642$; *r* speeded task = -

0.247, $p = 0.174$). Also, version did not significantly correlate with overall accuracy, $r = -0.188$, $p = 0.303$ Therefore, there was no evidence of significant version effects. When version (i.e.,1st stimulus set presented first, 2nd stimulus set presented first) was added to the model, the effect of task was no longer significant, $F(1,31) = 0.135$, $p = 0.716$.

Table 3

Accuracy by Emotion

Task	*Overall*	*Angry*	*Disgusted*	*Fearful*	*Happy*	*Sad*	*Surprised*	*Neutral*
non-speeded	0.908 (0.046)	0.856 (0.138)	0.894 (0.121)	0.799*** (0.172)	0.966*** (0.023)	0.917 (0.109)	0.932 (0.121)	0.966* (0.069)
speeded	0.899 (0.063)	0.883 (0.138)	0.890 (0.126)	0.715*** (0.207)	0.989*** (0.034)	0.947 (0.109)	0.894 (0.144)	0.977* (0.063)

Note. Mean (SD), * $p < .05$, *** $p < .001$

With respect to objective 5b, exploratory correlations revealed the following relationships between visual scanning and accuracy in this typically developing sample.

Table 4

Exploratory Visual Scanning and Accuracy Correlations (Pearson r).

Task	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral
	Mouth	Mouth	Mouth	None	Nose	None	Mouth
Non-speeded	-0.51**	NA	-0.33§§		NA		NA
Speeded	-0.43*	-0.30§	NA		+0.33§§		-0.64***
	None	None	None		Eyes		Eyes
Non-speeded					-0.43** %fix		NA
Speeded					-0.39* %fix		-0.32§

Note. § $p < .10$, §§ $p < .06$, * $p < .05$, ** $p \leq .01$, *** $p < .001$, correlations based on raw fixation data unless indicated.

Study 1: Discussion

Summary of Purpose and Findings

Overall, the goal of Study 1 was to the examine the visual fixations made by a group of typically developing adults as they complete a facial emotion labeling task under non-speeded and speeded conditions. Regarding the effect of AOI, consistent with previous research, this group of typically developing adults made more fixations to the eyes than the mouth or the nose. A similar number of fixations was made to the nose and

mouth, collapsed across emotion. The inter-emotion analyses revealed an effect of emotion on the number and proportion of fixations, particularly during the speeded task. Most notably, participants fixated the eyes of fearful faces more so than other emotions, and this difference was significant for all but angry and disgusted faces. They made more fixations to the lower half of fearful and happy faces, relative to other emotional faces. There was also a small main effect of task, and a 3-way task by AOI by emotion interaction on visual scanning such that participants fixated the eyes of happy faces more than the eyes of other emotional faces during the non-speeded task. During the speeded task, they made more fixations to the mouth of happy faces than other emotions. As such, during the non-speeded task they made proportionally more fixations to the eyes of happy faces relative to the eyes of other emotions and on the speeded task they made proportionally fewer fixations to the eyes of happy faces relative to the eyes of other emotions. Regarding reaction time, as predicted, participants were fastest at labeling happy faces. Reaction times were related to total number of fixations to each faces, along with the number of fixations made to the eye and nose regions. Participants were most accurate at labeling happy faces and least accurate at labeling fearful faces. Generally, the more participants fixated on the lower part of the face, the lower their accuracy. Happy and surprised accuracy were unrelated to fixation variables. Fixating the lower part of the face was related to higher accuracy for sad faces on the speeded task only.

Taken together, this study contributes several novel findings that expand upon the current facial emotion perception and visual scanning literature. Notably, this is the first known study examining the visual scanning of emotional faces to employ both a speeded and non-speeded task in which angry, disgusted, happy, fearful, sad, surprised and neutral

faces were randomly presented. Evidence of emotion- and task-specific visual scanning suggests that it is important to address both emotion and speed in patient studies. As discussed below, visual scanning was related to both reaction time and accuracy. These findings could help inform future eye-tracking based treatment studies.

Objective 1: Area of Interest (AOI)

The goal of objective 1 was to examine the number and proportion of fixations made to the eye, nose and mouth regions of the face. Like Vassallo et al (2009)'s findings, this study's AOI analysis provides clear evidence that typically developing adults make significantly more fixations to the eyes than other features of the face (Corden et al, 2008; Gillespie et al., 2015;Williams et al., 2008; Norton and Stark, 1971). Moreover, our results are also consistent with Vassallo et al.'s (2009) finding that attention (i.e., raw fixations) to the mouth, collapsed across emotion, does not differ from attention to nose. The mouth is frequently in participants' field of view (i.e., peripheral/parafoveal vision; Strasburger, Rentschler, & Jüttner, 2011) when viewing the nose and vice versa. Therefore, it is important to note that, consistent with the importance of the amygdala in mediating attention to the eyes (Pessoa and Adolphs, 2010), the typically developing adults in the present study spent significantly more time fixating on the upper part of the face (i.e., the eyes) than the lower part of the face.

The effect of AOI evidenced in the present study converges with previous eye-tracking (e.g., Vassallo et al., 2009) and non-eye-tracking studies (e.g., Smith et al., 2005) of FEP. This finding may be particularly informative for the development of future treatment research given that mounting evidence suggests that a relatively low number of fixations to the eyes of emotional faces may be a marker of reduced brain fitness in

neurological patients (Adolphs et al., 2005), persons with varying psychopathology (Gillespie et al., 2015; Marsh and Williams, 2006) and typically aging adults (Circelli et al., 2013). Vassallo et al. (2009) argue that reduced attention to the eyes reduces participants overall visual scanning "efficiency".

Exploratory correlation analysis demonstrating that fixations to the nose may account for 8-10 % of the variance in reaction time extends Vassallo et al.'s (2009) finding that those who exhibited longer reactions times made significantly more nose fixations. The effect of instructions aimed at reducing nose fixations warrants further study. It might be that nose fixations help to accommodate naturally occurring neurological / cultural variability or that reducing nose fixations could universally improve visual scanning efficiency (i.e., accuracy and reaction time) in all participants.

Evidence that our AOI effects converge with those of previous studies also reinforces the quality of the facial emotion stimuli created in-house as part of the current dissertation project. It suggests that participants responded to the new stimuli as anticipated and, therefore, these stimuli can be used to provide additional stimuli and greater power, in combination with the POFA (Ekman & Friesen, 1979) and JACFEE (Matsumoto and Ekman, 1989) stimulus sets.

Objective 2: Effect of Emotion

Unlike the majority of studies in typically developing adults (Loughland, Williams, & Gordon, 2002b; Vassallo et al., 2009; Williams, Loughland, Gordon, & Davidson, 1999), and in-keeping with objective 2, fixation differences were also analyzed by emotion in the current study. Our results are some of the first to demonstrate inter-emotion visual scanning differences among typically developing young adults. The inclusion of not only

a large number of stimuli but also a novel voice key based speeded task allowed us to demonstrate that typically developing individuals fixate the eyes of fearful faces significantly more than those of other emotions.

Although Vassallo et al. (2009) employed a similar paradigm, their study analyzed a total of 18 stimuli and therefore lacked the requisite power to conduct inter-emotion analyses. Similarly, Hunnius et al.'s (2011) study examined inter-emotion differences. However, this study employed only a non-speeded task (i.e., 10 second stimulus presentation) and was primarily interested in adults visual scanning of emotional faces in comparison to that of infants.

Consistent with hypothesis 2, which predicted that participants would make more fixations to fearful faces than other emotions, the inter-emotion data clearly demonstrate that typically developing adults not only make significantly more fixations to the eyes of fearful faces, but also significantly different fixation patterns to happy faces, particularly on the speeded task. Adolphs et al.'s (2005) seminal eye-tracking patient study illustrates that eye fixations are essential to accurate identification of fearful faces. Nonetheless, only a non-speeded task was employed in the Adolphs et al. (2005) study. Moreover, proportional fixation data but not raw fixation data were reported.

More specifically, our results indicate that during the speeded task, participants made the fewest overall fixations to the features of happy faces. In keeping with previous behavioural studies, happy faces are consistently labeled more accurately and more quickly. Therefore, number of fixations may be related to task difficulty, even among typically developing young adults.

Neuroimaging studies are needed to further explore how the neural substrates of happiness differ from that of negatively valenced emotions (Williams, McGlone, Abbott, & Mattingley, 2005). Imaging data (e.g., Lane, Reiman, Ahern, Schwartz, & Davidson, 1997) and patient lesion studies (Terasawa, Kurosaki, Ibata, Moriguchi, & Umeda, 2015) suggest that although an intact insular cortex is required for negative emotion processing (e.g., angry, fearful, disgust and sadness), happiness and positive valence discrimination are accomplished in the absence of insular activation / intact functioning. Morris, Frith, Perrett, Rowland, Young, Calder et al. (1996)'s seminal positron-emission tomography study demonstrated that left amygdala activation was positively correlated with fearful face intensity and negatively correlated with happy face intensity. Therefore, although more imaging data and combined imaging – eye-tracking studies are needed, the present study's inter-emotion fixation differences are consistent with available inter-emotion neuroimaging differences. It is important to note that fixation, speed and accuracy differences that emerge for happy faces relative to negatively valenced stimuli may be related to methodological limitations of most studies. Most studies have employed only one positive emotion (e.g., happy) and multiple negative-valenced faces, thereby making the positive discrimination easier than negative discrimination (Green et al. 2004).

Our emotion x AOI interaction and emotion x task interaction effects converge to demonstrate that our participants made the most fixations to the eyes of fearful faces. Our speeded task was especially useful for precipitating these effects. Again, consistent with Pessoa and Adolphs (2010) model and mounting facial emotion perception research (e.g., Smith et al., 2005), we found that the number of fixations made to the eyes of negative valence "withdrawal", high arousal emotional faces (fearful, angry, disgust;

Adolphs et al., 2002; Russel et al., 1989) was greater than the number of fixations made to the eyes of positive valence, "approach" emotional faces (happy, surprised) and low arousal faces (e.g., sad, neutral; Williams et al., 2008). Interestingly, participants' neutral face fixations were not unique. Participants appeared to be comparing neutral faces against the faces of other emotions (e.g., sad), consistent with findings from behavioural studies (Williams et al., 2008). Schurgin et al.'s (2014) recent study proposed that individuals are scanning for the absence of emotion when they view neutral faces.

Objective 3: Effect of Task

Consistent with our hypotheses, we found a small, but significant effect of task. Our happy and surprised face data suggest that participants made proportionally fewer fixations to the eyes of positively valenced faces during the speeded task than during the non-speeded task. Whether fixations to the lower region of the face facilitate valence discrimination, particularly during speeded conditions, warrants further study. It may be informative to analyze participants' initial mouth fixation times.

The present study's task-related findings are particularly relevant to future treatment development and emotion perception studies in two critical ways. First, the main effect of emotion and the emotion by AOI interaction were particularly salient during the speeded task. The proportional data suggest that visual scanning is more emotion specific under speeded conditions. It may be especially important to be aware of emotional cues during speeded conditions. Our results suggest that including both speeded and non-speeded eye-tracking tasks strengthened the current study and may be beneficial to future FEP research.

Second, despite these benefits, the similarities between the proportion of fixations to the features of the face on non-speeded and speeded emotion labelling tasks (see Figure 8) suggest that the two tasks could be used in a graduated fashion during emotion perception treatments. It may be that additional attention to the eyes of happy faces on non-speeded tasks facilitates self-regulation (e.g., oxytocin release, Meyer-Lindenberg,Domes, Kirsch, Heinrichs, 2011; amygdala changes, Adolphs & Pessoa, 2010, Vuilleumier, & Pourtois, 2007). Further, as discussed above, results on the speeded task suggest that attending to the mouth may allow for "quick" positive- vs. negative-valence discrimination.

Objective 4a and 4b: Reaction Time

Object 4a was designed to investigate the effect of emotion on reaction time and objective 4b aimed to explore whether visual scanning (i.e., fixation) variables were related to reaction time. The majority of emotion labeling research has included only a non-speeded task (e.g., Adolphs et al., 2005; Corden et al., 2008; Johnson et al., 2007; Schurgin et al., 2014) or a non-timed task (Bornhofen, & McDonald, 2008a; Gillespie, Rotshtein, Wells, Beech, Mitchell, 2015; Prochnow, Donell, Schäfer, Jörgens, Hartung, Franz, & Seitz, 2011). As predicted in hypothesis 4a, emotion influenced the speed at which emotional faces were labelled, with happy faces being labeled more quickly than other emotional faces. Further, fearful faces required the longest labeling time. The impact of emotion on reaction time identified in the current study converges with that of Vassallo et al. (2009) and Williams et al.'s (2009) findings. Happy faces were labeled more quickly than all other emotions in Vassallo et al.'s (2009) eye-tracking and Williams et al.'s (2009) behavioural study. Vassallo et al.'s (2009) participants also

labeled surprised faces more quickly than all negative emotions, and sad faces were labeled more quickly than fearful faces. No other significant differences were reported. Notably, follow-up t-tests determined that the only emotional faces women labeled more quickly than men were happy faces.

In Williams et al. (2008)'s behavioural study, pairwise comparisons demonstrated significant reaction time differences according to the following pattern, happy < neutral < sadness < anger < disgust < fearful. Like Vassallo et al.'s (2009) results, neutral faces were also labeled more quickly than negatively valenced emotions in the current study. Similarly, sad faces were labeled more quickly than fearful faces. This is not only consistent with the research differentiating happy and neutral faces from negatively valenced emotions. but further confirms the quality and validity of the stimulus battery created for, and employed in the current study.

Regarding objective 4b, the relationship between visual scanning and reaction time was not reported in Vassallo et al.'s (2009) study. As such, the current dissertation study is one of the only known eye-tracking studies in typically developing adults to explore the relationship between fixations made to emotional faces and reaction time. Evidence that longer emotion labeling times were associated with more fixations to the face, not only in the eye region, but also in the nose region, may have implications for future treatment studies. As discussed below, visual attention to the nose was only positively correlated to the accurate labeling of sad faces; this may actually represent a relationship between viewing of the mouth (i.e., in peripheral or parafoveal vision; Schurgin et al., 2014) and accuracy. Given that many patients with TBI experience reduced processing speed (e.g., Farbota, Sodhi et al., 2012; Ruttan et al., 2008),

increasing the efficiency of patients' scanning and thereby reducing the number of fixations made to emotional faces may reduce the labeling time. For instance, it may be important to determine whether fixating the nose is beneficial to emotion processing in some way (e.g., perhaps reducing feelings of anxiety or arousal). Alternatively, eye-tracking research in other neurological populations suggests that patients who exhibit high numbers of fixations to emotional faces have executive functioning impairments and may over-fixate features of the face (Clark et al., 2010). It may be valuable to determine whether labeling time among typically developing individuals and patients can be decreased by reducing fixations to the nose without reducing participant accuracy.

In addition to the information provided in terms of this dissertation's a priori reaction time hypotheses, one of the present study's novel contributions is that the reaction time data are approximately 1-3 seconds shorter than those reported by previous studies that did not use a voicekey (Vassallo et al., 2009; Williams et al., 2008). This is the case even for studies that incorporated some of the same stimuli (Vassallo et al., 2009) as the current dissertation study, and for studies that excluded surprised faces (Williams et al., 2008). A labeling task without surprised faces would be simpler than a labeling task with surprised faces as surprised and fearful faces are both high arousal emotions, and can sometimes be confused (Adolphs, 2002).

The reaction time results underscore the speed at which facial emotions are identified, even when an explicit response is required. As indicated above, patient populations, and specifically those with TBI, are frequently vulnerable to reduced processing speed (e.g., Fragerholm et al., 2015; Millis et al., 2001; Ruttan et al., 2008). Voicekey evidence that typically developing adults can label faces even more quickly

than previously reported suggests that slow processing speed may render facial emotion processing even more difficult than previously understood, particularly in social situations in which facial emotions are explicitly identified or discussed (e.g., family, friend and colleague interactions). Taken together, including a speeded task with a voicekey in this study provided invaluable information. This study's reaction time data replicated and extended previous effects of emotion on reaction time data. The data demonstrated some of the fastest explicit labeling times reported in the emotion labeling literature, and also provided some of the first evidence that visual scanning (i.e., fixations) of emotional faces is related to emotional labeling time.

Objective 5a and 5b: Accuracy

Consistent with hypothesis 5a, and studies of both behavioural (Williams et al., 2008) and brain injured patient populations (Aldophs et al, 1996; Bornhofen et al. 2008), we have shown that happy faces (i.e., positive valence faces) are identified more accurately than negatively valenced emotions. Focal lesion patient research (e.g., Adolphs, et al,, 1996) suggests that although neither left nor right hemisphere lesions impair the identification and rating of happy faces, intact right hemisphere functioning is essential for accurate labeling of negative emotions.

With respect to hypothesis 5b, the current exploratory correlational analyses demonstrating relationships between visual scanning and accuracy for fearful, angry, disgusted, sad and neutral faces in typically developing young adults extends Gillespie et al.'s (2015) findings and is one of the most comprehensive to date. These fearful and angry visual scanning and accuracy correlations converge with, and extend those of Gillespie et al. (2015). Their study did not include neutral faces. Also, the relationship

between visual scanning and disgusted, happy, sad and surprised face labeling accuracy was not reported. Our findings show that participants who look longer at the lower part of negatively valenced, high arousal emotional faces (i.e., angry, disgusted, fearful; Adolphs, 2002) are less accurate. Nonetheless, looking at the lower part of sad (i.e., negative valence, low arousal) faces may be beneficial. Some evidence suggests that this may facilitate neutral vs sad face discrimination, even though "sad eyes" also contain essential information (Williams et al., 2008). This is consistent with our finding that looking at the eyes of neutral and sad faces for longer periods of time was associated with reduced accuracy. A larger, more sex-balanced sample is needed to further investigate this finding. With respect to future treatment development studies, our findings provide clear evidence of the interaction between visual scanning and emotion-specific accuracy. Importantly, Rosenberg et al. (2014) recently demonstrated that stimulus difficulty is also related to emotion labeling accuracy. Difficulty is another variable that warrants further study.

Notably, a large internet- and *f*MRI-based study (i.e., involving 341 male university students / faculty; Corden, Critchley, Skuse, & Dolan, 2006), found that approximately 8.8% of typically developing men exhibit low fearful face labeling accuracy (i.e., score = $\leq$ 50%) and that this is related to reduced connectivity between the amygdala, the anterior superior temporal cortex and the temporal pole. These areas are central to Pessoa and Adolphs (2010) model, and they process face information in concert with the medial prefrontal cortex and fusiform gyrus. Together, these areas are sometimes referred to as the "social brain" (Kennedy & Adolphs, 2012). Particularly given the variability reported by Coden et al. (2006) and other studies, our sample

appears to be relatively representative of the typically developing population of young adults, and highlights the need for additional imaging studies investigating the relationship between accuracy and social brain function.

Conclusions

The current study extends the findings of not only Vassallo et al.'s (2009) eye-tracking study, but also the relevant and recent FEP literature (e.g., Gillepsie et al., 2015; Smith et al., 2005). Like Vassallo et al. (2009), we found that typically developing young adults fixate on the upper part of the face more than on both the nose and the mouth. Contrary to our hypothesis, but consistent with Vassallo et al. (2009), we found that number of fixations made to nose and mouth does not significantly differ. As discussed above, these findings are consistent with Pessoa and Adolphs' (2010) neuroanatomical multiple waves model of emotion perception and mounting studies of amygdala function and facial emotion perception. Notably, when fixating on the lower part of the face, it is likely that both the nose and the mouth are typically in participants' field of view (i.e., parafoveal vision), even when only one of these structures is in participants' central vision (Strasburger et al., 2011).

The present study also extends Vassallo et al.'s (2009) AOI findings by providing percent fixation data, which can be used as a basis of comparison when examining existing and future patient studies. Moreover, we found that number of fixations was strongly correlated with reaction time and that there are significant relationships between both number of eye and nose fixations and reaction time. Our novel voicekey-based paradigm allowed us to determine that typically developing adults are able to label facial emotions 1-3 seconds faster than previously reported. This suggests that individualized,

patient-specific interventions aimed at helping patients to make an efficient number of fixations to the face (e.g., reducing nose fixations) may reduce reaction time and improve social integration.

This study is one of the first to provide a detailed characterization of typically developing young adults' inter-emotion visual scanning differences to emotional faces. More specifically, our emotion x AOI interaction and emotion x task interaction effects converge to demonstrate that our participants made the most fixations to the eyes of fearful faces. Our speeded task was especially useful for precipitating these effects. We found that the number of fixations made to the eyes of negative valence, high arousal (i.e., "withdrawal") emotional faces (fearful, angry, disgust; Adolphs, 2002; Russell, Lewicka, & Niit, 1989) was significantly different from the number of fixations made to the eyes of positive valence (happy, surprised) and low arousal, negative valence faces (e.g., sad, neutral).

Whether the distribution of upper and lower face fixations made to emotional faces aids in participants' behavioural regulation and approach / withdrawal behaviours warrants further study. Consistent with our hypotheses, we found a main effect of task. Our happy vs fearful fixation data, together with our task data suggest that fixations to lower part of the face may facilitate valence discrimination, particularly during speeded conditions.

With respect to future treatment development studies, these results underscore the importance of including a large number of stimuli, and both a speeded and non-speeded task. Task effects suggest that non-speeded and speeded tasks could be utilized in a graduated fashion by rehabilitation patients vulnerable to processing speed impairments.

The speeded task is arguably more ecologically valid given the speed at which inter-personal judgements are made in everyday inter-personal social and professional situations (Spell & Frank, 2000). The emotion effects highlight the importance of the amygdala and the limbic system. Regarding this study's clinical implications, the findings suggest that individualized treatments that incorporate instruction to improve attention to the eyes of emotional faces (i.e., mediated by the amygdala), along with evidence-based treatments that enhance arousal (e.g., self-alerting; O'Connell, Bellgrove, Dockree, & Robertson, 2006), sustained attention (e.g., goal management training; Levine, Robertson, Clare, Carter, Hong et al., 2000; Levine, Schweizer, O'Connor, Turner, Gillingham et al., 2011) and relaxation (e.g., mindfulness meditation; Creswell, Way, Eisenberger, & Lieberman, 2007; Davidson, Kabat-Zinn, Schumacher, Rosenkranz, Muller et al., 2003; Jha, Krompinger, & Baime, 2007; Kabat-Zinn, 1994), may be especially effective for promoting social integration among neurologically injured patient populations.

Chapter 3

Visual Scanning of Emotional Faces following Traumatic Brain Injury

Moderate to severe TBI is often associated with FEP deficits – a consequential impairment in, and of itself (Green et al., 2004; McDonald, 2013). Evidence demonstrates that FEP deficits are related to social integration problems following TBI (Knox & Douglas, 2009). Social integration is an important predictor of life satisfaction and quality of life among individuals with TBI (Corrigan et al., 2007; Spell & Frank, 2000). Although many individuals with TBI regain physical, cognitive and basic language functioning, impaired social skills often impede effective participation at home, work and school. Further, social isolation has been reported to be "the single biggest" problem 10-15 years post injury (Thomsen, 1984).

Treatment of FEP impairments is critical if poor outcomes are to be minimized (Babbage et al., 2011; Radice-Neumann et al., 2007); however, few emotion perception interventions have been designed for patients with TBI to date (McCabe et al., 2007; Spell & Frank, 2000, McDonald et al., 2008). A growing number of studies in patients with other neurological conditions illustrate that aberrant visual scanning of emotional faces decreases FEP accuracy (e.g., Adolphs et al., 2005; Corden et al., 2008). Therefore, several questions were examined in the second half of this dissertation with the aim of informing future visual scanning-based FEP treatment studies in patients with TBI. The current study compared the amount of time spent attending to eyes, nose and mouth, and the remainder of the face in a group of patients with TBI and a control group. It explored whether visual scanning differences in the control group and TBI group differed by facial emotion, and it explored differences in emotion labeling time and accuracy in the TBI

group and the control group. Group differences in visual scanning were examined during a non-speeded and speeded task.

More specifically, this chapter addresses FEP in patients with TBI, and compares the results to those of typically developing adults. FEP was examined using the two FEP tasks described above. These differed according to pacing demands, with a non-speeded and a speeded task during which participants were asked to respond as quickly as possible. Emotion was also manipulated (i.e., angry, disgusted, fearful, neutral, happy, sad, and surprised).

Dwell time was measured both by proportion (i.e., relative fixation time in an AOI), and by raw values (i.e., total number of milliseconds in an AOI). Reaction time was measured during the speeded task only. Accuracy refers to the total number of emotions correctly identified.

Study 2: Objectives and Hypotheses

Objective 1a and 1b: Area of Interest (AOI)

To compare the visual scanning of emotional faces as measured by dwell time between groups, collapsed across emotion.

Objective 1. To compare dwell time to salient features and less salient features of the face between the control and TBI participant groups during the 1a non-speeded task, and 1b the speeded task.

Hypothesis 1. Based on existing non-TBI patient eye-tracking findings and FEP behavioural studies in patients with TBI, it was hypothesized that participants with TBI would exhibit different scanning patterns than controls. Specifically, on both the 1a) non-speeded task, and the 1b) speeded task, it was predicted that patients would evidence

shorter proportional dwell times to the eyes, and longer proportional dwell times to the nose and mouth relative to controls. Given that reduced speed of processing is a common impairment associated with TBI, it is predicted that the between group differences in AOI dwell time would be greater on the speeded task relative to the non-speeded task.

Objective 2: Effect of Emotion

Objective 2a. To examine 2ai) the effect of group on visual scanning by emotion by AOI on the non-speeded task and the 2aii) speeded task.

Hypothesis 2a. Based on the non-TBI patient findings reviewed in chapter 1, it was hypothesized that a significant group x emotion interaction would be observed on both the 2ai) non-speeded task and 2aii) - the speeded task. Further, it was predicted that control-group participants would exhibit more strategic visual scanning during the speeded task than participants with TBI. For example, among participants without TBI, larger inter-emotion effects would be observed on the speeded task than the non-speeded task. Group x emotion x AOI interactions would be observed for the individual facial features (e.g., the eye, AOI). Given existing literature in other patient populations, it was hypothesized that there would be a group by emotion interaction effect on visual scanning to the eyes in particular (i.e., proportion of dwell time spent attending to the eyes), which would be especially apparent for fearful faces and negatively valenced faces, more broadly.

Objective 2b. To explore effect of emotion on visual scanning of the eyes and the lower features of the face (i.e., nose and mouth) *within* the TBI group. A separate within-subject analysis was also conducted within the control group. This was meant to serve as a basis of comparison for the TBI group analysis.

Hypothesis 2b. Based on the results from the typically developing adults in chapter 2, it was hypothesized that AO1-specific 1-way ANOVAs would demonstrate that the patient group allocated more time to the eyes of some emotional faces (e.g., fearful) relative to others (e.g., neutral, happy). Further it was predicted that visual inspection of the partial eta squares would help determine whether, as hypothesized, the effect of emotion on visual scanning of the eye region was smaller within the patient group than it was within the control group.

Given evidence from other patient populations, it was hypothesized that 1-way ANOVAs would also demonstrate a within subject effect of emotion on visual scanning to the features in the lower part of the face (i.e., nose + mouth AO) within the patient group. Further, it was predicted that visual inspection of the partial eta squares would help determine whether, as hypothesized, the effect of emotion on visual scanning to the lower part of the face was larger in the patient group than it was within the typically developing group. The 2b within-subject effect of emotion hypotheses were examined in both the 2bi) non-speeded task and the 2bii) speeded task.

Objective 3: Reaction Time

To compare reaction time between groups (collapsed across emotion), and by emotion. The speeded task allowed for the examination of reaction time. Therefore, Objective 3 hypotheses relate to the speeded task data only.

Objective 3a. To compare reaction time between the TBI and control group 3ai) collapsed across emotions and 3aii) for each individual emotion.

Hypothesis 3ai. Given that processing speed impairments are common following TBI, it was hypothesized that there would be a significant effect of group on reaction time.

Hypothesis 3aii. It was also predicted that a significant group by emotion interaction and follow-up independent samples *t*-tests would demonstrate that the TBI group was slower than the control group at labeling all emotional faces, except happy faces.

Objective 3b. To examine the effect of emotion on reaction time *within* the TBI patient group.

Hypothesis 3b. A significant effect of emotion on patients' reaction time was hypothesized; however, it was predicted that the effect of emotion would be smaller than that which is observed in control group (i.e., based on the partial eta^2). It was hypothesized that planned comparisons would show that, like control participants, patients with TBI identify happy faces the fastest in comparison to the other emotions. Also, it was predicted that fearful faces would be labeled most slowly. Like those of the control group, the patient group's facial emotion labeling times for neutral, surprised and non-fearful negative valence faces were predicted to be slower than its happy face labeling times but faster than its fearful face reaction times.

Objective 3c. This was one of the first known studies to examine the relationship between visual scanning and emotional face labeling reaction time after TBI. Given the range in overall viewing times (i.e., reaction times), an initial aim was to determine whether time of first fixation to the eye was related to labeling times in the patient group.

Hypothesis 3c. Time of first eye AOI fixation was hypothesized to be correlated with overall reaction time and emotion-specific reaction times

Objective 4: Accuracy

To compare accuracy 4a between groups, and 4b within the patient group for each individual emotion.

Objective 4a. To determine whether overall FEP accuracy is significantly different between the patient and control groups 4ai when all emotions are combined and 4aii by emotion on both the non-speeded and speeded task.

Hypothesis 4a. Based on previous FEP behavioural studies in patients with TBI (i.e., reviewed in chapter 1), with respect to emotion labeling accuracy, it was predicted that controls would be significantly more accurate than patients on both tasks, at 4ai) labeling emotions overall, and 4aii) at labeling each emotion individually, especially fear, with the exception of happy.

Objective 4b. To compare FEP accuracy *within* the TBI patient group by emotion on both the non-speeded and speeded task.

Hypothesis 4b. It was hypothesized that patients with TBI would be less accurate at labelling negatively valenced faces, including fearful and neutral emotions, relative to happy faces, during both the non-speeded and speeded tasks.

Objective 4c. To examine the relationship between visual scanning (i.e., proportional dwell time; raw dwell time) of the eye region, nose region, and mouth region, and FEP accuracy in the TBI group.

Hypothesis 4ci. Based on Study 1, and previous eye-tracking studies in other populations reviewed in chapter 1, it was hypothesized that visual scanning (i.e.,

proportion of dwell time) to the lower part of the face (i.e., nose, mouth) would be negatively correlated with accuracy in the TBI group during both the non-speeded task and the speeded task.

Hypothesis 4cii. Conversely, it was hypothesized that visual scanning to the upper part of the face (i.e., eyes) would be positively correlated with accuracy in the TBI group.

Study 2: Method

Participants

Thirteen patients (9 males) with moderate-severe TBI were recruited from on-going research studies and the brain injury rehabilitation unit at the Toronto Rehabilitation Institute. Common inclusion criteria across both the patient and control groups included normal or corrected-to-normal face recognition (i.e., based on the Benton Face Recognition test, as in previous studies; Ietswaart et al., 2008). Soft contacts but not glasses were permitted. Patient group inclusion criteria were as followed: (1) Acute care medical diagnosis of TBI; (2) PTA of 1 hour or more and/or GCS of 12 or less either at Emergency or the scene of accident and/or positive CT or MRI findings; (3) age between 17 and 70; (4) able to follow simple commands in English based upon Speech Language Pathologist intake assessment; and, (5) competency to provide informed consent for the study or the availability of a legal decision maker. Patient group exclusion criteria included: (1) inaccessible medical chart; (2) TBIs that resulted from blast or penetrating injuries (3) conditions primarily or frequently affecting the central nervous system, including dementia of Alzheimer's Type, Parkinson's Disease, Multiple Sclerosis, Huntington's Disease, Lupus, or stroke; (4) history of a psychotic disorder or clinical depression (based on self-report); (5) not emerged from PTA by 6 weeks post-injury; and,

(6) failure on a symptom validity test (e.g., Test of Memory Malingering) during any of the other on-going research studies. Two males were excluded due to bifocal use that prevented the eye tracker from tracking the pupil. One female was excluded due to lack of medical chart access. This resulted in a patient sample of 10.

Patients had a mean age of 41 (S.D. = 13.61) and 17 (S.D. = 1.93) years of education. They had lived a mean of 84.83% (S.D. = 29.75) of their lives in a multicultural metropolitan city. A chart review determined that patients' self-reported symptoms of depression were well within normal limits (i.e., Beck Depression Inventory scores in the minimal-mild range, with only one participant reporting symptoms in the mild range) and their estimated intellectual functioning was in the average range or above based on measures with strong psychometric properties among patients with neurological conditions (e.g., Wechsler Test of Adult Reading, Wechsler Abbreviated Scale of Intelligence nonverbal reasoning subtest; Adolphs et al., 2002; Green, Melo, Christensen, Ngo, Monette,, & Bradbury, 2008; Strauss et al., 2006). Injury characteristics are presented in Table 5. In addition to normal visual perception, control participant inclusion criteria were as follows: 19 years of age or greater. Exclusion criteria were as follows: history of psychiatric illness, neurological condition or concussion requiring hospitalization, substance abuse, clinical depression or anxiety disorder (based on self-report), developmental disability, or ophthalmological condition. Additional demographic data are presented in Table 6.

Table 5

Patient Injury Characteristics

ID	*Sex*	*YOE*	*Age*	*Injury Mechanism*	*Lowest GCS*	*PTA / LOC / Aphasia*	*Injury Severity*	*Months Post TBI*
01p	M	18	52	Sports	12	NA	Moderate	4
02p	M	21	65	MVA, driver	3 (unresponsive)	30 days PTA	Very Severe	4
03p	M	15	49	Fall	NA	Aphasia	Moderate	24
04p	W	18	39	Sports	6	14 days PTA	Severe	12
05p	M	18	53	MVA, driver	4	18 days PTA	Very Severe	4
06p	M	16	37	Fall	3	21 days PTA	Very Severe	12
07p	M	18	40	Sports	14	3-4 days PTA	Moderate	4
08p	M	18	24	MVA, driver	5	14 days PTA	Very Severe	12
09p	W	17	25	MVA, passenger	6T-9	14 days PTA	Moderate -Severe	12
10p	W	14	27	MVA, pedestrian	4	14 days LOC	Very Severe	12

Note. LOC = loss of consciousness, MVA = motor vehicle accident, NA = not available, PTA = post-traumatic amnesia, T = two subscale

A convenience sample of 18 control participants was selected from the original Study 1 control sample. In addition to the Study 1 inclusion criteria, the Study 2 control group sample was selected based on sex and age. All males from the original sample and women who were 19 years of age or older (i.e., the oldest control sample females) were included in the Study 2 analysis. One control female (i.e., 15cf) born before 1992 was an outlier and was excluded. Her non-speeded and speeded task mean overall eye AOI proportional dwell times, collapsed across emotion, were approximately 2 standard deviations below the mean and inclusion of her data resulted in a violation of the normality assumption based on the Shapiro-Wilk test of normality (i.e., $p < .05$; Ghasemi, & Zahedias, 2012).

This resulted in a Study 2 control group sample of 17 participants (9 males). Participants had a mean age of 20.97 years (SD = 3.47) and 14.23 (S.D. = 2.67) years of education. They had lived a mean of 80.83% (SD = 24.51) of their lives in multicultural metropolitan city. Additional demographic data are presented in Table 4. Note that patient group participant 09p obtained eye AOI proportional dwell times that were approximately 2 standard deviations above the mean. She was not removed given that the Shapiro-Wilk test was not significant and variability is common among TBI samples. Table 6.

Study 2: Group Demographics

Group	Age	Years of Education	BFRT	Years in Metropolitan City (%)	Years in a Canada / US (%)
TBI					
10 (7 men)	41(13.61)**	17 (1.93)**	46.60 (3.95)	84.83 (29.75)	67.9 (34.18)
Control					
17 (9 men)	20.97(3.47)	14.23 (2.67)	47.18 (3.47)	80.83 (24.51)	86.65 (17.77)

Note. *M(SD)*. BFRT = Benton Face Recognition Test, ***p.* < .01

Data analysis. Similar to Study 1, visual scanning emotion recognition accuracy and reaction time data were analyzed using as series of between-within analysis of variance (ANOVA). In Study 2, group (i.e., TBI versus control) was the between subject variable. Independent variables included (i) facial expression (neutral, angry, disgusted, fearful, happy, sad, surprised), and (ii) area of interest (AOI) as independent variables. The dependent variables were as follows (i) raw dwell time, (ii) proportional dwell time, (iii) reaction time and (iv) accuracy. Correlations were also conducted to analyze the relationship between visual scanning (e.g., time spent in each AOI), and both reaction time and accuracy. Homogeneity of variance was evaluated using Levine's and Bartlett's tests. The reaction time data were positively skewed and were transformed using a logarithmic transformation according to Tabachnick and Fidell (2013). The Greenhouse-Geisser correction was applied when the assumption of sphericity was violated.

Results

Objective 1a and 1b: Between-Group Effect of Areas of Interest (AOI)

Regarding hypothesis 1, group and AOI effects were initially analyzed using a series of task-specific mixed 2 x 3 ANOVAs, with group as a between-subject variable and AOI as a within subject variable. As predicted, there was a significant main effect of group on participants' visual scanning for both the 1a non-speeded task and the 1b speeded task. The between-group effect was evident in both the proportional non-speeded task data, $F(1, 25) = 4.50$, $p = .036$, partial $\eta^2 = .16$ and the proportional speeded task, $F(1, 25) = 24.38$ $p < .001$, partial $\eta^2 = .49$. During the non-speeded task, patients with TBI looked at the less salient features of emotional faces combined (e.g., cheeks, forehead, chin), approximately 5.9% of the time and controls looked at the less salient

features of the face approximately 2.6% of the time, overall. During the speeded task, the TBI group attended to the less salient features of the face approximately 8.4% of the time and the control group looked at the less salient features of the faces approximately 1.8% of the time.

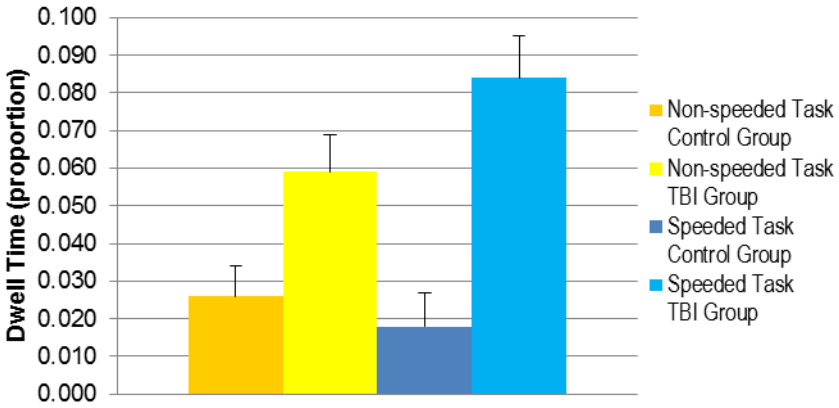

Figure 11. Dwell Time on Non-Area of Interest (AOI) Regions of the Face. Error bars indicate standard error around the mean.

Table 7

Percent Dwell Time on Non-Area of Interest (AOI) Regions of the Face

Group	Non-speeded Task	Speeded Task
Control	2.6% (0.008)	1.8% (0.010)
TBI	5.9% (0.009)*	8.4% (0.011)***

Note. Mean (SD), $p < 0.05$, *** $p < 0.001$.

As predicted, additional variance in visual scanning was also accounted for by significant group x AOI interactions. These emerged in the proportional dwell time data with respect to time spent fixating the eye, nose and mouth AOIs on both the non-speeded task, $F(1.36, 34.00) = 4.85$ $p < .025$, partial $\eta^2 = .163$, and the speeded task, $F(1.28, 31.90) = 7.48$ $p < .006$, partial $\eta^2 = .230$. Further, although both groups viewed the face stimuli for the same amount of time during the non-speeded task, there was a

marginally significant group x AOI interaction, $F(1, 36)= 3.56$, $p = .059$, partial $\eta^2 = .12$, that accounted for a moderate amount of variance in non-speeded task raw dwell time (Cohen, Miles & Shevlin, 2001). The group x AOI interaction did not account for a significant amount of variance in speeded task raw dwell time, likely due in part to the small sample size, $F(4.22, 105.45) = 1.98$, $p = .108$, partial $\eta^2 = .072$.

Planned independent samples *t*-tests demonstrated that on both the non-speeded task, $t(25) = -2.66$, $p = .013$ and the speeded task, $t(25) = -3.35$, $p = .003$, participants with TBI attended to the eyes for a shorter proportion of time. Also as predicted, the patient group attended to the mouth for proportionally longer relative to the control group on the non-speeded task, $t(25) =1.847$, $p = .077$, and the speeded task, $t(25) = 2.02$, $p = .055$. This visual scanning difference was marginally significant, likely due to a relatively small sample size.

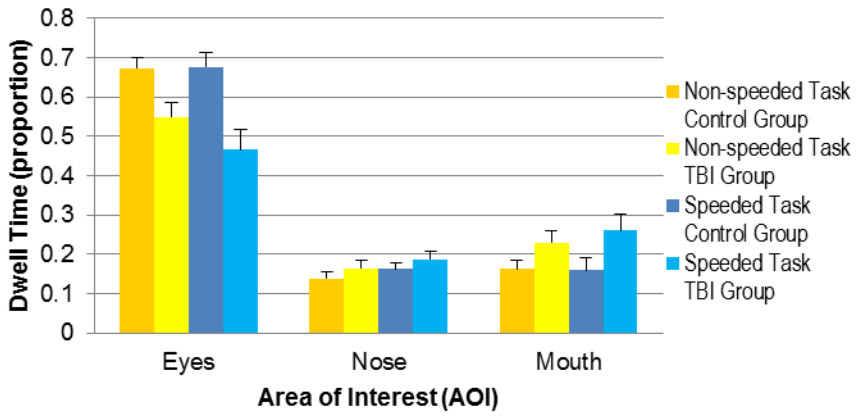

Figure12. Effect of Area of Interest (AOI) on Proportional Dwell Time. Error bars indicate standard error around the mean.

During the non-speeded task, when viewing time was held constant (i.e., at 4000 milliseconds), the raw dwell time data demonstrated that the patient group looked at the eyes of emotional faces for a shorter amount of time, collapsed across emotion $t(25) = -$

1.95, $p = 0.063$. The patient group also attended to the mouth for a longer amount of time, $t(25) = 1.78$, $p = 0.087$. These effects were marginally significant.

Interestingly, consistent with the reaction time data, below, patients looked at the speeded task faces for approximately 500 milliseconds longer, when the data were collapsed across emotion and AOI, resulting in a main effect of group on the speeded task raw dwell time data, $F(1, 25) = 7.49$ $p = .022$, partial $\eta^2 = .231$. Despite the patient group's longer overall speeded task response time, (see Objective 3), speeded task raw dwell time to the eyes did not differ significantly by group, $t(25) = .19$, $p = .854$. However, during the speeded task, the patient group fixated both the nose, $t(25) = 3.33$, $p = .003$, and the mouth, $t(25) = 3.10$, $p = .005$, for significantly longer than the control group.

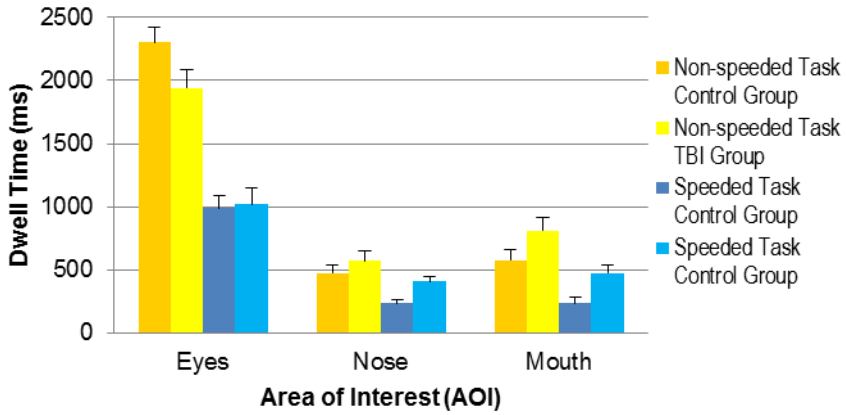

Figure13. Effect of Area of Interest (AOI) on (Raw) Dwell Time. Error bars indicate standard error around the mean, ms = milliseconds.

Objectives 2a and 2b: Between-Group and Within-Group Effects of Emotion

Regarding objective 2a, between-group emotion effects were initially analyzed using a series of task-specific, mixed 2 x 7 repeated measures ANOVAs, with group as a between-subject variable and emotion as a within-subject variable. With respect to hypothesis 2ai, the non-speeded task raw dwell time data evidenced a significant group x emotion interaction, $F(2.138, 53.457) = 10.64$ $p < .001$ partial $\eta^2 = .298$. Planned follow-up independent samples *t*-tests demonstrated that the TBI group spent significantly more time on the features of disgusted faces, $t(25) = 5.74$, $p < .001$. Although the patients spent less time on the features of all other faces as a group, sad, $t(25) = 1.78$, $p = .088$, was the only emotion for which this difference was marginally significant within the non-speeded task data. Given the relatively small main effect of group on the non-speeded task proportional data, the effect of group did not differ by emotion with respect to the non-speeded task proportional data, $p > .10$.

As predicted in hypothesis 2aii, there was a significant group by emotion interaction for the speeded task proportional dwell time data, $F(3.84, 96.07) = 3.17$ $p = .019$, partial $\eta^2 = .11$. Overall, the patient group looked at features (i.e., eyes, nose, mouth) of disgusted faces approximately 20% less than the control group, $t(9.08) = -3.74$, $p = .005$, illustrating that under time constraints they looked at less informative areas of the face (i.e., the cheeks) more than the control group and required more time overall. Similarly, they looked at the features of fearful, $t(11.90) = -3.16$, $p = .008$, sad, $t(9.07) = -3.28$, $p = 0.009$, and surprised faces, $t(25) = 3.52$, $p = 0.002$, approximately 6%, 10%, and 14% less, respectively. The aggregated feature-related proportional dwell times for angry, happy, and neutral faces were not significantly different by group ($p >$

0.10). Again, consistent with the reaction time data, the speeded task raw dwell time data indicated that patients needed more time (i.e., looked longer) on the aggregated features of neutral faces and all emotional faces relative to the control group, p = .006 - .074, except happy, p = .557, and sad, p = .149, faces.

The 3-way group x AOI x emotion interaction was not significant when the non-speeded task raw dwell time data were analyzed, $F(5.567, 138.997) = 1.80$, $p < .109$, partial $\eta^2 = .067$. The speeded task raw dwell time 3-way group x AOI x emotion interaction and the non-speeded task and speeded task proportional dwell time 3-way interactions were also not significant, $p > .10$. Therefore, the 3-way interactions were not analyzed in detail.

Notably, follow-up AOI-specific 2 x 7 ANOVAs addressing objective 2a, and a priori hypothesized group by emotion interaction effects on dwell time to the eyes confirmed a large group by emotion interaction on the 2ai non-speeded task proportional eye data, $F(1, 25) = 722.09$, $p = .013$, $\eta^2 = .221$; the 2aii speeded task proportional eye data, $F(1, 25) = 10.16$, $p = .004$, $\eta^2 = .289$. Nonetheless, it should be noted that these group differences were relatively constant across emotion. During the non-speeded task, the patient group spent proportionally less time on the eyes of angry, $p = .005$, disgusted, $p = .011$, happy, $p = .022$, sad, $p = .007$, and surprised faces, $p = .042$. During the speeded task, the patient group spent proportionally less time on the eyes of angry, disgusted, fearful, happy, surprised, $p < .001$- $p = .026$, and neutral faces, $p = 033$. This difference was marginally significant for speeded task sad faces, $p = .065$.

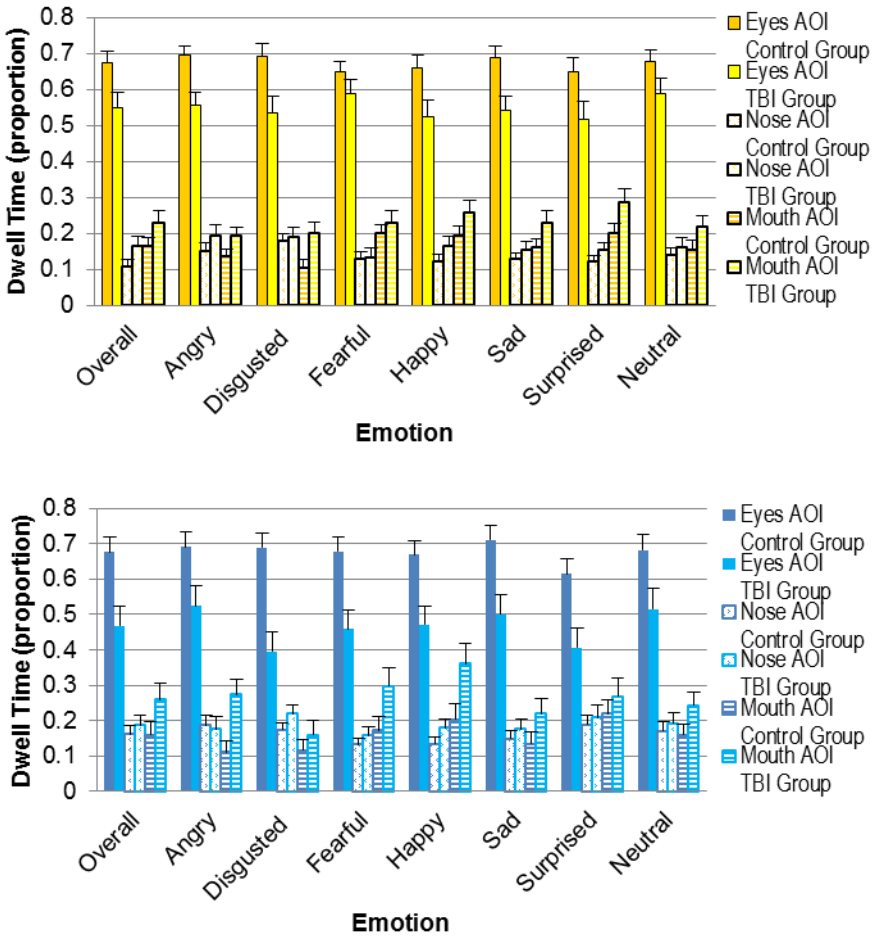

Figure 14. Effect of Emotion by Area of Interest (AOI) on Visual Scanning in the Control and TBI Groups. The top graph illustrates the effect of emotion on proportional dwell time to the eyes, nose, and mouth AOIs by emotion during the non-speeded task. The bottom graph illustrates the effect of emotion on proportional dwell time to the eyes, nose, and mouth AOIs by emotion during the speeded task. Error bars indicate standard error around the mean.

To further understand the within-subject emotion data, and with respect to objective 2b, planned 1-way ANOVAs were undertaken in the patient and control groups. In terms of hypothesis 2bi), the effect of emotion on raw dwell time to the eyes was marginally significant for the patient group, $F(6, 54) = 2.021$, $p = .079$, $\eta^2 = 183$ and

significant for the control group data, $F(2.39, 38.22) = 12.52$, $p < .001$, $\eta^2 = .439$, during the non-speeded task.

During the non-speeded task, patients spent significantly more time on the eyes of fearful faces than angry, $p < .001$, disgusted, $p = .012$, happy, $p = .025$ and surprised faces, $p = .035$. In addition to the eyes of fearful faces, they spent significantly more time on the eyes of neutral faces relative to happy faces, $p = 0.016$. For comparison purposes, during the non-speeded task, controls spent significantly less time looking at the eyes of disgusted faces relative to the eyes of all other emotional faces, $p < .001$-004, and neutral faces, $p < .001$. They also spent significantly less time on the eyes of fearful faces than the eyes of angry, $p = .032$, sad, $p = .012$ and neutral, $p = .015$ faces, and significantly less time on the eyes of surprised faces than the eyes of sad, $p = .029$ and neutral faces, $p = .020$.

Contrary to predictions in terms of the non-speeded task, the within-subject effect of emotion on visual scanning of the nose and the mouth was significant in the control group, $F(3.08, 49.82) = 6.25$, $p = .001$, $\eta^2 = .281$, but not the TBI group, $F(6, 54) = 1.82$, $p = .112$, $\eta^2 = .168$, using the raw data. Specifically, the control group looked significantly less at the features in the lower part of disgusted faces than all other emotional faces and neutral faces, $p < .001$ – $p = .012$. They also looked at the nose and mouth of angry faces significantly less than the nose and mouth of fearful faces, $p < .001$. These data suggest that there was more between-emotion variability in the control group's visual scanning of the lower part of the face when they are given more than sufficient time to label emotional faces. Further, their inter-emotion attention to the eyes also appears less strategic.

Regarding hypothesis 2bii, these analyses revealed a marginally significant effect of emotion on dwell time to the eyes for the speeded task with respect to the patient group, $F(6, 54) = 2.194$, $p = .058$, $\eta^2 = .196$, and a significant effect with respect to the control group, $F(3.73, 59.79) = 6.32$, $p < .001$, $\eta^2 = .283$.

Regarding hypothesis 2bii, on the speeded task, the patient group looked at the eyes of happy faces significantly less than all other emotions, $p = .037 - .049$, except disgusted faces. Time spent on the eyes of happy faces did not differ from time spent on the eyes of neutral faces, $p = 0.070$ and time spent on the eyes of disgusted faces was only marginally different from time spent on the eyes of happy faces, $p = 0.053$. Time spent on the eyes of fearful faces was not significantly different from time spent on the eyes of other negatively valenced faces, $p = .118$.

For comparison purposes, controls looked significantly longer at the eyes of fearful faces than the eyes of neutral faces, $p < .004$, and all emotional faces, except for disgusted faces, for which there was a marginal difference, $p < .088$. Similarly, on the speeded task, controls looked at the eyes of happy faces significantly less than all emotions, except for surprised, $p = .221$, and neutral faces, $p = .151$. Given that both the nose and mouth could be seen in participants' parafoveal vision (i.e., 5^o to the top and bottom of the point of fixation) when fixating the lower half of the face (Duchowski, 2003), the nose and mouth AOIs were combined to increase the power of the analyses. There was a within-subject effect of emotion on the patient group's visual scanning of the aggregated nose + mouth region for the speeded task, raw data, $F(6, 54) = 3.63$, $p = 0.004$, $\eta^2 = 0.287$. Specifically, patients looked at the nose and the mouth of angry faces significantly less than nose and mouth of surprised faces, $p = 0.018$. Similarly they

looked at the nose and mouth of happy faces significantly less than the nose and mouths of disgusted, $p = 0.004$, fearful, $p = 0.021$, and surprised, $p = 0.004$, and the nose and mouth of sad faces significantly less than the nose and mouths of fearful, $p = 0.031$ and surprised faces, $p = 0.015$. During the speeded task, the effect of emotion on the time spent fixating the nose and mouth was not significant in the control group, $F(6, 96) = 1.04$, $p = .405$, $\eta^2 = .061$.

Therefore, as hypothesized, visual inspection of the eta^2 values suggests that during the speeded task, the within-subject effect of emotion on the visual scanning of the lower features of the face (i.e., nose + mouth AOI) was greater in the patient than in the control group. In contrast, visual inspection of the eta^2 values suggests that during the speeded task, the within subject effect of emotion on the visual scanning of the eyes was greater in the control group than in the patient group.

Objective 3: Reaction Time

As in Study 1, response times (i.e., voice-onset times) for all speeded task trials were analyzed. As predicted in hypothesis 3a, a mixed design 2 x 7 repeated measures ANOVA revealed a large significant between-group main effect, $F(1,25)=13.34$, $p <.01$, partial $\eta^2 = 0.35$, and a significant between-within group x emotion interaction, $F(6, 150)=2.76$, $p =.014$, partial $\eta^2 = 0.10$.

Further, as predicted in hypothesis 3a, planned independent samples *t*-tests revealed that the TBI group was slower than the typically developing group to label surprised faces, all negative-valence emotions, $p = 0.013 – 0.029$, and neutral faces, $p = 0.02$. Taking the groups' unequal variances into account, the difference between the control and TBI groups' disgusted face labeling time was marginally significant, $p =$

0.051. As predicted, the two groups' happy-face labeling times were not significantly different, $p = 0.24$.

Table 8

Control Group Reaction (i.e., Emotion Labeling) Times by Emotion (milliseconds)

	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral	Overall
Mean	**1748.03***	1988.28	**2183.26***	1279.71	**1658.08***	**1692.55***	**1549.09***	**1728.43***
SD	92.16	336.95	187.17	123.08	121.13	113.94	97.13	105.99
Range	1176.54	1018.11	1289.59	807.30	1076.10	999.45	1100.12	1153.66
	-2670.77	-7120.72	-4213.07	-2896.46	-2621.79	-2710.72	-2478.68	-2652.30

Note.* $p <. 05$, indicates between-group differences.

Table 9

TBI Group Reaction (i.e., Emotion Labeling) Times by Emotion (milliseconds)

	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral	Overall
Mean	**3264.27***	3976.12	**3731.12***	1689.20	**2798.84***	**4275.07***	**2115.98***	**3289.11***
SD	1852.13	2689.04	1556.45	1240.71	1367.78	3139.32	781.98	1407.82
Range	1286.58	1380.52	1305.97	782.57	1285.70	1098.96	1257.80	1194.05
	-7096.89	-8620.95	-6510.44	-4965.57	-56290.10	11725.12	-4020.48	-5568.75

, * $p <. 05$, indicates between-group differences.

There was a significant within-group effect of emotion in the patient group, $F(6, 54)=7.43$, $p < .001$, partial $\eta^2 = 0.45$. Regarding hypothesis 3b, it was predicted that patients would be significantly faster at labeling happy faces than all other emotions. However, likely in part due to the small sample size, this hypothesis was only partially supported.

As predicted, patients with TBI were faster at labeling happy faces than fearful faces, $p = 0.023$, disgusted faces, $p = 0.024$ and surprised faces, $p = 0.026$. In addition to being slower than happy-face labeling, fearful-face labeling was also slower than neutral-faces labeling in the patient group, $p = 0.031$. Examination of individual patient reaction times indicated that these data were not skewed by the three patients tested at 3-4 months post-injury.

Contrary to predictions, visual inspection of the partial eta^2 values suggests that the within-subject effect of emotion on reaction time was approximately equal in the patient and control groups, with emotion accounting for 45% and 37% of the variance in reaction time in the two groups, respectively. The within control group analysis conducted for comparison purposes, $F(3.09, 49.49)=9.21$, $p < .001$, partial $\eta^2 = 0.37$, indicated that control group happy-face labeling reaction times were significantly faster than the control group angry-, $p < .001$, fearful-, $p < .001$ sad-, $p < .01$, and surprised-face, $p < .001$, labeling reaction times. In addition to happy-face labeling, fearful-face labeling times were significantly slower than sad-, $p < .05$, surprised-, $p < .01$, and neutral-face, $p < .01$, labeling times. Interestingly, patients and controls showed similar overall patterns of inter-emotion reaction time differences. As demonstrated in Table 9, patients' reactions times formed the following pattern: Happy RT < Neutral RT < Sad RT < Angry RT < Fearful RT < Disgusted RT < Surprised RT. Table 8 shows that control group reaction times formed the following pattern Happy RT < Neutral RT < Sad RT < Surprised RT < Angry RT < Disgusted RT < Fearful RT.

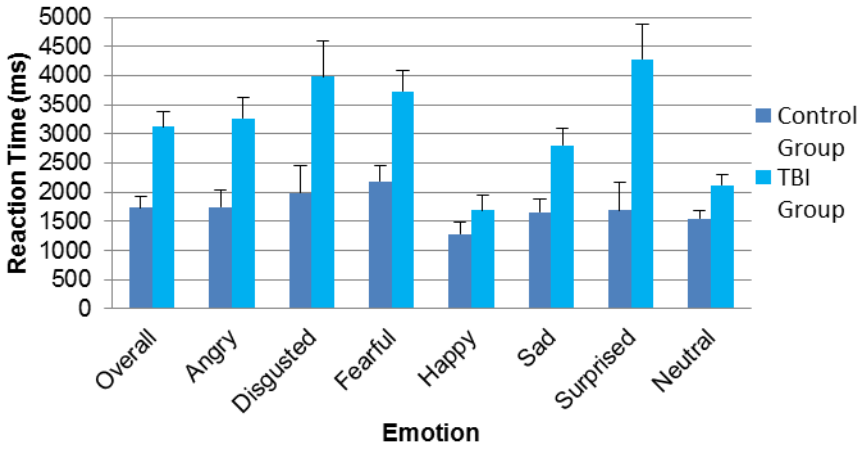

Figure 15. *Emotional Face Labeling Times by Emotion by Group.* Error bars indicate standard error around the mean.

In terms of hypothesis 3c and the relationship between reaction time and the visual scanning variables, it was hypothesized that *first* eye fixation would be correlated with reaction time. As predicted, time of first eye AOI fixation was correlated for several facial emotions within the patient group. Notably, for fearful faces, time of first eye fixation accounted for more than 60% of the variance, Rho(10) =0.79, p =0.006, R^2 = 0.69, adjusted R^2 =0.65, p = 0. 003. Like with overall reaction time, the other high-intensity negative-valence emotions (i.e., angry, R^2 = 0.17, p =0.23, Rho=0.54, p =106; disgusted, R^2 = 0.39, p =0.054), surprised faces, R^2 = 0.38, p =0.058), and neutral faces, R^2 = 0.31, p = 0.092, the later the first eye-fixation (i.e., longer latency), the longer the overall reaction time.

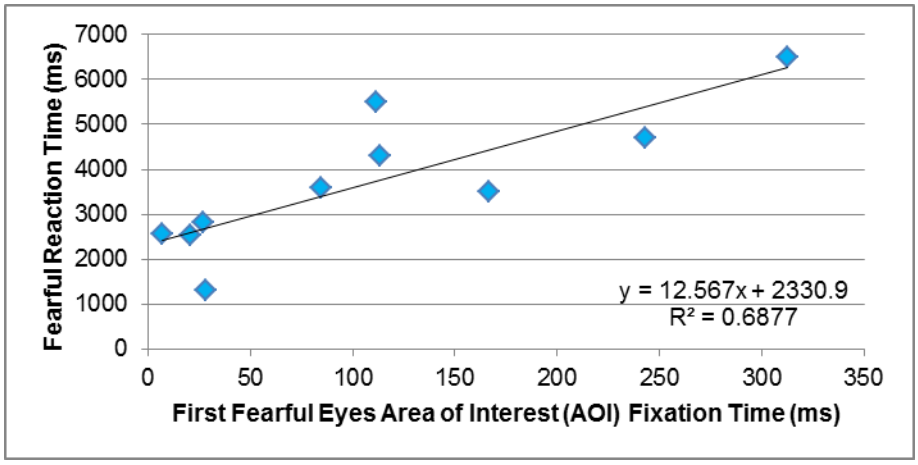

Figure 16. Fearful Emotion Labelling (i.e., Reaction) Time Versus Time of First Fearful Face Eye Fixation. This scatter plot illustrates the relationship between time of first fixation to the eyes of fearful faces and fearful face labeling time.

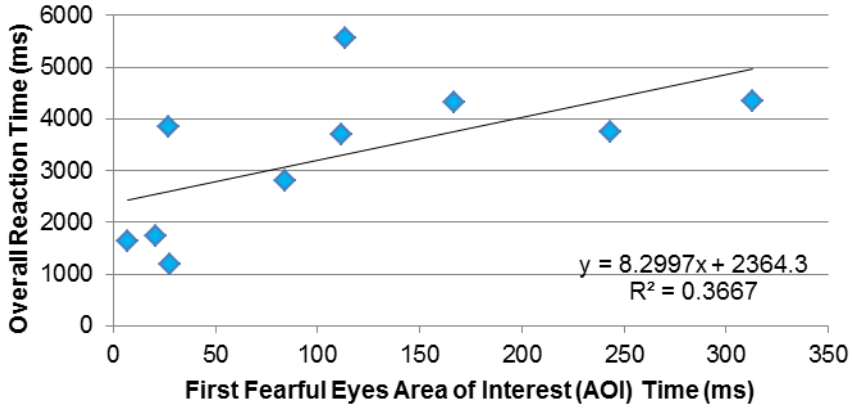

Figure 17. Reaction Time Across Emotion Versus Time of First Fearful Face Eye Fixation. This scatter plot illustrates the relationship between time of first fixation to the eyes of fearful faces and overall mean emotion labeling time.

Objective 4: Accuracy

Preliminary 2 X 7 ANOVAs indicated that the effect of task on accuracy was not significant among the patient group $F(1, 9) = 1.69$, $p = .23$, partial $\eta^2 = .158$, or the control group $F(1, 16) = 0.118$, $p = .74$, partial $\eta^2 = 0.007$. Therefore, with respect to Hypothesis 4ai, accuracy data were collapsed across task. A 2 X 7 repeated measures ANOVA evidenced a significant main effect of group on accuracy. A main effect of group indicated that the patient group in the current study was less accurate when labelling facial emotions overall, in comparison to the control group, $F(1, 25) = 4.32$, $p = .048$, partial $\eta^2 = .15$ Further, despite the relatively high overall mean accuracy of both groups, given the small standard deviations, the overall TBI group mean (i.e., TBI Group $M = 0.830$; $SD = 0.121$) was more than 1.50 standard deviations below the control group mean (i.e., Control Group $M = 0.89$; $SD = 0.045$).

Moreover, 40% of the TBI group in the current dissertation study achieved a Z-score of – 1.50 and would be classified as FEP impaired based on Babbage et al.'s (2011) liberal criteria for impairment whereas only 12% of the control group scored 1.5 standard deviations or more below the mean. When Babbage et al.'s (2011) more conservative cut-off of 2.0 SDs below the mean was employed, the level of impairment in the TBI group remained unchanged at 40% while the level of impairment in the control group decreased to 0%.

Regarding hypothesis 4aii, a significant group by emotion interaction emerged, $F(4.17, 104.25) = 2.67$, $p = .034$, partial $\eta^2 = .10$. Emotion-specific group differences were analyzed by task. Planned independent-samples *t*-tests demonstrated that as a group, patients were marginally to significantly worse at labeling angry and disgusted ($p =$

0.013-0.067) on both the non-speed and speeded task and at labeling surprised faces during the non-speeded task (p = 0.044). Contrary to predictions, fearful face labelling accuracy did not differ significantly by group, p = 0.69 on either task. Consistent with hypotheses, happy accuracy did not differ by group on the non-speeded or speeded task.

Table 10

TBI Group Accuracy by Emotion

Task	Overall	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral
non-speeded	0.841 (0.106)	**.800*** (.229)	**.738*** (0.181)	0.775 (0.164)	0.993 (0.030)	0.838 (0.196)	**0.825*** (0.169)	0.938 (0.121)
speeded	0.819 (0.140)	**.786*** (0.226)	**0.700*** (0.289)	0.773 (0.232)	0.978 (0.049)	0.800 (0.237)	0.750 (0.257)	0.963 (0.084)

Note. *Mean (SD) * p <. 05,* indicates between-group differences

Table 11

Control Group Accuracy by Emotion

Task	Overall	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral
non-speeded	0.895 (0.041)	**0. 846*** (.136)	**0.912*** (0.106)	0.75 (0.19)	0.975 (0.053)	0.882 (0.129)	**0.934*** (0.100)	0.949 (0.089)
speeded	0.900 (0070.)	**0.904*** (0.113)	**0.904*** (0.113)	0.74 (0.22)	0.963 (0.060)	0.941 (0.126)	0.860* (0.182)	0.985 (0.042)

Note. *Mean (SD), * p <. 05,* indicates between-group differences

In terms of hypothesis 4b and the within TBI group effects, a planned 1-way within-subject ANOVA analyzing the patient group accuracy found that consistent with Hypothesis 4b, there was a significant main effect of emotion, F(3.46, 31.12)= 5.00, p = .004, partial η^2 = .357 on TBI group accuracy. Planned comparisons demonstrated that patients were significantly less accurate when labeling negatively valenced faces (i.e., angry, disgusted, fearful, sad) and surprised faces, relative to happy faces, p = 0.003 – 0.026, and neutral faces, p = 0.001 – 0.047. This pattern was also observed in the control group data, F(3.78, 60.47)= 11.01, p < .001, partial η^2 = .408, with negatively valenced faces and surprised faces being labeled significantly less accurately than happy faces, p < 0.001 – 0.041, and neutral faces, p = 0.001 – 0.047. Unlike the patient group, the control

group was also significantly more accurate at labelling angry, $p = .002$, disgusted, $p = .003$, sad, $p = .002$ and surprised faces, $p = .001$, relative to fearful faces. Within the patient group, there were no significant accuracy differences between fearful and emotions other than happy and neutral.

Finally, with respect to Hypothesis 4ci, exploratory Spearman correlations within the patient group demonstrated that longer dwell times to the lower part of the face (i.e., nose, mouth) were associated with lower accuracy scores, particularly with respect to disgusted, happy, sad and neutral faces (See Table #12). Despite the negative correlations between the visual scanning of the lower regions of the face and accuracy, in terms of hypothesis 4cii, no relationships between the visual scanning of the eyes and accuracy emerged.

Table 12

Exploratory Visual Scanning and Accuracy Correlations (Pearson r) in the TBI Group

Task	Angry	Disgusted	Fearful	Happy	Sad	Surprised	Neutral
	None	Nose	None	Nose	Nose	Nose	Nose
Non-speeded		-.673*		-.696* Pro	-.578* -.697*Pro	-.545§§	-.528§§
							Mouth
Speeded							-.517§

Note. § $p < .10$, §§ $p < .06$, * $p < .05$, ** $p \leq .01$, *** $p < .001$(1-way); raw data unless indicated; pro = proportional data

Study 2: Discussion

Summary of Purpose and Findings

Overall, the purpose of the study was to compare patients with TBI and typically developing individuals on their emotion recognition accuracy and visual scanning of emotional faces, and to assess whether this differed by emotion. With regard to viewing patterns, the essential question was whether patients differed in their degree of attention to and processing of high content areas (i.e., the eyes and mouth) vs. low-content areas (i.e., everywhere else). Taken together, the Chapter 3 data reveal that the typically developing group and the group with TBI scanned the emotional faces differently, with respect to the amount of attention allocated to features of the emotional faces. These differences varied by emotion and were evident during speeded and non-speeded conditions, to a lesser extent. The raw dwell time data and proportional data converge to demonstrate that, as a group, patients spent more time on the lower part of the face when viewing time was held constant (i.e., during the non-speeded task), and proportionally more time on the lower part of the face, and less time on the eyes when speed was a component of the task (i.e., during the speeded task) and the patient group's slower reaction times are taken into account. The non-speeded task raw dwell time data demonstrate that the patient group spent more time on the features of disgusted faces, particularly the mouth, and less time on the features of all other faces, relative to the typically developing group, although these differences were only marginally significant for sad and neutral faces. The speeded task proportional data demonstrated that patients spent proportionally less time on the aggregated features of disgusted, fearful, sad and surprised faces, while there were not significant between-group differences for the time

spent attending to the features of angry, happy and neutral faces. In sum, patients required more time to complete the speeded task, and consequently spent more time on the features of the face relative to controls, particularly the nose and mouth. Reaction time differences were not significantly different for happy faces. Both the patient and control groups achieved mean accuracy scores above 80%. Nonetheless, the patient group was significantly less accurate than the control group, and exhibited a higher rate of impairment based on Babbage et al.'s (2011) criteria. The patient group was less accurate than the control group at labeling both disgusted and surprised faces. Like controls, patients were more accurate at labeling happy and neutral faces, relative to negatively valenced faces and surprised faces. Unlike patients, controls were also significantly better at labeling angry, disgusted, sad and surprised faces relative to fearful faces.

Objective 1a and 1b: Between-Group Area of Interest (AOI) Effects

The aim of objective 1 was to examine group differences in time spent (i.e., dwell time) attending to the features of emotional faces. As predicted, patients with TBI scanned the emotional faces differently than the typically developing group. On both the non-speeded task and the speeded task, participants with TBI spent proportionally less time looking at the eyes of emotional faces and proportionally more time looking at the mouth. Importantly, these effects were similar yet greater during the speeded task than the non-speeded task. A similar pattern revealing decreased attention to the eyes and increased attention to the lower part of face was observed in the raw data during the non-speeded task.

These AOI effects suggest that task did not have a functionally meaningful impact on group differences in attention to the facial features of emotional faces. The group with TBI looked at the nose and mouth more than the control group on both the non-speeded and speeded task. Although raw dwell time to the eyes differed by group on the non-speeded task and not the speeded task, the raw dwell time nose and mouth data expand on the proportional data outlined above. They indicate that it is likely the difference in dwell time to the lower part of the face that is precipitating the group differences, with the TBI group looking at the eyes of emotional faces proportionately less than the typically developing group on both the non-speeded and speeded tasks. If decreased processing speed explained the group differences in visual scanning, the TBI group would look at all the features of the face more than the control group during the speeded task. This would include the eyes, not just the nose and the mouth. Notably, visual inspection suggests that effect sizes for the proportional dwell time AOI group differences were larger for the speeded task than the non-speeded task. Therefore, although the AOI group differences were similar on the non-speeded and speeded, these differences were especially evident in the speeded-task data.

The visual scanning patterns observed in both the TBI-group proportional speeded and non-speeded task raw data are relatively similar to those which have been observed in a patient with severe bilateral amygdala damage (Adolphs et al., 2005), in patients with autism spectrum disorder (Corden et al., 2008; Neumann, Spezio, Piven & Adolphs, 2006; Pelphrey, Sasson, Reznick, Gregory, Goldman, & Piven, 2002), and in patients with other neurodevelopmental conditions that compromise the amygdala and fusiform gyrus (e.g., 22q11.2 deletion syndrome; Campbell, McCabe, Leadbeater, Schall,

Loughland, & Rich, 2010), and the corpus callosum (Bridgman, Brown, Spezio, Leonard, Adolphs & Paul, 2014). Again, the raw data on the speeded and non-speeded tasks illustrate that patients with TBI attend to the features of the face in the lower part of the face more than controls. The tendency for patients with TBI to look at the lower part of the face more than controls while still spending some (albeit proportionally less) time on the eyes may be somewhat specific to patients with TBI. This possibility requires further study as some patient studies report mainly proportional data (e.g., Adolphs et al., 2005).

Fisher, Rushby, McDonald, Parks, and Piguet's, (2015) recent MRI study documented both amygdala and insula atrophy among their patients with moderate to severe TBI (N = 19), compared to their age-, sex- and education-matched controls. Their TBI group also exhibited lower levels of arousal (e.g., skin conductance levels) when viewing angry, happy and neutral faces. Fisher et al. (2015) report significantly reduced insula and the amygdala volumes in TBI patients, with reductions in volume of 15-18% for the combined structures. The amygdala is particularly important for fear and threat detection (Pessoa & Adolphs, 2010). The insula aids in the explicit identification of disgust and other negative emotions (Johnston et al., 2007). It also helps to signal the presence of social information and is part of a network that includes the ventromedial frontal cortex (Fisher et al., 2015; Pessoa & Adolphs, 2010). Given that network disruption and disconnection is a cardinal feature of TBI (Hayes et al., 2016), damage to the white matter tracts (Green et al., 2004) that connect the amygdala and other structures critical to social functioning (Adolphs, 2002a; 2009) may also impact patients' eye-tracking and FEP performance.

Although the magnitude of the proportional differences in attention to the upper and lower AOIs observed between the patient and control groups in the current dissertation study is similar to those reported in other patient studies (e.g., Adolphs et al., 2005; Corden et al., 2008), participants in the current study looked at the eye region of the face for proportionally longer than has been reported in most other studies. More specifically, in Corden et al.'s (2008) study, patients with Asperger's syndrome looked at the eyes of fearful, happy, sad and surprised faces approximately 15% less than their typically developing participants, with patients looking at the eyes approximately 27-35% of the time, and controls looking at the eyes 40-50% of the time. In Adolphs et al.'s (2005) study, the group difference between SM (i.e., the patient with severe bilateral amygdala atrophy due to Urbach-Wiethe disease) and Adolphs et al.'s (2005) typically developing controls was approximately 17-37%, depending on the emotion; the control group looked at the eyes approximately 35-55% of the time, and SM looked at the eyes approximately 15-28% of the time.

The patient group in the current study looked at the eyes approximately 20% less than the typically developing group, on average, collapsed across task and emotion. As stated above, despite the typically developing-patient group difference found in this study being relatively similar to that which has been reported in other patient studies, patients in the current study looked at the eyes approximately 55% of the time during the non-speeded task, and approximately 40% of the time during the speeded task. The typically developing group in the current study looked at the eyes approximately 68% of the time collapsed across task and emotion.

If it were only the TBI patient group that were looking at the eyes proportionally more than patient groups in autism or other neurodevelopmental group studies, one might conclude that the differences in attention to the eye AOI are due exclusively to differences in underlying etiology, with SM, and patients with other neurodevelopmental conditions having more compromised amygdala and limbic system function than that experienced by patients with TBI (e.g., Fisher et al., 2015).

Even though the patient group exhibits significantly less attention to the eyes than the typically developing group in the current dissertation study, both groups spend proportionally more time on the eyes than in other eye-tracking studies. Thus, it is important to consider the effect that using 112 "novel", or "unique" emotion models to depict the emotions may have had on the results. Many eye-tracking studies of static emotional faces use one of the Ekman-Friesen batteries, which include 60-110 stimuli involving 10-16 different models (e.g., Corden et al., 2008).

To this point, Sullivan, Campbell, Hutton and Ruffman's (2015) recent eye-tracking study employed 36 stimuli including approximately 16 different emotion models in a paradigm that was participant-paced, but did not ask participants to respond as quickly as possible. The proportional dwell times exhibited by their young adult group (i.e., 63%) were similar to those evidenced by our typically developing group (i.e., 68%). As participants likely viewed each model 2-3 times throughout Sullivan et al.'s (2015) study, novelty (i.e., on initial model presentation) may have had more of an effect on amygdala-mediated attention to the eyes in Sullivan et al.'s (2015) study than in studies in which emotional face models were repeated several times (e.g., Corden et al., 2008). Given the above, it is suggested that the novelty of each of the current dissertation study's

112 models may have increased amygdala activation, and concomitant attention to the eyes in both our typically developing control and patient groups. Different emotion models were used for each emotion stimulus employed in this dissertation study to help minimize the potential confound of explicit memory impairment in the TBI group (e.g., Millis et al., 2001; Ruttan et al., 2008) and potential differences in the effect of familiarity between the TBI group and the typically developing control group.

In addition to presenting each model only once, another important methodological difference between the current dissertation study and other published studies is that few patient or control FEP eye-tracking studies have included a speeded emotional face labeling task (Adolphs et al., 2005; Bridgman et al., 2015; Campbell et al., 2010; Loughland, Williams, & Gordon, 2002; Mancuso et al., 2015; Pelphrey, Sasson, Reznick, Goldman, & Piven, 2002). Vassallo et al.'s (2009) study is an exception. Trial times were approximately 2 to 3 seconds longer in Vassallo et al.'s (2009) study than in the current dissertation study, perhaps because their study did not use a voice-key. Similarly, although Corden et al.'s (2008) task was self-paced, participants were not encouraged to respond as quickly as possible. In addition to stimuli differences, the design of our speeded task may have contributed to between-study differences in eye-tracking.

The proportional between-group upper and lower AOI differences were greatest for our speeded task. The speeded task AOI results may have greater generalizability to patients' everyday life than a non-speeded task, as social functioning requires quick and efficient identification of emotional information (Spell & Frank, 2000). A speeded task similar to that which was used in the current dissertation study may be valuable to future assessment and intervention studies.

Further, individuals with TBI may look at the less salient features of the face (e.g., cheeks) of the face more than controls, perhaps because the features of the face are more stimulating than the cheeks (Adolphs et al., 2005) or because TBI often reduces patients' sustained attention (Mancuso et al., 2015). The attention of individuals with TBI may drift away from the features of the face to the larger undefined areas of the face (e.g., cheeks). In sum, patients and controls exhibit potentially clinically relevant visual scanning differences when labeling emotional faces. Patients spend proportionally more time on the lower part of the face and proportionally less time on the features of the face overall.

As indicated in the introductory chapter, Mancuso et al. (2015) recently published an eye-tracking study examining FEP in patients with schizophrenia and those with TBI. Their findings likely underscore the importance of evaluating FEP following TBI using a speeded task. Contrary to the current dissertation study, Mancuso et al. (2015) used a fixed presentation task only and found no significant differences in their TBI and control groups' visual scanning of emotional faces. As noted above, this dissertation study's AOI group differences were smallest within the fixed presentation raw data, in part because all participants were asked to look at the face for the same amount of time. Further, a speeded task may be more relevant to everyday life than a non-speeded task as social interactions usually occur relatively quickly (Spell & Frank, 2000). Several methodological differences likely account for the diverging results, including their use of a fixed-presentation task only.

Mancuso et al. (2015) also reported participants' raw data, not their proportional data. Most eye-tracking studies involving patients have emphasized participants'

proportional data rather than their raw data (Adolphs et al., 2005; Bridgman et al., 2014; Corden et al., 2008; Pelphrey, Sasson, Reznick, Gregory, Goldman, & Piven, 2002). Proportional data may provide a more sensitive measure because it examines participants' relative attention to an AOI rather than their attention to an AOI in isolation.

Mancuso et al.'s (2015) presentation time was 1 second longer (i.e., 5 seconds) than our non-speeded task presentation time, and they employed the Ekman and Friesen battery, which repeats each emotion model approximately 6 times rather than the 1 time utilized in this dissertation study. Therefore, Mancuso et al.'s (2015) results may provide additional evidence that it is important to consider presentation time, along with the effects of novelty and familiarity when evaluating FEP following TBI. Finally, unlike the current study, it did not include neutral faces. Additional research is needed to determine the impact of neutral (i.e., at rest) faces on FEP in patients and typically developing populations. Neutral faces may make a FEP experiment more challenging and more ecologically valid. Overall, the results of the current dissertation study indicate that across both tasks and data types (i.e., raw data, proportional data), patients with TBI spend more time on the lower part of the face, and equal or less time on the eyes relative to typically developing participants, taking processing speed differences into account (e.g., Farbota, Sodhi et al., 2012). Mancuso et al.'s (2015) results highlight the need for additional FEP eye-tracking studies in patients with TBI.

Objectives 2a and 2b: Between-Group and Within-Group Effects of Emotion

Regarding the between-group emotion effects, the TBI group spent less time on the aggregated features (i.e., eyes, nose, mouth) of the face on the non-speeded task, and proportionally less time on the aggregated features of the face on the speeded task, across the majority of emotions, except angry, happy and neutral faces, relative to controls. Therefore, as in other groups with potential bilateral amygdala (e.g., Adolphs et al., 2005) and limbic system impairment (Corden et al, 2008), between-group effects on visual scanning were largely consistent across emotions. Notably, although the majority of group by emotion by AOI interaction effects were not significant, the eye-AOI-specific analyses confirmed that patients spent proportionally less time on the eyes of emotional faces than controls. As detailed in the accuracy and reaction time sections of this dissertation, the patient group was also less accurate and slower when labeling facial emotions relative to the control group.

The recent eye-tracking study of Vaidya et al. (2014) found that although nose and mouth fixations can aid in the identification of overt emotional expressions and subtle expressions of happiness, they contribute little to no predictive value to the identification of other subtle emotions (e.g., morphed stimuli). In their study, eye fixations were essential for the identification of subtle expressions of fear, disgust and surprise. Angry and sad faces were not included. Given Vaidya et al.'s (2014) findings, and the TBI patient group's propensity for looking away from the features of arousing emotional faces (i.e., non-happy, non-neutral faces, Adolphs et al., 2002; Russell, 1980), their data suggest that remediating visual scanning may reduce reaction time and increase accuracy in some TBI patients.

Importantly, Adolphs, Baron-Cohen, and Tranel's (2002) behavioural study showed that patients with unilateral amygdala damage and brain injuries that do not involve the amygdala were impaired at identifying complex social emotions (i.e., flirtatiousness, arrogance, guilty, admiring) and at identifying basic (Ekman, 1992) and complex emotions from the eyes only (i.e., using the Reading the Mind in the Eyes Test), even when they were able to accurately identify basic emotions from the entire face. The differences between the TBI and the control group suggest that the TBI group demonstrated impairment when labeling basic emotions, in conjunction with concomitant visual scanning differences, relative to controls. Given Adolphs, Baron-Cohen et al.'s (2002) findings, their impairments may be even greater when labeling more subtle emotions, or when portions of the face (i.e., nose, mouth) are obscured. Zupan, Babbage, Neumann, and Willer's (2014) recent findings provide evidence that individuals with TBI exhibit more difficulty labeling subtle facial emotions than obvious facial emotions.

In terms of objective 2b, the patient and control groups exhibited contrasting within-subject emotion effects on the non-speeded task and the speeded task. During the speeded task, patients exhibited only small inter-emotion differences with respect to their attention to the eyes, and moderate inter-emotion effects with respect to their attention to the lower part of the face (i.e., nose + mouth). During the non-speeded task, patients exhibited inter-emotion differences with respect to their attention to the eyes, and limited inter-emotion differences with respect to their attention to the lower part of the face. In contrast, the control group exhibited the opposite pattern, exhibiting emotion-specific attention to the eyes on the speeded task and emotion-specific attention to the lower part of the face on the non-speeded task. Consistent with other patient populations

(Adolphs et al., 2005), this suggests that patients with TBI exhibited reduced emotion specificity and efficiency when scanning emotional faces with limited time. The control group's visual scanning appeared to be less efficient only when they were given more than ample time to label the emotions.

Although the amount of time the TBI group allocated to the eyes of happy faces was less than that which was allocated to the eyes of negatively valenced emotional faces on the speeded task, inter-emotional differences did not emerge with respect to negatively valenced faces. The patient group did not allocate additional time to the eyes of fearful faces on the speeded task, relative to other negatively valenced emotions. In contrast, during speeded task, controls looked longer at the eyes of fearful faces than the eyes of neutral faces, and the eyes of all emotional faces, except for disgusted faces, faces for which there was a marginally significant difference (i.e., based on their raw dwell time).

Overall, much of this dissertation's data converge to demonstrate that the patient group used information form the eye-region of the face less effectively than the control group, particularly under time constraints.

Objective 3: Reaction Time

As predicted in Hypothesis 3ai, there was a large effect of group on reaction time. As a group, those with TBI were approximately 1.5 seconds slower overall; the slowest patient with TBI was 3.6 seconds slower than the control group mean. Notably, with respect to Hypothesis 3aii, the TBI group was slower to label neutral faces, and all emotional faces, except happy and disgusted faces relative to the control group. The largest emotion specific differences emerged for disgusted (i.e., *M* difference = 2 s) and surprised faces (i.e., *M* difference = 2.5 s). Despite the magnitude of this between-group

difference, the difference was marginally significant (i.e., $p = 0.051$). This result was likely impacted by the sample size and relatively large standard deviations for disgusted-face labeling reaction times.

Mathersul et al.'s (2009) online study of 1000 typically developing 6- to 91-year-olds found that speed of explicit facial emotion labeling was associated with information processing speed (as measured by a Trail-Making-Test-Part-A type test and the speed at which a target blue circle could was located among a set of distractor circles), inhibition / impulsivity scores (e.g., errors on a go-no-go task) and a digit span forward attention-span / short-term memory task. Although analysis of the effect of cognition on FEP is beyond the scope of the current study, processing speed, attention / inhibition, memory and arousal impairments are common among individuals with TBI (Farbota, Bendlin et al., 2012; Fisher et al, 2015; Millis et al., 2001; Rassovsky et al., 2006; Ruttan et al., 2008). Therefore, it is likely that longer reaction times among the TBI participants are related to several factors, including processing speed, attention and memory impairments associated with their underlying neurological injuries (Farbota, Sodhi et al. (2012); Hayes et al., 2016; Ietswaart et al., 2008; Mancuso et al., 2015; McDonald et al., 2006; Stuss, 2011).

Regarding Hypothesis 3b, the within TBI group analysis demonstrated that patients labeled happy, and neutral faces more quickly than fearful faces. This pattern is similar to that of the typically developing adults in the current study, as well as those in other published studies, taking stimuli and other methodological differences into account (e.g., Vassallo et al., 2009; Williams et al., 2008). Although Williams et al.'s (2008)

study did not include surprised faces, it found that middle-age adults were slowest to label fearful faces and fastest to label happy faces.

Slightly fewer inter-emotion differences emerged in the patient group than in the control group. The effect of emotion on reaction time accounted for a relatively similar amount of variance in patient and control group reaction times (i.e., 45% vs. 37%). Interestingly, the patient group was least accurate on disgusted and surprised faces and evidenced the slowest reaction times when labelling disgusted and surprised faces. The control group was least accurate on fearful faces and recorded the slowest reaction times when labeling disgusted and fearful faces. Taken together, this suggests that as a group, both patients and controls in the current study were aware of the inter-emotional differences in the face stimuli and altered their visual scanning and reaction time based on emotion and difficulty.

Adolphs (2002) explains that happy faces belong to the superordinate category "happy" whereas negative emotions can be thought of as belonging to the subordinate category "unhappy". Neuroanatomically, Pessoa and Adolphs (2010) and Habel et al. (2007) explain that the amygdala is activated less by happy faces than by threatening expressions (e.g., fearful, angry). Further, it may be that focusing on the mouth aids in fast happy-face labeling and valence discrimination, even though focusing on the mouth increases negatively-valanced-face labeling times.

Kolb et al. (2002) demonstrates that the frontal cortex is important for accurate identification of surprised faces. Several researchers have demonstrated that it is involved in complex decision-making (Stuss, 2011). Vassallo et al. (2009)'s typically developing controls labelled happiness fastest followed by surprised faces. Given that compromised

frontal lobe functioning is common following TBI, it may be that longer surprised-face labeling times are common among individuals with TBI.

With respect to Hypothesis 3c, and the relationship between visual scanning and reaction time, this study is also one of the first to document a relationship between earlier time of initial eye fixation and shorter overall reaction time in participants with TBI. Vassallo et al. (2009) report that greater dwell time to the nose and longer reaction times were found in their male group relative to their female group, although they did not examine the relationship between nose dwell time and overall reaction time. Corden et al.'s (2008) study of participants with Asperger's syndrome is one of the few patient studies to include a timed eye-tracking task. Although participants in Corden et al.'s (2008) study were not asked to label the faces as fast as possible, their Asperger's group was marginally slower than their control group and also attended to the nose and mouth proportionally more than controls. Exploratory correlations between overall nose and mouth raw dwell time and reaction times suggest that more power (i.e., a larger sample) would be needed to examine these relationships in this dissertation sample. Nonetheless, the relationships between initial eye fixation time and reaction time, along with Corden et al. (2008) and Vassallo et al.'s (2009) findings suggest that at least some visual scanning variables are related to patients' and typically developing individuals' overall emotion labeling time.

Overall, the patient group was slower to label emotional faces than the control group. Further, as predicted, they were slower to label all emotional faces, except happy faces. Studies in other patient populations (e.g., older adults) suggest that slower reaction

times are likely related to compromised neurological functioning and concomitant cognitive impairment (i.e., in attention, speed of processing; Farbota, Sodhi et al., 2012; Rassovsky et al., 2006; Ruttan et al., 2008). The patient group evidenced fewer inter-emotion reaction time differences than the control group, suggesting less emotion specificity in its reaction times. Nonetheless, both the patient and control group were slowest to label the emotions at which they were least accurate. Importantly, in the patient group, later eye-fixation times were associated with longer reaction times. These data provide further support for the utility of eye-tracking analysis when implementing and evaluating evidence-based FEP treatments designed to reduce FEP processing time. Notably, one of the only available longitudinal studies of FEP during the subacute (i.e., 2- to 3-months post-injury) and chronic stages (1-year post-injury) found that untreated impairments in FEP accuracy show little, or no spontaneous improvement over time. Farbota, Sodhi et al.'s (2012) cognitive study demonstrates ongoing white matter change and decreases in processing speed from 2- to12-months post-injury and from 1- to 4-years post-injury. Targeted FEP intervention to increase the effectiveness and efficiency of patients' visual scanning may help to reduce processing time and improve social functioning.

Objective 4: Accuracy

As predicted in hypothesis 4ai, the patient group was less accurate than the control group. This is consistent with several behavioural studies of patients who are in the subacute stages of injury (Green et al., 2004; Ietswaart et al., 2008), and those who are one year or more post-injury (Allerdings, & Alfano, 2006; Croker & McDonald, 2005; Hornak, Rolls & Wade, 1996; Ietswaart et al., 2008; Knox, & Douglas, 2009;

Mancuso et al., 2015; McDonald, Bornhofen & Hunt, 2009). As stated above, Babbage et al.'s (2011) widely cited review reports that FEP accuracy impairments occur in approximately 13% to 39% of patients with TBI. Although 40% of the patient sample obtained an accuracy score 2 SDs below the control group mean, and therefore met the criteria for FEP impairment established by Babbage et al. (2011), it is important to note that both the control and patient group in the current study obtained an overall accuracy score above 80%.

More specifically, in terms of individual emotions and hypothesis 4aii), the patient group was significantly less accurate than the control group at labeling disgusted and surprised faces. The frontal cortex (Kolb et al., 2002) has been shown to play a fundamental role in surprised and disgust perception.

Adolphs (2002a) argues that both typically developing adults and patient groups confuse surprised and fearful faces as well as disgusted and angry faces, and to a lesser extent sad and neutral faces. Given Wright et al.'s (2008) and Pessoa and Adolphs's (2010) work on the importance orbitofrontal-amygdalar connections, it may be that the frontal cortices are especially important in facial emotion categorization and decision-making (Bechara, Damasio, & Damasio, 2000). The frontal cortex is especially vulnerable in TBI (Bigler, 2001; Hayes et al., 2016).

Williams et al.'s (2008) large web-based study of typically developing adults speaks to the concept of complexity and superordinate categories to some degree. Their study included angry, disgusted, fearful, happy, sad and neutral faces. Given that fearful and surprised are frequently confused and angry and disgusted are often confused, it is notable that when surprised faces were not included, disgusted faces, not fearful faces

were the least accurately identified. This suggests that individuals with TBI are vulnerable to the FEP errors observed in the typically developing population as well as TBI-specific errors (e.g., due to differences in visual attention to the eyes, classification errors).

The majority of research investigating FEP after TBI has found that when patients are impaired, they exhibit impairments when identifying fearful faces, and those of negatively valenced emotions, more generally relative to controls (e.g., Croker & McDonald, 2005; Rosenberg et al., 2014). Although group differences in the labelling of fearful faces did not emerge in the current dissertation study, the patient group was less accurate at labeling disgusted and surprised faces, as discussed above. Consistent with Hypothesis 3b, the patient group exhibited emotion specific impairments. Within-group analyses demonstrated that the TBI group was less accurate at labeling all negatively valenced emotional faces, including fearful faces, as well as surprised faces, relative to happy, and neutral faces. Again, this suggests that TBI-related FEP accuracy impairments are not specific to a specific negative emotion.

Like many patient case studies (e.g., Adolphs et al., 2005; Calder, Keane, Manes, Antoun, & Young, 2000) and group studies among brain injured patients with other types of neurological conditions (Johnson, Stout, Solomon, Langbehn, Aylward, & Cruce, 2007), Fisher et al.'s (2015) recent TBI study demonstrates that damage to the limbic system (i.e., amygdala, insula) and its frontorbital connections likely contributes to many of the between-group and within-TBI-group differences observed among this dissertation study's TBI sample. The amygdalae are critical to emotional face labeling (Habel, Windischberger, Derntl, Robinson, Kryspin-Exner, Gur et al., 2007), including that of

fearful, sad, and happy faces (Fusar-Poli et al., 2009). Pessoa and Adolphs (2010) argue that the amygdalae and its cortical (i.e., visual, orbitofrontal) connections are critical to not only FEP processing, but the processing of biologically significant information more broadly, including novelty, salience, ambiguity, and unpredictability.

Consistent with Fisher et al.'s (2015) finding that the amygdala and insula are compromised following TBI, several studies identify the insula as important in disgusted-face processing, and to a lesser extent angry-face processing (Fusar-Poli et al., 2009; Hennenlotter, Schroeder et al., 2004). The 4a between-group and 4b within-TBI group accuracy findings are also consistent with Tonks et al. (2009) and Possea and Adolphs' (2010) models (please see General Introduction) in addition to Babbage et al.'s (2011) report that whole brain volume is positively correlated with FEP following TBI.

Ietswaart et al. (2008) caution against the over-interpretation of inter-emotion between- and within-group differences among patients with TBI, given the diffuse nature of their injuries. They cite significant correlations between their TBI group's inter-emotion reaction time and accuracy scores in their sample of patients with mild, moderate and severe TBI and propose that accuracy scores are more related to inter-emotion differences in identification and labeling difficulty, rather than the emotions themselves. For example, for reasons discussed above, fearful faces are more difficult to label than happy faces. As such, Ietswaart et al. (2008) suggest that FEP labeling reaction time may be a useful index of impairment in the TBI population.

Consistent with Hypothesis 4ci, visual scanning (i.e., dwell time) to the lower part of the face (i.e., nose, mouth) was negatively associated with accuracy in the TBI group. More specifically, scanning of the lower part of happy and sad faces was

negatively associated with accuracy during the non-speeded task; scanning of the lower part of disgusted, sad, surprised and neutral faces was negatively correlated with accuracy during the speeded task. This is one of the first patient studies to report a significant relationship between the visual scanning of emotional faces and FEP accuracy.

The visual scanning-accuracy relationships documented in the patient group differ somewhat from those reported among typically developing adults in Chapter 2 of this dissertation study. In the Chapter 2 typically developing adult sample, fixations to the lower part of the faces were negatively correlated with fearful, angry, disgusted, sad and neutral face accuracy. Similarly, Gillespie et al.'s (2015) study involving typically developing adults and those with psychopathic traits found that fixations to the eyes (minus fixations to the mouth) were associated with fearful and angry face labeling accuracy.

Contrary to Hypothesis 4cii visual scanning to the eyes was not significantly correlated with accuracy in our sample of patients with TBI. Like Adolphs et al.'s (2005) patient with bilateral amygdala damage, a recent study of patients with ventromedial prefrontal cortex (VMPFC) lesions (n=3) found that patients with VMPFC lesions made fewer fixations to the eyes and were less accurate at labeling fearful faces than controls Wolf, Philippi, Motzkin, Baskaya, & Koenigs, 2014). It is important to note that neither of these studies report significant correlations between decreased attention to the eyes (i.e., fixations / dwell time) and accuracy. They simply report a co-occurrence in their patient groups. Although this dissertation study's patient and control group's fearful face labeling accuracy was not significantly different, the patient group did spend proportionally less time on the eyes of all negatively valenced faces relative to controls,

and was less accurate at labeling all negatively valenced faces overall. Further, visual scanning of the eyes of fearful faces during the non-speeded task was positively associated with fearful labeling accuracy during the speeded task.

Conclusions

The exploratory findings evidencing visual scanning differences between our TBI and control groups highlight the need for a larger sample. As a group, patients with TBI looked proportionally longer at the features of lower part of face (i.e., the nose and the mouth), particularly on the speeded task. They also looked less at the features of the face and more at the less salient features of the face (e.g., cheeks, chin). They were less accurate and slower to label the emotional faces than the control group. Our patient group results suggest that it would be valuable to study the relationships between the visual scanning of emotional faces and facial emotion accuracy and labeling times. In the current dissertation study, looking at the lower part of the face was associated with lower accuracy scores and longer emotion labeling times, overall. Future studies that assess these relationships in larger, closely-matched samples using both dwell time and fixation data would be beneficial. Regarding clinical implications, this study suggests that targeting patients' visual scanning of emotional faces may decrease identification time and improve FEP accuracy.

Chapter 4: General Discussion

Integration of Chapter 2 and Chapter 3

Taken together, the chapter 2 and chapter 3 typically-developing group analyses suggest that the subsample of control participants that was selected based on age for the between-group study (i.e., chapter 3) is representative of the overall sample (i.e., chapter 2). As in Corden et al.'s (2008) between-group study, which incorporated both dwell time and fixation data, the control group dwell time data presented in chapter 3 are representative of the fixation data presented in chapter 2. The dwell time data were employed in chapter 3 given evidence that participants with executive functioning impairments are prone to long duration fixations, potentially making their fixation data less representative than their dwell time data (Clark, et al., 2010). As indicated in Chapter 1, Tonks et al.'s (2009) model of emotion perception illustrates that TBI often compromises executive functioning abilities (Levine et al., 2011; Stuss, 2011).

Although both our control participants and our patients spent more time attending to the eye AOI than the nose or the mouth AOI, our patient group spent significantly more time attending to the lower part of the face than our control group, particularly on the speeded task. Overall, the patient group also spent significantly more time on non-feature areas of the face (e.g., cheeks); again, this difference was greatest on the speeded task.

Regarding the impact of emotion on visual scanning, both the Chapter 2 and the Chapter 3 results indicate that typically developing adults' visual scanning of emotional faces is emotion-specific. During the speeded task, they identified happy faces with fewer fixations and less dwell time than all other emotions. Conversely, fearful faces

were identified with more fixations and dwell time than sad, happy and marginally more visual scanning than disgusted faces. The typically developing adults in both Study 1 and the Study 2 samples attended to the eyes of happy faces less than the eyes of other emotions during the speeded task. During the non-speeded task, the number of fixations participants made to the eyes of fearful faces was only marginally greater than the number of fixations made to happy faces. This suggests that typically developing adults' visual scanning of the eye region of the face is more emotion specific when processing emotions under speeded task constraints. The Chapter 3 patient findings indicate that the patient group looked at the eyes of emotional faces proportionally less than the typically developing adult group. This difference was relatively constant across emotion and task, with the exception of the eyes of disgusted faces on the speeded task and the eyes of fearful faces on the non-speeded task. The results suggest that the patient groups' visual scanning of the eye region was less emotion-specific than the control group's under speeded task constraints. Group differences in visual scanning were larger on the speeded task than the non-speeded task.

Together, Chapter 2 and Chapter 3 suggest that the controls required under 2 seconds to label the emotional faces (i.e., 1700 ms), on average, collapsed across emotion. Patients were approximately 1.5 seconds slower, although the slowest participant with TBI was approximately 3 seconds slower than the slowest typically developing adult in this sample. Interestingly, although both our control and TBI groups achieved overall accuracy scores of above 80 percent, the TBI group was less accurate overall, and at labeling angry, disgusted and surprised faces, specifically. Fearful face accuracy did not differ by group. While both groups were more accurate at labeling

happy faces than all other emotions, only the control group was more accurate at labeling angry, disgusted, sad and surprised faces relative to fearful faces. As a group, the patients evidenced equivalent difficulty labeling surprised faces and all negatively valenced emotions. The TBI group analysis provides preliminary evidence that time of first eye-fixation was related to overall labelling time among the patients with TBI. Consistent with emerging data from other populations (e.g., Gillespie et al., 2015), visual scanning of the lower part of the face was associated with lower accuracy scores in both patients and control participants. Accuracy did not differ by task. Regarding future intervention studies, this research suggests that non-speeded and speeded FEP eye-tracking tasks could be used in a graduated fashion.

Limitations

It is important to acknowledge that this study's patient sample was a convenience sample, consisting of eligible patients enrolled in on-going TBI studies at the Toronto Rehabilitation Institute. The small sample size limits the strengths of the conclusions and the generalizability of the findings. Converging evidence from larger (i.e., patient $N = 37$) studies of consecutively enrolled patients suggest that FEP accuracy impairments are a relatively stable and frequent feature of TBI sequelae (e.g., Ietswaart et al., 2008). Additional data collection would provide increased power to detect true effects and yield greater analytic stability that could increase generalizability. This would help to determine whether marginally significant effects are significant in a larger sample. Given the sample size, and the number of analyses conducted, it is also important to acknowledge the possibility of type 1 error. Several exploratory analyses were conducted for the purposes of understanding the data. Despite the medium to large effect sizes

reported, the significance of some findings may be overstated. A larger sample, more stringent alpha values and more targeted hypotheses testing may help to reduce the probability of incorrectly rejecting the null hypothesis. Nonetheless, like the current dissertation study, several exploratory eye-tracking studies have employed small samples (Neumann, Spezio, Piven & Adolphs, 2006; Pelphrey et al., 2002; Wolf et al., 2014).

Of particular importance, the control group was also a convenience sample, and the group differed in demographic characteristics from the patients, particularly by age and sex. In addition to the relatively small sample size of the patient group, there was insufficient power in the analyses to control for the effects of age and sex. Further data collection, which was beyond the scope of the current study, should include a sample of control participants who are more closely overlapping in demographic characteristics with those of the patient group[3]. These demographic differences are important because sex and age can impact FEP. For example, Mathersul et al. (2009)'s large web-based behavioural study found that women logged faster reaction times on a facial emotion-labeling task than men. This is similar to the sex-based reaction time differences reported in Vassallo et al's (2009) eye-tracking FEP study. Mathersul et al. (2009) also report that women were more accurate than men when labeling fearful and angry faces. Although sex-based differences in FEP labeling accuracy do not always emerge (Vassallo et al., 2009), when they occur, women are consistently found to be more accurate than men. Gur, Gunning-Dixon, Bilker & Gur (2002)'s neuroimaging study found that women have

[3] The control study was designed and community-based recruitment was initiated before it was decided that in-house stimuli would be created and validated. The latter involved more than two years of work and allowed for the possibility of differing novelty effects in the control and patient groups to be taken into account. Given the additional time invested in stimulus development, the final dissertation typically developing group was recruited through the York University Undergraduate Participant Pool (please see the Methods Section) rather than the community. Additional control group data will be collected before the publication of chapter 2 so that possible age and gender effects can be investigated.

larger orbitofrontal regions and may exhibit greater connectivity between the amygdala and orbitofrontal cortex than men (Kogler et al., 2016; Williams et al., 2005). Nonetheless, when women were removed from the current study analyses, the effects of group on dwell time, reaction time and accuracy remained. Thus, even though there were a larger number of women in our sample, this suggests that these outcomes were not explained by sex differences.

In their study of typically developing participants age 6 to 91 years, Williams et al. (2009) found that FEP labeling was fastest for young and middle aged adults and slowest for older adults, age 70 to 91. Labeling of happy faces improved with age while labeling of negative emotions (angry, disgusted, fearful, sad) decreased with age, even in the 18- to 59-year-old group. Therefore, the reaction time data were reanalyzed with the oldest patient (i.e., age 65) removed and it was confirmed that the between-group main effect on FEP labeling reaction time remained. Thus, as with sex, it appears that the reaction time findings were not likely attributable to the impact of older age in the TBI group. This dissertation's TBI group was slower to label the emotions than the control group. The control group dwell time data presented in chapter 3 are consistent with the control group fixation data presented in chapter 2. This is consistent with previous studies (e.g., Corden et al. 2008). It is hoped that future research will examine this dissertation study's patient fixation data in greater detail.

Although the majority of facial emotion recognition studies employ static stimuli, like the ones used in the current study, dynamic stimuli are becoming increasingly more popular, as they allow for increased generalizability to everyday social interactions (Jiang, Li, Recio, Liu, Luo, Zhang, et al., 2014). Additional eye-tracking studies that

replicate and expand upon the current study by incorporating both static and dynamic faces (Chevallier, Parish-Morris, McVey, Rump, Sasson, Herrington, & Schultz, 2015) are needed. For example, while dynamic emotional faces are often labelled more accurately and more quickly than static emotional faces, Jiang et al., (2014), report that static emotional faces (i.e., happy, angry, neutral) are identified more quickly when participants are specifically instructed to prioritize speed. Understanding the interaction between dynamic stimuli and speed-related instruction may have important implications for emotion-perception rehabilitation treatments. Paradigms that ask participants to explicitly label static emotional faces have been found to identify a higher rate of impairment among individuals with traumatic brain injury (McDonald et al., 2006; 2008) and therefore may be especially relevant during the assessment process. The importance of the relationship between performance on potentially more challenging static FEP stimuli tasks and social functioning cannot be overstated (Knox & Douglas, 2009). In keeping with Adolphs et al.'s (2002) finding that some patients with brain injuries who do not exhibit labeling impairments on static FEP batteries are impaired on the "Reading the Mind in the Eyes" Test (Baron-Cohen et al., 2001), future eye-tracking studies may benefit from including the Mind in the Eyes Test as a FEP impairment screener. Additional studies of the interaction between emotional valence (i.e., positive vs negative) and difficulty are also needed (Ebner et al., 2011; Green et al., 2004; McDonald et al., 2013; Rosenberg et al., 2015). For example, Rosenberg et al. (2015) recently studied FEP accuracy in a group of participants with TBI relative to that of a group of typically developing adults. They examined accuracy when the intensity of the emotion was at 100% and when the intensity of the emotions was consistent across emotions.

This group argues that one of the reasons positive emotions may be identified more accurately is that they are typically displayed with more intensity than negative emotions. At 100% intensity, their TBI group was found to be less accurate at identifying negative emotions than their typically developing control group. When intensity (i.e., difficulty) was equated across all emotions, they found that their TBI group had more difficulty accurately identifying all emotions, not just negative emotions, relative to their control group. Finally, the work of Rosenberg et al. (2014) highlights the need to acknowledge that happy faces may also be easier to identify than negative emotions, simply because most paradigms include a small number of positively valenced faces (i.e., happy) and a larger number of negatively valenced faces (i.e., angry, disgusted, fearful, sad)

Clinical implications and Treatment Development

To date, evidenced-based features of published FEP intervention studies have resulted in the evaluation and/or integration of several components: 1) Instruction and practice designed to increase the perceivers' attention to facial features of emotional faces (e.g., McDonald et al., 2009); 2) distributed practice (McDonald & Bornhofen, 2008); 3) mimicry (McDonald et al., 2009); 4) problem solving (orienting to task and appropriate steps, i.e., attention to features) and self-monitoring; and, 5) non-attention related social skills training (e.g., giving complements, initiating conversation; McDonald et al, 2008). The use of targeted instruction aimed at increasing attention to facial features and the eyes, in particular, is consistent with evidence of the association between amygdala damage and decreased recognition of fearful (Adolphs et al., 1994) and other negatively valenced faces (Adolphs et al., 1999; Adolphs et al.'s, 2005; Pessoa & Adolphs, 2010) Given that individuals with TBI are vulnerable to attention impairments (e.g., Bonnelle et

al., 2001; Levine et al., 2008; Ruttan et al., 2008), in conjunction with damage to the amygdala (Fisher et al., 2015) and amygdala-related connections (Pessoa & Adolphs, 2010), there is clear neuroanatomical evidence for this intervention approach.

Interestingly, the recent study of Neumann, Babbage, Zupan, and Willer (2015) was a randomized FEP intervention that built upon McDonald and colleagues' (e.g., Bornhofen & McDonald, 2008a) and others' research. They used gradually fading cues that directed the attention of participants with TBI toward facial features, targeted participants' imitation and introspection, and aimed to increase participants' associative and conceptual knowledge about emotions. Although this training improved participants' ability to label emotional faces in the experiment, intervention benefits did not transfer to other outcome measures, such as a decrease in aggression, increased empathy or an improved ability to label the emotional theme of a vignette.

Given McDonald et al.'s (2009) "modest" intervention results and the lack of generalizability of Neumann et al.'s (2015)'s finding to other outcome measures, it may be especially important to account not only for susceptibility to focal amygdala damage, but also the increased likelihood of diffuse white matter damage (Green et al., 2004; Hayes et al., 2016). Recent reviews documenting the amygdala's connectivity with much of the cortex (Pessoa & Adolphs, 2010; Ray & Zald, 2012) suggest that scanning impairments may resemble a combination of those displayed by patients with focal damage (Adolphs et al., 2005) and by those with more distributed and subtle neurological impairments (e.g., older adults; Sullivan et al., 2015). This suggests that detailed eye-tracking analysis, similar to that which was undertaken for this dissertation, may be helpful during assessment, treatment implementation and outcome assessment.

McDonald et al. (2009) explain that blanket instruction to attend to the eyes, followed by the mouth and nose may increase working memory and task demands, in a population vulnerable to working memory and processing speed impairments (e.g., Millis et al., 2001). This may account for the finding that suggesting that instruction to attend to facial features actually decreases FEP accuracy in some individuals with TBI (McDonald et al., 2009). Consistent with this finding, Sullivan et al. (2007; 2015) found that attending to the eyes was correlated with FEP accuracy in young adults, but not older adults (in whom subtle neurological declines are well documented; Tomaszczyk et al., 2014).

In addition to its relevance to facial-feature cuing, recent neuroanatomical data may also provide clues as to why "mimicry" / "imitation" interventions are not evidenced to be efficacious, at least in some individuals with TBI (McDonald et al., 2009). Bailey et al. (2012) report that ventral prefrontal damage impairs patients' ability to successfully mimic angry faces. Their results suggest that ventral prefrontal damage may impact the ability of some individuals with TBI to effectively implement mimicry interventions.

Beyond practice and general social skills training, intervention studies reported to-date have involved problem solving and self-monitoring (Bornhofen & McDonald, 2008b; McDonald et al., 2008). While McDonald and colleagues incorporated goal-setting, problem solving and self-monitoring training into their treatments to increase attention to facial features, these monitoring instructions lacked the self-alert features (i.e., arousal training and task-oriented cuing, e.g., "now" cue) that have been shown to be fundamental to rehabilitating dorsal lateral sustained attention deficits (O'Connell et al., 2008) and goal management impairments (Levine et al., 2011).

Moreover, McDonald et al.'s (2009) self-monitoring training did not include mindfulness tools to enable patients to internally stop, self-regulate and reorient attention (e.g., Kabat-Zinn, 1994). Fisher et al. (2015) document reduced autonomic nervous system arousal (i.e., skin conductance levels) following TBI when viewing emotional faces. It is also noteworthy that Mancuso et al.'s (2015) recent eye-tracking study found that patients with TBI who had lower attentional vigilance scores (i.e., true omission errors on the Sustained Attention to Response Test) fixated more on the mouth of emotional faces. Given neuroanatomical evidence of DLPFC-parietal cortex TBI-related damage (Levine et al., 2008; Stuss, 2011, Bonelle et al., 2011) and concomitant attention and executive functioning impairments (Green & Turner, 2010; Levine et al. 2011), self-alerting and mindfulness are likely essential features of effective FEP interventions for people with TBI. The self-monitoring training included in McDonald et al.'s interventions appears to have emphasized external cuing and rehearsal while that which is emphasized by Robertson, Levine and colleagues (i.e., Levine et al., 2011), and encouraged in mindfulness meditation (e.g., Kabat-Zinn, 1994) appears to facilitate a more internal locus of attentional control. The latter may be more likely to facilitate far transfer when incorporated into facial emotion perception interventions.

Eye-tracking evidence may enable individuals with TBI to better appreciate "less efficient" or "off-task" aspects of their visual scanning (e.g., looking at the forehead/ lower part of the face") so that when they find themselves not attending to facial expressions or not understanding social situations, they can initiate mindfulness and reengage their attention in a more optimal way. Mindfulness is likely to facilitate more optimal functioning of the prefrontal attention systems. This, in turn, may result in more

"naturalistic" improvements in facial emotion-related scanning, and perhaps attention and cognition, more generally. Notably, evidence of possible age (Sullivan et al., 2015) and sex (Vassallo et al., 2009) effects on emotional face processing suggest that an element of "personalization", which incorporates eye-tracking based assessment and person-specific (e.g., age, sex / gender) strategies for FEP optimization, may be beneficial.

Interestingly, Creswell et al. (2007) suggest that emotion labeling activates the VMPFC and networks typically associated with mindfulness meditation (e.g., the process by which individuals are aware and open to present moment experience). In this study, emotional face labeling activated the VMPFC and this covaried with the deactivation of the amygdala. This effect was found among individuals with high scores on the Mindful Attention Awareness Scale, but not among individuals with low scores on the scale (Ray & Zald, 2012). Given the above, much of which illustrates the vulnerability of frontal networks in TBI and the impact that this has on FEP, Creswell et al.'s (2007) results are consistent with the concept of integrating self-alert training, mindfulness and facial emotion perception labeling into possible FEP treatment.

Consistent with the relationship between facial emotion perception, social functioning and quality of life (Knox & Douglas, 2009; Scheten et al., 2008), and the distributed nature of facial emotion processing (Adolphs et al., 2002; Pessoa & Adolphs, 2010), it would likely be beneficial to the rehabilitation of individuals with TBI and their return to productivity if FEP, self-alert training (e.g., O'Connell et al., 2008) and mindfulness (e.g., Green & Turner, 2010) were integrated into a comprehensive FEP treatment program. It is hypothesized that the use of eye-tracking technology throughout

the FEP training process (i.e., assessment, implementation, outcome evaluation) may be extremely valuable.

General Conclusion

Overall, this dissertation provides some of the first evidence that patients with TBI are vulnerable to scanning emotional faces differently than typically developing adults. Although this dissertation's TBI and control group both attended to the eyes of emotional faces more than the nose or the mouth, the TBI group spent proportionally more time on the lower part of the face (i.e., nose, mouth) than the control group. Emotion had a significant effect on visual scanning, reaction time and accuracy among both the control and TBI groups. Our results add to emerging evidence that visual scanning of emotional faces is emotion-specific and suggest that visual scanning of emotional faces is less efficient following TBI. As a group, the patients were less accurate and required more time when labeling emotional faces relative to the typically developing group. Scanning of the lower part of the face was associated with decreased accuracy in both the typically developing and TBI groups. The longer patients took to attend to the eyes after being presented with an emotional face, the more time they required to label the emotion. It is hoped that these findings will contribute to the development of future evidence-based treatment studies.

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Appendix A.1: Consent Form for York University Participants

CONSENT FORM: Investigations of Facial Perception in the Normal Brain and Following Traumatic Brain Injury (TBI)

Principal Investigators:
Dr. Robin Green, Senior Scientist and Toronto Rehab Supervisor
Head, Cognitive Neurorehabilitation Sciences Lab, Toronto Rehabilitation Institute

Alexandra Arnold Oatley, PhD Student,
Cognitive Neurorehabilitation Sciences Lab, Toronto Rehabilitation Institute
Department of Psychology, York University

Research Assistant:
Marika Dabek
Cognitive Neurorehabilitation Sciences Lab, Toronto Rehabilitation Institute

York University Supervisor and Faculty Contact:
Dr. Maxine Gallander Wintre, Professor
Department of Psychology, York University

Purpose of the Research:
The purpose of the project is to determine how people look at faces and how this is affected by traumatic brain injury. You will be participating in the control-group phase of the project. Data collected during this phase will be compared to that of data collected during the patient phase. The results of the research will be reported in an academic journal and at academic conferences. No identifying information (e.g., participants' names) will be included. This consent form will give you a basic idea of what the research is about and what participation will involve. If you would like more information, please feel free to ask.

Study Procedures: If you agree to participate, you will be asked to do some visual tasks. You will see some pictures and will be asked different questions about them. For example, for you might be asked to rate how much you like them or whether they look young or old. While you are looking at the pictures, we will be taking some measurements of your face using a video camera. You can simply ignore the camera. We will explain the purpose of it after the experiment is over. Mascara can affect the quality of the recording. Therefore, you will be asked not to wear mascara during the study.

As part of the study, you will also complete a leisure-activity questionnaire. You will also be asked to provide some demographic information (e.g., age, years of education, Country of origin). **Most participants will complete the entire study in one 1-hour session.**

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research. **.**

Benefits of the Research and Benefits to You: There are no direct benefits to you as a participant in this study. However, you will be contributing to knowledge that could help people with brain injury in the future. If you are participating as part of York University's Undergraduate Research Participant Pool (URPP), you will receive 1 research-participation credit.

Voluntary Participation: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer will not influence any relationship you may have with York University or the Toronto Rehabilitation Institute now, or in the future.

Withdrawal from the Study: You can stop participating in the study at any time, for any reason, if you so decide. If you decide to stop participating, and you are participating as part of the URPP, you will still receive a participation credit. Your decision to stop participating, or to refuse to answer particular questions, will not affect your relationship with the researchers, York University, Toronto Rehab or any other group associated with this project. In the event that you withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

Confidentiality: All information you supply during the research will be held in confidence and your name will not appear in any report or publication of the research. The data will be collected using a video camera, hand-written notes and a self-report questionnaire. Your paper-based data will be safely stored in a locked facility. The video recordings will be anonymized and stored on a secure server at Toronto Rehab. Only the research staff will have access to this information. The data will be stored for a maximum of 10 years. After this time, the digital video files will be deleted and Toronto Rehab's confidential-document service will dispose of all paper-based data. Confidentiality will be provided to the fullest extent possible by law.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact me or my York Supervisor, Dr. Gallander Wintre. You may also contact the office of the Graduate Program in Psychology. This research has been reviewed and approved by the Human Participants Review Sub-Committee of York University's Ethics Review Board and the Research Ethics Board at the Toronto Rehabilitation Institute. It conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process or about your rights as a participant in the study, please contact the Sr. Manager & Policy Advisor for the Office of Research Ethics, 5th Floor, York Research Tower, York University.

Legal Rights and Signatures:

I_____ consent to participate in the *"Investigations of*
Participant Name (please print)

Face Perception" study being conducted by Alexandra Arnold Oatley. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent.

Signature_____ **Date**_____
Participant

Signature_____ **Date**_____
PhD Student Investigator / Research Assistant

Appendix A.2: Consent Form for Toronto Rehab – UHN Participants

CONSENT FORM: Investigations of Facial Perception in the Normal Brain and Following Traumatic Brain Injury (TBI)

Principal Investigators:

Dr. Robin Green, Toronto Rehabilitation Institute

Alexandra Arnold Oatley, Toronto Rehabilitation Institute

Research Assistant:

Marika Dabek, Toronto Rehabilitation Institute

Introduction
You have been invited to participate in a research project on the Neuro Rehabilitation Program. The project examines how people look at faces and is funded by the National Sciences and Engineering Research Council of Canada (NSERC). This consent form will give you a basic idea of what the research is about and what participation will involve. If you would like more information, please feel free to ask.

Study Procedures
If you agree to participate, you will be asked to do some visual tasks. You will see some pictures and will be asked different questions about them. For example, for you might be asked to rate how much you like them or whether they look young or old. While you are looking at the pictures, we will be taking some measurements of your face using a video camera. You can simply ignore the camera. We will explain the purpose of it after the experiment is over. Mascara can affect the quality of the recording. Therefore, you will be asked not wear mascara during the study.

The tasks will take a total of 1 hour to complete, and you will be reimbursed $20 to cover expenses such as parking.

If you have participated in other research studies with Dr. Green, information obtained from these studies may be used in the present study so we don't have to ask some things twice. This information would be accessed by Dr. Green and Alexandra Arrnold-Oatley. If this applies to you, please check below to give your consent for us to use the following information:

- Your neuropsychological file which includes all data from past clinical and experimental assessments. This includes:

Yes	No	
❑	❑	Demographic information (e.g. age, gender, years of education)
❑	❑	Medical information from your chart (e.g. nature of injury, MRI findings)
❑	❑	Neuropsychological test scores

If you are not a participant in the Recovery Study, we will request demographic information from you (e.g., age, years of education, Country of origin).

Risks and Discomforts
Participating in this study does not involve any known risks to you. If you feel tired, you can stop and rest. If you become anxious or uncomfortable during any of the tasks, you can stop at any time. You may withdraw from the study at any time, and still receive your reimbursement. In addition, your current or future care at the Toronto Rehabilitation Institute will not be affected in any way if you choose to withdraw from this study.

Benefits
There are no direct benefits to you as a participant in this study. However, you will be contributing to knowledge that could help people with brain injury in the future.

Confidentiality
The information obtained for this research study will be kept locked in a secure area and will only be made available to researchers involved in the study. If you wish, this information can also be made available to your therapist. Any information that identifies you personally (e.g. name, address) will be removed before any results from the study are published.

Participation
You are free to choose *not* to participate in this study. You are also free to withdraw from the study at any time without affecting any health care you may be receiving at Toronto Rehab.

Your Rights

If you have questions concerning the study, you can call Dr. Robin Green. If you have any questions about your rights as a research participant, or about any ethical issues relating to this study, you can contact the Chair of the Research Ethics Board, Dr. Paul Oh. You will receive a copy of this consent form.

Consent
I have had the chance to discuss this study and I am satisfied with the answers to my questions. I voluntarily consent to participate in this study.

Participant Name: _____

Signature: _____ Date: _____

Person who obtained consent: _____

Signature: _____ Date: _____

Appendix B.1: Debrief Sheet for York University Participants

DEBRIEFING INFORMATION LETTER: York University Version

Reading Emotions from Faces

Principal Investigators:
Dr. Robin Green, Toronto Rehab
Alexandra Arnold Oatley, PhD Student, Toronto Rehab and York University

Research Assistant:
Marika Dabek, Toronto Rehab

York University Graduate Supervisor and Faculty Contact at York University:
Dr. Maxine Gallander Wintre, York University

Funding: Natural Sciences and Engineering Research Council of Canada (NSERC)

Introduction

We appreciate your participation in our study, and thank you for spending the time helping us with our research.

During the experiment, you were told that we would be taking some measurements of your face using a video camera and that we would explain the purpose of this after the experiment.

The purpose of the experiment is to better understand the way in which people scan emotional faces. After traumatic brain injury, some people have difficulty reading facial emotions. We are investigating the possibility that the eye-movements that they make may influence their perception of emotional faces.

The video camera allowed us to monitor your eye-movements during the experiment. We did not tell you that the camera selectively measured your eye-movements because it may have influenced your responses during the study and might have rendered the results invalid.

Because some elements of the video tracking task are different from what was originally explained, we have another consent form for you to read and sign if you are willing to allow us to use your data from this experiment for research purposes.

This form is a record that the purpose of the study has been explained to you, and that you are willing to allow your information to be included in the study. Any current or future care at Toronto Rehabilitation Institute will not be affected in any way if you choose not to give this permission.

If you would like any further information or you think of some other questions, please do not hesitate to contact Alexandra Arnold Oatley or Dr. Maxine Wintre. If you have any questions about your rights as a participant in our study you may also contact the Sr. Manager & Policy Advisor for York University's Office of Research Ethics. We really appreciate your participation, and hope that this has been an interesting experience for you.

Appendix B.2: Debrief Sheet for Toronto Rehab – UHN Participants

DEBRIEFING INFORMATION LETTER

Reading Emotions from Faces

Principal Investigators:
Dr. Robin Green, Toronto Rehabilitation Institute
Alexandra Arnold Oatley, Toronto Rehabilitation Institute

Research Assistant:
Marika Dabek, Toronto Rehabilitation Institute

Funding: Natural Sciences and Engineering Research Council of Canada (NSERC)

Introduction

We appreciate your participation in our study, and thank you for spending the time helping us with our research.

During the experiment, you were told that we would be taking some measurements of your face using a video camera and that we would explain the purpose of this after the experiment.

The purpose of the experiment is to better understand the way in which people scan emotional faces, a type of face perception. After traumatic brain injury, some people have difficulty reading facial emotions. We are investigating the possibility that the eye-movements that they make may influence their perception of emotional faces.

The video camera allowed us to monitor your eye-movements during the experiment. We did not tell you that the camera selectively measured your eye-movements or that we were specifically interested in how you read the emotions on the faces because it may have influenced your responses during the study and might have rendered the results invalid.

Because some elements of the video tracking task are different from what was originally explained, we have another consent form for you to read and sign if you are willing to allow us to use your data from this experiment for research purposes.

This form is a record that the purpose of the study has been explained to you, and that you are willing to allow your information to be included in the study. Any current or future care at Toronto Rehabilitation Institute will not be affected in any way if you choose not to give this permission.

If you would like any further information or you think of some other questions, please do not hesitate to contact Alexandra Arnold Oatley or Dr. Robin Green. If you have any questions about your rights as a participant in our study you can also contact Dr. Paul Oh, the Chair of the Toronto Rehab Research Ethics Board. We really appreciate your participation, and hope that this has been an interesting experience for you.

Appendix C.1: Postdebriefing Consent Form for York University Participants

POST-EXPERIMENT CONSENT FORM

Project Title: Investigations of facial emotion perception in the normal brain and following traumatic brain injury (TBI)

Principal Investigators:
Dr. Robin Green, Senior Scientist and Toronto Rehab Supervisor
Alexandra Arnold Oatley, PhD Student

Research Assistant:
Marika Dabek

York University Supervisor and Faculty Contact:
Dr. Maxine Gallander Wintre

At the start of the experiment, I was told that I would be told the purpose of the video camera after the experiment. During the debriefing session, I learned the purpose of the video tracking" task and was given further information of the larger purpose of the study. Having this fuller information might have influenced the way I responded and this might have made the results of the study invalid.

I have now received a complete explanation as to the purpose of the task and the video-camera, and have had an opportunity to ask any questions about this and to have them answered.

I agree to give permission for the researchers to use my data (or information I provided) in their study.

I am also aware that I may contact Alexandra Arnold Oatley, or Dr. Maxine Wintre if I have any concerns or comments resulting from my involvement in this study. Further, I am aware that I may contact the Sr. Manager & Policy Advisor in the Office of Research Ethics at York University if I have questions about my rights as a participant in this study.

Participant Name: _____

Signature:_____ **Date**_____

Person who obtained consent: _____

Signature:_____ **Date**_____

Appendix C.2: Postdebriefing Consent Form Toronto Rehab - UHN Participants

POST-EXPERIMENT CONSENT FORM

Project Title: Investigations of facial emotion perception in the normal brain and following traumatic brain injury (TBI)

Principal Investigators:
Dr. Robin Green
Alexandra Arnold Oatley

At the start of the experiment, I was told that I would be told the purpose of the video camera after the experiment. During the debriefing session, I learned the purpose of the video tracking" task and was given further information of the larger purpose of the study. Having this fuller information might have influenced the way I responded and this might have made the results of the study invalid.

I have now received a complete explanation as to the purpose of the task and the video camera, and have had an opportunity to ask any questions about this and to have them answered.

I agree to give permission for the researchers to use my data (or information I provided) in their study.

I am also aware that I may contact Alexandra Arnold Oatley, or Dr. Robin Green if I have any concerns or comments resulting from my involvement in this study. Further, I am aware that I may contact Dr. Paul Oh if I have questions about my rights as a participant in this study.

Please indicate if you would like the information you provided to be made available to your therapist.

Yes	No	NA
❑	❑	❑

Participant Name: _____

Signature: _____

Date: _____

Person who obtained consent: _____

Signature: _____

Date: _____

Appendix D: Data Example

Appendix E: TBI Sample Injury Characteristics and Neuropsychological Profiles

ID	Sex	Injury Severity	Months Post TBI	General Lesion Location	Sustained Attention / Speed (TMT-A)	Complex Attention / Speed (TMT-B)	Processing Speed (SDMT Oral)	Reading Test / Verbal IQ (WTAR)	Visual Reasoning (WASI)	Verbal Reasoning (WASI)	Verbal Learning (RAVLT)	Visual Learning (RVDLT)	Depression (BDI)
01p	M	Moderate	4	Left	VS	VS	LA-A	HA	VS	HA	A	A	Minimal
02p	M	Very Severe	4	Bilateral	BI	A	LA-A	S	VS	HA	A	BI-LA	Minimal
03p	M	Moderate	24	Bilateral	BI	A	MI	NA	HA	LA	BI	LA	Minimal
04p	W	Severe	12	Cerebellum	HA	A	S	S	S	HA	LA	A	Mild
05p	M	Very Severe	4	Bilateral	A	A	S	HA	S	A	A	VS	Minimal
06p	M	Very Severe	12	Bilateral	HA	S	A	S	VS	S	HA	A	Minimal
07p	M	Moderate	4	Right	A	A	A	HA	VS	S	A	S	Minimal
08p	M	Very Severe	12	NA	LA	LA	A	HA	S	HA	LA	HA	Minimal
09p	W	Moderate -Severe	12	Bilateral	HA	A	A	HA	S	HA	LA	BI	Minimal
10p	W	Very Severe	12	Bilateral	BI	LA	BI	NA	A	A	LA	BI	Minimal

Note. Patients demonstrated a high level of overall intellectual functioning, with Reading and Visual Reasoning scores in the average to very superior range.
MI = moderate impairment, BI = borderline impairment, LA = low average, A = average, HA = high average, S = superior, VS = very superior