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Performance Validity Assessment Of Bona Fide And Malingered Traumatic Brain Injury Using Novel Eye-Tracking Systems

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PERFORMANCE VALIDITY ASSESSMENT OF BONA FIDE AND MALINGERED TRAUMATIC BRAIN INJURY USING NOVEL EYE-TRACKING SYSTEMS

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DEDICATION

"The power that elevates the few is to be found in their industry, application and perseverance under the promptings of a brave, determined spirit."

- Mark Twain

This is for you, Mom and Dad,

In thanks

For nurturing my spirit,

Teaching me bravery and determination

&

Imbuing me with the confidence to strive for success

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Although my name stands alone as the author of this document, the scope of this project far exceeds the text found within. This study was made possible by the creativity, dedication, and hard work of a huge research team, comprised of too many individuals to name. Though, a select few played such an instrumental role from beginning to end that personal acknowledgement is absolutely necessary. First and foremost, the support and advice provided by my advisor, Dr. Lisa J. Rapport, and my dissertation committee members, Dr. Douglas Whitman, Dr. Robin Hanks, and Dr. Patricia Siple, have been paramount in the initiation, progress, and success of this dissertation. To you all, I wish to express my deepest gratitude.

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CHAPTER 1 INTRODUCTION

Many decisions result in banal effects, reorganizing causal sequences so subtly that they are hardly recognizable as decisive. Some judgments are made unconsciously, and yet, others seem rooted in long periods of effortful thought. Most important for the purposes of this study are those deliberate decisions that may bring forth profound repercussions, given the contexts in which they are made.

Within the clinical, medical, and forensic contexts, decisions often lead to grave consequences. Diagnostic judgment, and the subsequent access to treatment and resources that follows, is an area of significant importance to both patients and clinicians. For example, Newman-Toker and Pronovost (2009) demonstrated that incorrect diagnoses made by expert, medical employees account for roughly 60,000 fatalities a year, a statistic that effectively qualifies these errors as the sixth leading cause of death in the United States. Although these particular statics describe misdiagnoses or prescriptive errors within the biomedical field, the serious implications of this data must not be viewed as a problem isolated to any one branch of science. Instead, all disciplines that directly impact the diagnosis, treatment, or rehabilitation of patients must guarantee its commitment to decisional accuracy by fostering empirically guided improvements to the strategies used to make these decisions.

Among the assorted fields of clinical science, neuropsychology is one that will not only benefit from improvements in decisional accuracy but also may contribute greatly to the understanding of how judgments and choices are made. In particular, neuropsychology offers a shrewd perspective on the neuroanatomical bases of decisional behavior, pays close attention to classical psychometrics, and does a good job at assessing conceptual constructs (e.g., cognitive functions) using empirically-based, standardization methods. Nevertheless, neuropsychology

remains a young discipline that has not fully grown into its position at the intersection of biology and neuroscience; although, signs of its growth are already evident. Computer science technologies such as neuroimaging, the human genome project, and cognitive neuroscience, for example, have dramatically shaped the our understanding of neuropsychological processes (Bilder, 2011). As clinical science and technology further converge, stronger and more refined links can be made between neuropsychological constructs (e.g., such as effort) and the structure and function of neural circuits, cellular and molecular systems, and genomics (Bilder, 2011). Furthermore, by linking these neuropsychological concepts to specific methods of measurement, a more objective evaluation of a test's construct validity can be ascertained (Bilder et al., 2009).

In contrast to the recent breakthroughs in cognitive neuroscience, imaging techniques, and psychometric theory, the evolution of neuropsychological testing per se appears stunted. The bridging of cognitive constructs, to task indicators, to specific biological processes is far from complete, and it appears to be largely a result of poor incorporation of modern technologies into clinical assessment strategies; rather, paper-and-pencil instruments have been maintained as the standard tools used in neuropsychological evaluation (Podell, DeFina, Barrett, McCullen, & Goldberg, 2003). Fortunately, at least the ground has been broken by the burgeoning adoption of computerized assessment in clinical settings, and the door to implementing the refined methodology from cognitive neuroscience has been opened. For example, computerized and virtual reality instruments have begun to be used in the assessment of cognitive constructs (Nagut, Matu, Sava, & David, 2016) such as attention (Adams, Finn, Moes, Flannery, & Rizzo, 2009), memory and learning (Matheis et al., 2007), and spatial abilities (Parsons et al., 2004). As neuropsychology evolves and takes on new methodological perspectives, the incorporation of more subtle task manipulations and trial-by-trial analyses will be enabled, thereby producing

increased sensitivity and specificity when detecting faint, individual differences in neural system function and its associated behaviors (Bilder, 2011).

In order to integrate technology into neuropsychology meaningfully, the immensity of data obtained from computerized assessments must be explored, decoded, and operationalized. One area of psychology that likely provides the most insight into understanding this information is cognitive neuroscience. An important branch of this field, Judgment and Decision-making (JDM), typically aims to deduce decisional processes from observable decision outcomes. Advances in computer based technologies, such as mouse-tracing (Franco-Watkins & Johnson, 2011), have allowed this research paradigm to capture the underlying cognitive processes linked to decision-making behavior. Hence, the current study aimed to incorporate JDM methodologies into a clinically applicable, neuropsychologically-based methodology, thereby allowing JDM theory to guide the formation of novel, testable, and clinically useful hypotheses.

These hypotheses have been primarily centered on an important problem in the clinical application of neuropsychological assessment: *effort*. Purposeful presentation of effort test failure (EFT; Webb, Batchelor, Meares, Taylor, & Marsh, 2012) is a significant problem to accurate assessment, especially among compensation seeking individuals. It has been estimated that approximately 30-50% of neuropsychological forensic cases, the majority of which are TBI-related, may involve suspect effort or feigned impairment (Larrabee, 2003; Larrabee, Millis, & Meyers, 2009; Binder & Kelly, 1994); hence, research investigating the identification of this construct is crucial. Much of the rigorous malingering research has employed *analog design*: a simulation paradigm in which healthy adults assigned to feign TBI (sometimes coached in how to succeed) are compared to healthy adults instructed to put forth best effort (Heilbronner, Sweet, Morgan, Larrabee, & Millis, 2009; Larrabee, 2012). Among the many strengths of this design is

the level of experimental control; however, it is faulted for having low ecological validity relative to *known-groups* designs (i.e., inclusion of groups of persons with a bona fide clinical condition). Perhaps as a result of methodological limitations, or due to the historical focus on outcome measures as opposed to in vivo processes, it is unfortunately noted that the current strategies used to judge effort in medico-legal traumatic brain injury (TBI) assessments are unacceptably inaccurate, especially in regards to sensitivity to purposefully poor task performance (Binder & Kelly, 1994).

Section 1.1 – Clinical Need

With approximately 1.7 million new injuries each year (of which 275,000 are hospitalized), and 5.3 million people living with injury-related deficits, TBI is a significant health problem in the United States (Faul et al., 2010; Finkelstein, Corso, & Miller, 2006). Furthermore, TBI has come to be considered the signature injury resulting from the 2001 to 2007 wars in Iraq and Afghanistan. The estimated number of services members who have met criteria for probable to severe TBI have ranged from 32,000 (Maruta, Suh, Niogi, Mukherjee, & Ghajar, 2010) to 195,547 (Lange, Pancholi, Bhagwat, Anderson-Barnes, & French, 2012) during that time. TBI can result in an array of complex, variable, and long-lasting cognitive deficits. Memory impairments are especially common and long-lasting following TBI (Lezak, Howieson, Loring, & Hannay, 2004). These symptoms are typically diagnostically dependent on the subjective reports of the patient concerning the characteristics of their injury, especially in cases of Post Concussive Syndrome (PCS), or Mild TBI (mTBI) (Maruta et al., 2010). Although formal cognitive evaluations routinely include standardized measures of memory (Lezak et al., 2004) to supplement these subjective reports, the validities of these tools are vulnerable to the level of effort provided by the examinee during testing.

The base rate for malingering in compensation-seeking cases involving post-concussive neurocognitive deficits, such as memory impairment associated with mild head injury, is estimated at 40% (Larrabee et al., 2009). Other estimates approximate 30% of civil cases, 20% of criminal cases, and 10% of medical cases as suspect of feigned neurocognitive impairments, memory deficits being the most commonly reported (Mittenberg, Patton, Canyock, & Condit, 2002). Research investigating poor performance on neuropsychological assessments of TBI in military services members has begun to burgeon, as well. Results from four recent studies estimate that 11% to 60% of service members appear to be providing purposeful poor performance during neuropsychological testing (Lange et al., 2012). Task underperformance may result for a myriad of reasons, both conscious and unconscious (Lynch, 2004). Without accurate means of assessing effort, clinicians are left with test results of questionable validity. Invalid assessments then often lead to an assortment of diagnostic decisional errors, from which follow medical and legal consequences such as: misdiagnoses, improper intervention strategies, inaccurate outcomes from treatment efficacy studies, and unfair allocation of resources and monetary compensation.

Currently, increased public awareness of cognitive deficits following even mild TBI has given rise to an increasing number of individuals seeking medico-legal compensation for damages (Pankratz & Binder, 1997). As a result, the official position of the National Academy of Neuropsychology (Bush et al., 2005), the American Academy of Clinical Neuropsychology (Heilbronner et al., 2009), the Department of Defense and the Department of Veteran Affairs (Maruta et al., 2010) stipulate that the assessment of symptom validity is an essential aspect of all neuropsychological evaluations and demands greater attention by researchers. It is also commonly recognized that of the various methods available to evaluate TBI, neuropsychological

testing provides critical information regarding changes in attention, working memory, and executive functioning: cognitive processes that are commonly affected by TBI (Maruta et al., 2010).

Presently, a large number of stand-alone performance validity tests (PVTs) are commonly used during neuropsychological evaluations to assess for test-performance validity. Of the measures specifically designed to assess for purposeful poor performance, the PVT paradigm is the most popular among neuropsychologists (Constantinou, Ashendorf, Fisher, & McCaffrey., 2005; Slick, Hopp, Strauss, & Spellacy, 1996). Although published by independent parties, these tests share two common features: (1) they are related to aspects of memory performance as this cognitive domain is highly susceptible to impression management among persons undergoing neuropsychological evaluation for TBI; and (2) they employ a two-alternative forced-choice format that utilizes the known probabilities of correct responding given no prior exposure to the test stimuli (Hiscock & Hiscock, 1989).

Despite establishing the standard of prevailing practice to include multiple indices of effort (Boone, 2009; Binder & Kelly, 1994; Bush et al., 2005; Slick, Sherman, & Iverson, 1999), even with the use of a PVT specifically recommended in a neuropsychological assessment (Inman & Berry, 2002; Binder & Kelly, 1994), the decisional accuracy in identifying feigned cognitive impairment remains unacceptably low. Many of the "gold standard" stand-alone measures are highly susceptible to coaching and can be easily identified by examinees as measures of effort or malingering (Cato, Brewster, Ryan, & Giuliano, 2010). "Embedded" measures have been created in an attempt to rectify this problem by acting as indices derived from standard ability tests commonly administered in a neuropsychological battery (i.e., "built in") that are able also to signify non-credible or "suspect" performance. Nevertheless, the

classification accuracy yielded from these traditional methods has produced adequate specificity at the expense of relatively low sensitivity (Bush et al., 2005). Moreover, TBI sequelae commonly include adverse effects on motivation and engagement, which can undermine appreciation of the importance of accurate cognitive evaluations; thus, misclassifications of bona fide TBI as malingering due to poor performance are a risk. These issues represent an important problem because individuals who feign impairment unfairly stress the legal and healthcare systems. Conversely, patients who are wrongly classified as supplying poor effort are unfairly accused as feigners and unjustly restricted from accessing the resources they deserve. Decisional accuracy can improve through the incorporation of state-of-the-science technologies into assessment batteries. Specifically, the inclusion of eye-tracking technology in routine cognitive assessments can provide reliable biomarker data (i.e., patterns of oculomotor movement) capable of significantly improving sensitivity to feigned neurocognitive deficits.

Section 1.2 – Computer Technology and Psychological Assessment

Experimental neuroscience research has generally demonstrated that computer based methodologies, such as eye-tracking, afford fine-grained measurements that quantify cognitive processes, such as attention, at the automatic level (Franco-Watkins & Johnson, 2011; Maruta et al., 2010). Unfortunately, technologies such as these have been underutilized in clinical assessment settings for a number of reasons: they are cost prohibitive, there exists a belief that they may produce error due to questionable client or clinician technological sophistication, or there may simply be an unawareness of the clinical and research applications (Trull, 2007). Fortunately, a few studies have demonstrated not only the feasibility of incorporating computer technology into assessment, but also allude to their positive contributions to the understanding of cortico-behavioral processes as well as diagnostic reliability and validity. For example,

computerized administration of the MMPI-2 significantly reduced testing time (and therefore examinee fatigue), while maintaining the test's reliability and validity (Forbey & Ben-Porath, 2007). Other technologies, such as electronic diaries and ambulatory biosensors (Haynes & Yoshioka, 2007), have been developed and suggested for use in multimodal clinical assessment in the hopes of reducing error due to clinical judgment. Yet, little research so far has carefully scrutinized the incremental validity of adopting these measures into batteries alongside traditional assessment techniques (Trull, 2007).

Section 1.3 – Eye Tracking

Eye tracking is a method of measurement by which a researcher may use the distinguishing features of the eye (e.g., corneal reflections, iris-sclera boundary, or the dark contrast of the pupil size) to plot the temporo-spatial movements of the eyes in order to infer attentional point-of-regard (Duchowski, 2002). Hence, it provides refined information about the oculomotor patterns of an examinee at any given time (Poole & Ball, 2005). The eye-tracking paradigm is founded primarily on an premise often cited in the neuroscience and reading literature: the Eye-Mind assumption (Just & Carpenter, 1980). This premise states that eye placement (i.e., fixation) on a target presumes strong relationship with working memory and attention (Orquin & Mueller, 2013), immediate processing of information associated with the target (Jacob & Karn, 2003; Goldberg & Katvol, 1999; Just & Carpenter, 1976), and gaze duration (i.e., the time the eye remains fixated on the target) is an index of the time taken for information comprehension (Mello-Thomas et al., 2005; Hauland, 2002). Basic support for this assumption has been seen in spatial-problem tasks and reading tasks, demonstrating that overt attentional shifts appear to move in tandem with eye movements during complex information

processing (Rayner, 1998). In other words, eye tracking provides a dynamic trace of a participant's directed attention and uncovers the hierarchy of immediate cognitive processes.

Fixation and gaze are merely two of many oculomotor measures that can be produced by eye-tracking methods. For example, saccades, or rapid simultaneous movement of both eyes, have been linked to search strategy, recognition of meaningful cues (Goldberg & Kotval, 1999), and may allow for inferences to be drawn about a viewer's expectancies and goals (Cowen, Ball, & Delin, 2002). Fixation spatial density (i.e., search efficiency; Cowen et al., 2002), repeated fixations (i.e., meaningfulness of the target stimuli; Goldberg & Kotval, 1999), time to first fixation (i.e., index of attention-getting properties of the target; Byrne, Anderson, Douglas, & Matessa, 1999), blink rate (i.e., an index of cognitive workload; Bruneau, Sasse, & McCarthy, 2002), and pupil dilation (i.e., index of cognitive effort; Marshall, 2007) make up some of the complex measures of eye movement generally studied. Furthermore, many of these measures have been combined and analyzed temporally to develop scanpath variables (i.e., saccade-fixate-saccade sequences) capable of further refining the connection between visual processes and cognitive functioning (Goldberg & Kotval, 1999). Specifically, scanpath duration, length, and movement patterns along the transition matrix (i.e., the virtual grid upon which gaze and affiliated movements are plotted) have been linked to scanning efficiency and uncertainty (Goldberg, Stimson, Lewenstein, Scott, & Wichansky, 2002; Hendrickson, 1989), effortful search focus, scanpath regularity (i.e., index of change in search strategy), and saccade/fixation ratios (i.e., ratio of processing to searching behavior) (Goldberg & Kotval, 1999). Due to its ability to capture such a wide range of oculomotor diversity, eye-tracking measures provide a methodological advantage to studying cognitive and perceptual processes (Inhoff & Radacah, 1998). Overall, eye tracking data have also been shown to produce keen, objective, and

quantitative evidence of overt attentional processes (Duchowski, 2002), problem-solving, reasoning, mental imagery, and search strategies (Poole & Ball, 2005; Jacob & Karn, 2003).

Recent advances in the eye-tracking industry have enabled the manufacture of accurate, affordable, non-invasive, and easily manipulated hardware systems capable of reducing measurement error during testing to a clinically acceptable level (Homqvist et al., 2011). Although older systems have successfully described oculomotor phenomena (e.g., gaze dysfunction, saccadic irregularities, etc.) in experimental contexts using TBI participants, cumbersome apparati limited the generalizability of obtained test results. Contemporary, state-of-the-science technologies have significantly reduced the invasive characteristics found in older systems, however. Thus, eye-tracking systems are currently capable of being adequately applied to clinical settings for purposes such as enhancing diagnostic accuracy or to inform treatment considerations.

Psychological testing has historically focused on decision outcomes, or *what* answer is chosen. At best, these paper-and-pencil testing paradigms could only be supplemented by clinical observations of test-taking behaviors, which can be unreliable and inaccurate. In order to shift the assessment methodology paradigm to a point where testing can home in on in-vivo behavioral processes, or *how* an answer is chosen, the incorporation of reliable, temporally accurate technology is required (Franco-Watkins & Johnson, 2011). Fortunately, contemporary eye-tracking systems are now capable of measuring a large number of acute oculomotor behaviors accurately and reliably, and their incorporation into neuropsychological batteries provides the unique opportunity for neuropsychological assessment to capture evidence of deficits too subtle to detect when using traditional neuropsychological measures (Maruta et al., 2010). For example, the momentary lapses in attention commonly seen in TBI patients can be

astutely measured via eye-tracking methods that assess oculomotor markers such as gaze duration, saccade patterns, off-target movements, and gaze switching in high temporal resolution (Franco-Watkins & Johnson, 2011). Oculomotor patterns are sensitive biomarkers of cognitive impairment even after mild injury. Additionally, because several oculomotor indices that characterize bona fide TBI are beyond conscious control, these indicies provided an optimal method to assess the processes that underlie ETF. Hence, eye tracking provided unique insights into how TBI survivors and healthy adults engaged neuropsychological assessments of test validity, allowing enhanced diagnostic accuracy regarding symptom validity and deliberate dissimulation. Given the fledgling nature of this type of assessment, the luxury of consulting normative oculomotor statistics is presently unavailable. Therefore, hypothesis generation relied predominantly on theory. JDM research, in particular, provided a structured starting point for interpreting these sensitive biomarkers.

Section 1.4 – Judgment and Decision Making

Within the field of cognitive neuroscience, judgment and decision-making (JDM) research in particular, "judgments" and "decisions" are considered separate constructs. *Judgments* are best defined as the cognitive processes of appraising two specific factors: valance and likelihood. The former involves appraising a perceived object or event as good/bad or right/wrong, whereas the latter entails forming conclusions about the likeliness of that object or event leading to anticipated consequences. *Decisions*, which follow from *judgments*, represent the commitment to a single course of action from a varied set of options. Once a decision is made, its consequences are judged and influence subsequent behaviors or choices (Vohs & Luce, 2010). It is from this perspective that JDM theory may help elucidate the clinical application of oculomotor behaviors in an assessment setting. Neuropsychological tests (i.e., PVTs) aimed at

differentiating bona fide from simulated TBI typically relies on forced-choice measures that require examinees to decide between two, simultaneously presented items: one a target and one a foil. Although statistical prediction models provide diagnostic conclusions (i.e., albeit, limited) based on outcome scores, little attention has been paid to the processes involved while making this decision. By understanding how people make choices cognitively, linking this to observable, quantitative behavioral data (i.e., concurrent oculomotor profiles), and integrating these biomarkers into the interpretation of neuropsychological assessment data the predicative accuracy of performance validity tests may increase.

In order to best appreciate how decisional processes might be evaluated, it is useful to recognize that the study of judgment and decision-making has strong ties to economic theory and mathematical models. Early thought about JDM phenomena assumed a mathematical underpinning to the theoretical understanding of decisional effectiveness. From this evolved key definitions regarding the utility of a decision, with particular focus set on judging whether a decision is "normative," or best able to provide maximal utility in domains such as pleasure or satisfaction (Vohs & Luce, 2010). Generally, the dominant perspective adopted by economists involves the belief that humans are utility maximizers who, given sufficient reasoning abilities, should aim to decide on the normative option regardless of the surrounding circumstances. Initially coined by von Neumann and Morgenstern (1944) as the *Subjective Expected Utility Theory*, this theory was derived to unify the processes of judging the likelihood and value of a decisional outcome within the context of an economic vacuum. Specifically, this model involves quantifying the likelihood so as to be able to compare distinct options. Although such a straightforward perspective provides simplicity in conceptualizing how people are expected to act when confronted with making a decision, it is gravely limited by its lack of ecological

validity. In other words, the complex context of daily life often provides far more variables than would be expected in a "vacuum;" hence, people often appear to act in an "incompletely rational" (Kahnemann, 2003) fashion and make decisions for which reasonable motives are apparently absent or ambiguous. As a result, this theory has been largely discarded by contemporary social psychology. Regardless, within the standardized confines of a neuropsychological assessment, the number of confounding variables may be sufficiently reduced. Therefore, this version of JDM theory may provide a useful and quantitative method of assessing distinct decisional options, particularly on a dichotomous, forced-choice test, for example.

JDM theory evolved a psychological perspective in order to enhance understanding of the complexities inherent in human decision making. From this psychological perspective arose *Prospect Theory*, an orientation that provides unique insight into when and why individuals seem to make irrational choices (Vohs & Luce, 2010). Formally, Prospect Theory highlights the importance of attending to the decision maker's unique reference point when assessing the options associated with decisional outcomes. In other words, psychologically-based JDM theory focuses on the relative nature of decision-making across person and setting, and assumes that only by acknowledging the point of view of the examinee will predictions about the decisional process be made more incrementally valid. It is at this point, precisely, that the intersection between JDM, social neuroscience, and the aims of this study can be seen most clearly. Namely, embodied cognition, or the perspective that cognitive processes are deeply rooted in the body's interactions with the world, provides insight into the subjective judgments leading to a decision via perception and action (Wilson, 2002). By tracking patterns of oculomotor behavior during a

clinical assessment, it may be possible to infer which cognitive processes are underlying the choices made from one trial to the next.

A key tenet of psychologically framed JDM theory states that decisional outcomes do not have absolute values; rather, the value attributed to a decision is inherently dimensional and best understood as "better" or "worse" than alternative options. The effects of this dimensionality by reference point interaction have been shown in studies using scenarios that manipulate a participant's possible losses or gains. One of the most consistent findings upon which this research converges is that the psychological impact of a loss is much greater than that of a gain; bad is stronger than good (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001). Also dependable are results demonstrating that humans are generally poor at maintaining a consistent value judgment and often struggle with accurately estimating the objective base rate of an event's occurrence. Taken together, it is apparent that the preferences that individuals construct to inform their decisions are rarely stable, but rather highly susceptible to the situation in which they are made. Therefore, the attention of JDM research shifted to studying those situational features that alter preferences, and by extension, decisions. It is here that research begins to aid in constructing hypotheses concerning decisional behavior in a test setting.

Section 1.4.1 – Sunk Costs in the JDM Paradigm

One principle that likely influences the effort supplied in a clinical assessment is commonly known as *sunk costs*. Economic theory suggests that if an outcome becomes undesirable, no matter how many resources (e.g., time, money, energy, emotion, etc.) have already been invested to achieve it, the goal should be forgone. However, social psychology consistently shows that human decisions often neglect to follow this rule (Vohs & Luce, 2010). Rather, it seems that the more that has been invested in attaining a goal, the less likely one is to

give up on it regardless of the changing value associated with that outcome. Striking evidence for this behavioral phenomenon has been shown again and again in the intimate partner violence literature (Rusbult & Martz, 1995). In terms of malingering, one hypothesis is that individuals who have "sunk" their resources into fooling the exam will continue to demonstrate consistent behaviors (e.g., oculomotor patterns, in the case of this study) on subsequent tests,even if this behavioral strategy consequently increases their appearance as a faker. Based on similar theoretical grounds, yet reciprocal to the latter hypothesis, it may be the case that individuals who invest substantial effort at the start of a battery will maintain that level of effort, assuming they have the cognitive capacity or psychological resources to act in such a manner.

Section 1.4.2 – Framing in the JDM Paradigm

Framing may act as another guiding principle in JDM. Preferences for an outcome can change depending on how the outcome was described or understood. For example, if an outcome is framed to emphasize potential gains, it is common to see reductions in risky behavior, whereas risk seeking tends to follow loss oriented framing (Vohs & Luce, 2010). Within a clinical assessment of TBI, there will likely be patterns of performance that align more or less with risk taking depending on the orienting perspective of the test taker. Bona fide patients who see the assessment as a legitimate method of gaining needed treatment or monetary compensation may appear to perform in a manner that is generally risk averse (e.g., a lower incidence of random responding or guessing, which will likely coincide with a particular and stable pattern of oculomotor movements towards the chosen target). Conversely, a TBI simulator may frame the outcome of the assessment as a potential loss of opportunity to acquire financial compensation, thus, riskier test-taking behaviors may be expected. This latter effect may be further explained by the *attraction effect* (Huber, Payne, & Puto, 1982), which states that an unwanted option makes a

closely related, less aversive option seem more attractive. The use of eye tracking during a forced-choice test will likely contribute to a clear demonstration of this effect. For example, when given two targets the TBI simulator will likely perceive the correct choice as aversive (i.e., correct responding when attempting to feign disability is antithetical to their goal of appearing impaired); thus, this principle of JDM theory would predict unconscious, oculomotor movements to focus on the foil (e.g., via quicker saccadic fixation, longer gaze duration, or an increased frequency of regressive transitions towards the foil).

As was mentioned earlier, decisions and judgments are perpetually informing one another via a causal relationship. After a decision is made, the resulting consequences are evaluated and judged. Subsequently, this judgment informs the next decision that needs to be made. Temporal linearity is inherent to the process of making a choice; hence, a subject's in vivo *decisional process* remains entirely independent from any *actual* resulting outcome, which informs their *judgment process,* and so on (Vohs & Luce, 2010). In other words, JDM theory suggests that any choice is composed of two distinct processes, which together constitute the reason behind why a choice was made. Given the historic inability to measure a decisional process in a fine-grained manner, however, inferences made about this process seem to be necessarily contingent upon a priori knowledge about preceding judgmental processes. These hypotheses rely on JDM theory and research, which supplies a priori knowledge about an examinee's likely judgment process, assuming their group membership (e.g., in this study, bona fide TBI/good effort vs. Simulated TBI/poor effort) is also known. For example, it must be known up front that a subject is categorized as a bona fide TBI group member in order to presume that their test-taking decisions may be informed by a particular framing judgment (e.g., avoiding risks is in line with their goals given the potential gains of performing with adequate effort during a neuropsychological test).

Unfortunately, a priori information about a patient's group membership is typically unknown in clinical settings; hence, speculation about the judgments these subjects bring into the test setting and the reasons for which they form their decisions will remain unclear. Fortunately, having incorporated fine-grained eye-tracking methods during decisional tasks in a clinical assessment, information about decisional processes can be gathered without needing to surmise the orientation of their judgments. Rather, decisional processes can be inferred by linking the cognitive processes defined by the cognitive neuroscience and eye-tracking literature to the oculomotor biomarkers demonstrated when making a decision. Furthermore, having used a known-group design, a priori knowledge about potential judgment processes can clarify which decisional processes are associated with both judgment processes and group membership.

When judging the utility of a decision, it is important to reflect on the amount of time taken to make a reasonably sound choice. A primary reason to attend to this variable is the fact that humans are not boundless cognitive processors. Given our inherently limited information-processing capacities, it is adaptive to utilize cognitive shortcuts or heuristics when making choices. The concept of bounded rationality (Simon, 1955) was first coined to humanize thinking about decision making within the economic sphere, asserting that people are generally adept at making "good enough" decisions quickly. The evolutionary viewpoint, in particular, avers that many human behaviors are founded on strategies that balance the tradeoff between effort and successful outcome. For example, using heuristics saves on the time required to make a decision, especially when information pertaining to the outcomes is complicated (Gigerenezer & Goldstein, 1996). Although relying on heuristics often yields decent outcomes, its implementation increases the risk of errors. When decisions are associated with high-stakes outcomes, however, the consequences of making an error will typically be emphasized.

Therefore, JDM theory suggests that greater effort will be spent on carefully evaluating the circumstances of certain types of decisions. One question that comes to mind concerning applicability of these findings to the current study is how oculomotor patterns may indicate the use of heuristics in deciding on an objectively simple task.

Section 1.4.3 – Low Effort in the JDM Paradigm

One of the most influential factors leading to decisional errors is inadequate effort (Vohs & Luce, 2010), and a useful framework for understanding how this may occur is Kahneman and Frederick's (2002) System1/System 2 model. *System 1* relies on brief information review and emotion to enable fast, low-effort deciding. *System 2* produces more deliberate decisions through the expenditure of greater effort and time. Generally, errors tend to increase when the evaluator shows an overreliance on System 1 processing, which itself relies heavily on heuristics. Within the framework of this study, it is assumed that heuristic thinking such as "To look impaired, I must perform in a manner that appears impaired" may be over-utilized by TBI simulators, thereby producing a test profile that is rife with errors or incongruent oculomotor patterns on even the easiest tasks. Furthermore, reaction time in directing one's gaze towards a target is also a likely candidate in associating eye movement with underlying cognitive processes. Although reliance on a heuristic such as this may be damaging to the simulator's goals (i.e., classifying them as a malingerer), there is evidence to suggest that other heuristics may prove beneficial to the bona fide TBI patients.

It is important to realize that some decision tasks are inherently intuitive and require the use of "listening to your gut" (Hammond, Hamm, Grassia, & Pearson, 1987). This is especially true of performance validity tests, many of which are constructed to be so easy that even profoundly impaired individuals can pass them. Second, it is possible to incorrectly process

information, albeit in an effortful way, thereby decreasing the chance of achieving the outcome goal (Wilson & Schooler, 1991). Similarly reported, people tend to make more irrational decisions when forced to justify a choice (i.e., exert more cognitive effort) because they choose based on what is defensible rather than what is logical (Simonson, 1989). This will likely play a pivotal role in the performance of the TBI Simulators, as these individuals will likely not select targets based on their actual memory, but rather they will rely on naïve rationales of how the test works to guide their decisions.

Overall, JDM research findings direct attention to a few clinically salient factors that may affect eye-movement patterns during an assessment. These include variables such as value inconsistency, accurate reflection on the base rate of errors (i.e., simulators may misinterpret how poorly they suspect TBI survivors to perform on PVTs), reaction speed, heuristic driven behavior, and contextual framing.

Section 1.5 – Neuroanatomy of Visual Processing and TBI

One of the key features of TBI, diffuse axonal injury (DAI), is commonly the result of shear-strain injury following rotational acceleration forces (Meythaler, Peduzzi, Eleftheriou, & Novack, 2001). Damage is typically seen at the white-grey matter junction, corpus callosum, and superior colliculi, among others (Edelman & Goldberg, 2001). TBI has been widely shown to result in an assortment of cognitive deficits, with the most common cited at 1 year post injury being: memory deficits, impaired attention, and slowed processing speed (Hammoud & Wasserman, 2002; Dikmen, Machamer, Winn, & Temkin, 1995).

Eye movements have been shown to be a sensitive measure of dysfunction following head injury, particularly in cases of severe injury, as it implies some degree of conscious brain activity (Stewart-Amidei, 1991; Hutton, Nagel, & Lowenson, 1984). One area of the brain that

tends to be highly susceptible to damage following DAI is the shared neural substrate (i.e., white matter tract) connecting the prefrontal cortex (PFC), parietal cortex, frontal eye fields, and supplementary eye fields to the cerebellum (Hutton & Tegally, 2005; Chen, Holzman, & Nakayama, 2002). Simply stated, the primary means of communication between areas actively implicated in attentional processes and *smooth pursuit eye movement* (SPEM) is typically injured following injury (Contreras, Ghajar, Bahar, & Suh, 2011).

SPEM is a voluntary oculomotor movement activated by the presence of a moving target within the visual field. As demonstrated by Contreras and colleagues (2011), the association between attention and SPEM appears to be moderated by damage to the aforementioned white matter tract, thereby producing reliable differences in SPEM behavior between TBI participants and healthy controls on a word-recall memory task. The deficits in stochastic phase synchronization (i.e., binocular vergence, a measure of SPEM) seen in TBI patients during this memory task are reportedly exacerbated by increased cognitive load, especially when tracking targets horizontally (Contreras, Ghajar et al., 2011). From these results, specifically in regard to decreased within-group variability as cognitive load increases, it is argued that the manipulation of cognitive load in SPEM tasks may prove diagnostically efficient given the clear distinctions in oculomotor patterns between TBI survivors and healthy controls.

As reported in a review by Thiagarajan, Ciuffreda, and Ludlam (2011), 50 - 90% of mTBI survivors show empirically documentable oculomotor dysfunction following acute care, which is 3 to 4.5 times the rate of oculomotor deficits observed in the general population (i.e., 20-30% of the general population seek clinical care as a result of deficits in oculomotor function). Among people with TBI, various forms of visual dysfunctions are commonly demonstrated; yet, the most common is the vergence dysfunction *convergence insufficiency*

(Thiagarajan et al., 2011). Deficits of this kind are typically long-lasting; one study reported that 42% of patients showed convergence insufficiency 3 years post injury (Cohen, Groswasser, Barchadski, & Appel, 1989). Typically, DAI produces dysfunction in vergence (i.e., the simultaneous movement of both eyes to maintain binocular vision), accommodation (i.e., maintenance of focus), version (i.e., directional, synchronous movement), strabismus (i.e., improper alignment), and cranial nerve palsy (Ciuffreda et al., 2007). This is not entirely surprising, as multiple areas of the visual system (i.e., 12 of the cranial nerves that influence visual process) are commonly disrupted after TBI (Suchoff, Ciuffreda, & Kapoor, 2001). Of the deficits demonstrated, problems in vergence are found most frequently, with 56.3% of mTBI patients exhibiting them. Nevertheless, the majority of mTBI patients (51.3%) also show other oculomotor dysfunction as well: saccadic dysmetria (51.3%), accommodative insufficiency (41.1%), and strabismus (25.6%; Ciuffreda et al., 2007). The consequent results of these deficits are numerous; however, per patient report, general vision-based symptoms and trouble with reading are most common (Thiagarajan et al., 2011; Ciuffreda et al., 2007).

Observable signs of injury following DAI have largely been limited to macroscopic lesions due to restrictions in traditional neuroimaging techniques (e.g., computerized tomography and magnetic resonance imaging). However, advances in this field have enabled more sensitive measures of the microstructure of white matter tissue (WM), which may act as an important biomarker of TBI and aid in predicting outcomes (Huisman et al., 2004). Diffusion tensor imaging (DTI) in particular, which estimates the orientation of white matter fiber bundles and provides an index of fractional anisotropy, is able to quantify changes in tissue structure following DAI (Caeyenberghs et al., 2010; Nakayama et al., 2006). Research in this domain has demonstrated that DAI following TBI may produce deficits in dynamic eye-hand coordination

during predictive and manual tracking tasks (Suh et al., 2006; Heitger et al., 2007) such as increased visuomotor tracking error and prolonged tracking lag (Caeyenberghs et al., 2010; Heitger et al., 2007). Findings such as these support the high incidence of structural damage to the following sensory, afferent, inputs post DAI: medial lemniscus, posterior thalamic radiation/optic radiation, and middle cerebellar peduncle (Caeyenberghs et al., 2010; Kraus et al., 2007). Damage to the optic radiation, in particular, has been found to result in specific oculomotor patterns in TBI survivors such as early generation of saccades, increased oculomotor error, and increased within-subject variability (Suh et al., 2006). Furthermore, these results demonstrate that eye movement functioning is able to act as sensitive functional markers capable of predicting prognosis better than neuropsychological assessment or patient report (Heitger et al., 2009).

Disruptions in the cortico-cerebellar connections post DAI have been shown to be a hallmark of TBI, leading to oculomotor deficits and impairment in cognitive functions such as memory, attention, and executive function (Suh et al., 2006). Of the oculomotor deficits defined, smooth eye pursuit impairments have been the most rigorously studied. These findings suggest that oculomotor deficits are correlated with memory and learning as well as executive functioning; therefore, oculomotor deficits may be a strong indicator of cognitive deficits following TBI (Suh et al., 2006). Careful analysis of this pattern has lead to the contemporary understanding that decreased attention due to disruptions of cortico-cerebellar circuits often produces increases in saccade generation (Nagel et al., 2005). Generally, these results suggest that oculomotor error variability can act as an index of "moment-to-moment" attention during a tracking task (Suh et al., 2006).

Section 1.6 –Visuo-Memory Processes: Lying and Familiarity Responses

The association between eye movements and cognitive functions, such as attention and language processing (i.e., reading), has been well documented (Rayner, 2009). More recent research has demonstrated that eye movements are related to memory, as well. In particular, oculomotor patterns can reveal memory of previous experiences, independent of verbal report or conscious recall (Hannula et al., 2010). These results are based on certain fundamental associations between eye movements, visual processing, and memory.

Eye movements are not random. Rather, they are directed by two distinct factors: *stimulus characteristics*, such as its luminance, hue, or visual arrangement (Buswell, 1935; Antes, 1974), and *previous experience* (e.g., episodic and semantic memory). Memory can influence eye movement during visual processing in a number of ways. For example, semantic memory of contextual cues (e.g., a picture of a farm) may induce visual expectations (e.g., farm animals, equipment, etc.); resultantly, eye movement tends to focus on discrepancies (e.g., an octopus in the farm scene) when the stimulus does not conform to what is expected (Loftus & Mackworth, 1978). Similarly, target detection speed is increased by either brief (Hollingworth, 2009) or repeated exposure to a visual scene (Brockmole, Castelhano, & Henderson, 2006), and patterns of eye movements during visual processing tasks have been shown to change as viewing instructions change (Yarbus, 1967). Findings such as these suggest that general world knowledge robustly affects the manner in which a visual stimulus is evaluated (Henderson, 2003).

Early attempts to explain the association between mnemonic processes and eye movement yielded theories such as the *scanpath hypothesis* (Noton & Stark, 1971), which proposed that recognition of visual cues is mediated by the repetition of initial scanning patterns during subsequent viewings of a stimulus. As technological advancements became more

sophisticated, however, newer measures of oculomotor behavior were studied and revealed keener characteristics concerning oculomotor-mnemonic processes. Measures such as these are typically divided into two categories, overall viewing and directed viewing. As detailed by Hannula et al. (2010), the former attends to overall patterns of oculomotor movement when viewing an entire visual display, and includes specific measures such as: saccade amplitude, number of regions fixated, number of transitions between regions, first return fixation, first-order entropy, second-order entropy, and chi-square/asymmetric lambda. The latter refers to eye movements associated with specific areas, or areas of interest (AOI), within the visual display. These measures include: number of fixations, fixation duration, proportion of fixations, proportion of time, number of transitions into/out of a critical region, duration of first gaze, and number of fixations in the first gaze. For example, scanpath analyses during two-choice gaze tasks have shown that fixation duration increases for the chosen alternative at the end of the trial and fixation frequency reflects comparison processes (Orquin & Mueller, 2013; Glaholt & Reingold, 2011).

Research into these measures has generally demonstrated that oculomotor patterns can reveal memories of visual stimuli previously experienced. For example, Snyder, Blank, and Marsolek (2008) provided evidence that *novelty preferences* (i.e., influence of memory on oculomotor patterns) reflect the activation of an unconscious, perceptually-facilitated form of implicit memory during forced-choice novelty tests. Also reported was neurological evidence suggesting that this memory system uses repetition suppression, in the perirhinal cortex and surrounding visual association areas, to actively bias visual attention away from previously viewed information. These implicit, oculomotor patterns have been found across a variety of visual categories: famous/non-famous faces (Althoff & Cohen, 1999), familiar/unfamiliar

buildings (Althoff et al., 1998), and novel scenes (Ryan, Althoff, Whitlow, & Cohen, 2000). As outlined by Hannula and colleagues (2010), the specific oculomotor behavioral patterns witnessed included decreased numbers of fixations to pre-experimentally familiar items relative to novel items, decreased region sampling to previously viewed stimuli (Althoff et al., 1998) regardless of task demand (e.g., emotion labeling vs. recognition task), and increased fixations to critical regions that change (Ryan et al., 2000). Generally, it appears that implicit memory for various experiential factors (e.g., specific items, spatial relations, and temporal sequence) influence oculomotor patterns in measurable and consistent ways. Notably, these influences appear to occur rapidly and oft times outside of conscious awareness (Hannula et al., 2010).

A primary indicator of the speed at which these processes unfold is reflected by the eyes' rapid accumulation of previously viewed content, thereby allowing attention to be quickly routed to areas of change within the first few fixations (Ryan, Hannula, & Cohen, 2007; Parker, 1978). Similarly, oculomotor-based memory effects have been demonstrated using response time between stimulus presentation and movement of the eye (Hannula & Ranganath, 2009). Specifically, these authors demonstrated that rapid, disproportionate viewing effects specific to memory tasks, regardless of task demands, tend to occur within 500-750 ms after stimulus onset, and up to 1000 ms prior to explicit behavioral activity. Overall, results such as these lend support to the proposition that eye movements provide a degree of temporal accuracy capable of reflecting remembered content at an implicit level.

The attention literature has provided strong evidence that eye movements can be *unconsciously influenced*. As an example, novel images flashed in a scene tend to receive disproportionate amounts of viewing, even when participants are instructed to avoid looking at them (Belopolsky, Kramer, & Theeuwes, 2008). Change to the visual scene appears to be one of

the most robust mediators of unconscious visual processing, as demonstrated by participants viewing of a modified AOI despite their reported unawareness of the modification (Hollingworth, Williams, & Henderson, 2001). This unconscious oculomotor preference has been shown to exist during visual comparison tasks (i.e., forced choice tasks), a finding that holds specific importance to the present study. Specifically, Snyder and colleagues (2008) found that explicit recognition responses during these tasks were not affected by experimental manipulation of task demands during the learning trials (e.g., pairing a target image with a neutral vs. valenced object); yet, eye-movement expressions of memory were affected. Therefore, they conclude that the mechanisms underlying oculomotor memory and explicit reports of memory must be distinct from one another. Some have even gone so far as to suggest that conscious awareness is preceded by oculomotor memory effects, rather than the other way around (Ryan & Villate, 2009). It appears that these implicit oculomotor expressions of memory offer a unique method of examining implicit visual memory: a trait of particular importance in a context where explicit poor performance or feigned impairment may jeopardize the validity or utility of traditional diagnostic assessment tools.

Oculomotor dysfunctions and patterns observed after TBI have been well documented; similarly, patterns characteristic of normal decision-making during visual tasks among healthy adults have been well documented. Findings from these lines of research have not been applied to performance validity assessment; however, in combination, they offer a promising avenue in the assessment of performance validity. Accordingly, this study evaluated contributions of oculomotor patterns to detection of purposeful poor performance, as would be the case in feigned TBI impairment. The main hypothesis was that indexes derived from oculomotor patterns of performance would facilitate differentiating bona fide TBI from simulated TBI.

CHAPTER 2 AIMS OF THE CURRENT STUDY

The specific goal of this study was to enhance diagnostic accuracy in identifying bona fide TBI from feigned neurocognitive impairment by integrating novel technological methods, capable of measuring decisional processes at a more refined level, into diagnostic assessment techniques. Specifically, it was expected that eye-tracking during standard cognitive testing would yield supplementary information that would elucidate processes of decisional strategies in vivo and enhancing decisional accuracy concerning the validity of effort put forth during a clinical assessment. To address these aims, a known-groups design assessed 39 adults with bona fide TBI, 42 healthy adults coached to simulate TBI, and 50 healthy adults putting forth best effort. This study investigated the combination of a performance validity test (PVT) with eye-tracking indices resulting in efforts of improving classification accuracy between the groups. The methodology of the study was constructed to address three specific objectives.

Section 2.1 – Specific Objectives

A. Examine oculomotor patterns among healthy adults providing full effort, adults with bona fide TBI, and adults simulating TBI during a neuropsychological assessment. Identify patterns of oculomotor differences between the areas of interest (AOIs) defined for a standardized and commonly-used test: Test of Memory Malingering (TOMM). Sequences identified as common or rare within groups will provide a normative baseline of oculomotor events or strategies associated with bona fide TBI, good effort, and malingered neurocognitive impairment. The rates at which high probability sequences identified in one group occur in other groups will also be examined. Identified variables will be assessed in relation to each other, aiming to answer the hypothesis that discriminant validity will be identified between differing oculomotor behaviors, and thus provide unique measures of

cognitive constructs such as attention, visual processing, and effortful directed focus.

B. Create and operationalize oculomotor variables consistently demonstrated during the administration of the TOMM and assess the association of each variable with correct responding on the TOMM. Furthermore, associations among the identified oculomotor indices and measures of cognitive function were analyzed to examine evidence of convergent validity for constructs hypothesized to be assessed by oculomotor behaviors.

C. Determine the predicative accuracy discriminating between groups using oculomotor performance patterns. Following the discovery of those oculomotor variables that demonstrate significant group discrimination, assess whether their combination with the clinical pass/fail criteria of the TOMM adds meaningfully to the diagnostic accuracy in detecting feigned neurocognitive impairment (i.e., deciphering simulated cognitive impairment from bona fide impairment and healthy functioning).

CHAPTER 3 METHODS

Secion 3.1 – Participants

The initial sample of 142 participants who met all inclusion criteria consisted of 43 adults with TBI and 99 healthy adults (53 full effort healthy comparisons and 46 simulators). The pool of 131 participants with usable data comprised 39 adults with TBI and 92 healthy adults (50 full effort healthy comparisons and 42 simulators).

Participants with TBI were recruited from the Southeastern Michigan Traumatic Brain Injury System (SEMTBIS), which is part of the TBI Model Systems (TBIMS) program funded by the National Institute on Disability and Rehabilitation Research. Inclusion criteria for the SEMTBIS research project stipulates that all participants have incurred a medically-documented moderate to severe TBI as indicated by the following: post-traumatic amnesia lasting at least 24 hours, loss of consciousness for at least 30 minutes, Glasgow Coma Scale score less than 13 upon arrival to the emergency department, or the detection of abnormal intracranial status via neuroimaging. Further, participants must have received acute care within 72 hours of injury, been transferred to a rehabilitation unit, and have been at least 16 years old at the time of injury. Thus, the sample excludes persons with mild injuries or very severe brain injuries who did not receive inpatient rehabilitation and those with very severe injuries who could not engage sufficiently in the assessment process. SEMTBIS participants who agreed to be contacted for future research projects were notified of an opportunity to participate in the current study by the SEMTBIS research coordinator. Interested individuals were screened for eligibility and scheduled by the research team.

A sample of neurologically healthy adults were recruited for the TBI simulator group (n = 42) and for the HC control group (n = 50) from the Southeastern Michigan area. Recruitment

was conducted via newspaper advertisements and flyer postings throughout the Wayne State University campus and the Detroit Metro area. The exclusion criteria for healthy adults included history of neurological or psychiatric conditions, including: brain injury, dementia, stroke, epilepsy, multiple sclerosis, and psychotic disorders. Furthermore, because the current study required the use of eye-tracking technology during the course of examining neuropsychological performance, participants whose vision relied on the use of progressive and/or bifocal eyeglasses were also excluded, given that these corrective lenses significantly interfered with equipment calibration and tracking.

Complete demographic data for each group are presented in Table 1. Also included are the descriptive statistics for estimated IQ and neuropsychological measures of cognitive fuctioning, including Trails A and B, Digit Span, and Symbol-Digit Coding. The TBI group (n = 39) was predominantly African-American (89.7%) men (87.2%) with a mean age of 45.3 years (SD = 12.8) and mean education of 12.2 years (SD = 2.1). As identified by the WTAR, the standard score for the group was 84.6 (SD = 11.7). The injury statistics for the TBI group showed that at hospital admision the mean GCS score was 7.5 (SD = 2.7), mean length of post-traumatic confusion was 82.1 hours (SD = 209.7), and the mean length of time since injury was 154.3 months (SD = 85.5).

The SIM group (n = 42) also was primarily African-American (54.8%) men (54.8%), with a mean age of 44.4 years (SD = 16.9), mean education of 14.5 years (SD = 2.0), and mean WTAR standard score of 105.3 (SD = 11.9). Comparisons of the groups found no significant difference on age (F[2,128] = 1.23, p = .30) or proportions of self-reported race (F[2,128] = 2.10, p = .13), though education (F[1,128] = 12.9, p < .001) and proportion of men (F[1,128] = 1.30, p = .003) were significantly different.

Section 3.2 – Materials and Apparatus

Section 3.2.1 – Tobii Studio

The Tobii TX-300 Eye Tracking System includes proprietary gaze capture software called Tobii Studio. Tobii Studio was used to calibrate procedures and control the onset and offset of the TX-300 recording processes. The software manages calibration recording, and data storage of tracking sessions. It provides a very basic interface to program stimuli presentation and gather data on eye-tracking variables in user-defined areas of interest (e.g., scan paths, fixation frequency, and gaze durations); however, the software does not support interactive design, such as a response box to collect accuracy and response time data for individual trials. A digital version of the TOMM that paralleled the clinical test required that examinees make choices via stimbox button presses, which is followed by feedback given their choice.

Section 3.2.2 – E-Prime 2.0

E-Prime 2.0 is a frequently-used software package that provides researchers a wide array of tools to build comprehensive research and test paradigms. This software package supports interactive input devices that direct the course of a task, provide feedback, and record behavioral data (e.g., reaction time, input accuracy, timing logs, etc.). E-Prime 2.0 was used to design a digital version of the TOMM that functioned with precision (i.e., presented stimuli with uniform timing), recorded user input, scored input for accuracy, and presented feedback as demanded by the analog version of that PVT.

As indicated in the E-Prime 2.0 User Manual (Psychology Software Tools, Inc., 2007), this software enables robust and reliable task development while reducing timing lag via use of its hierarchical TrialList, SlideState, and Slide Sub-Objects procedures. The TrialList defines and orders experimental variables, their attributes (i.e., recurring definitions of the experimental conditions), and permits repetition of variables across levels (i.e., BlockLists) of the experiment.

Slides, or SlideStates once contextually defined and populated by Sub-Objects, act as template workspaces upon which variables (e.g., images and/or text) are rendered. Developing the TOMM required the use of SlideImages (e.g., a Sub-object on a Slide designed to render an image) and SlideText (e.g., a Sub-Object on a slide designed to render text) to contextually define the Slide into an active SlideState.

Each SlideState and Sub-Object maintains its own property settings. Initial attempts to create SlideStates for each of the TOMM's 200 discreet items, bifurcated by distinct attributes depending on the Trial to which the item belongs, produced runtime lags due to oversized script procedures that burdened the CPU's memory and processor, leading to runtime errors and system crash. Therefore, BlockLists were used in conjunction with the included E-Basic Script (EBS) tool and InLine Objects to insert segments of user-written script aimed at specifying task-dependent changes to the SlideStates and their Sub-Objects without needing to populate 200 distinct Slides for each of the TOMM items. EBS script operates using language similar to Visual Basics for Applications (VBA) in that it utilizes object-based programming language and commands to encapsulate data and routines into a single unit that can be applied to a single SlideState and its associated BlockList. The effect of grouping together functions that apply to a specific block of a SlideState's Sub-Objects reduced coded syntax length; hence, CPU memory and processing power was freed to address image buffering and rendering. This important function was also augmented with the use of E-Prime's PreRelease tool, which allows an event (e.g., the rendering of an image file) to be prepared prior to the termination of the SlideState that precedes its release. This procedure allows E-Prime to work on buffering as much work as possible, as early as possible, allowing the CPU to execute blocked trials seamlessly and guard against excessive buffering lag. Given the precise nature of the TX-300's recording activation

and termination from one item to the next, all efforts to reduce E-Prime's runtime and buffering lag was crucial to maintaining confidence that recorded events aligned correctly with the stimuli presented during a trial of the TOMM.

Section 3.2.3 – E-Prime Extensions for Tobii

In order to successfully link these E-Prime functions with the TX-300 hardware, the inclusion of a secondary software package, E-Prime Extensions for Tobii (EET), was necessary. The EET software package was specially created to allow Tobii Technologies eye tracking hardware to communicate with E-Prime developed task paradigms. Using a proprietary local server, the Tobii Eye-Tracking Server (TET Server), EET provides E-Prime with utilities for specifying and collecting the type of oculomotor gaze data to be recorded by the TX-300. EET controls sending and receiving signals to start and stop gaze data recording based on E-Prime task demands, logging timing events, and logging and storing gaze data output in a unified file structure. The combined result of the EET and TET server, in conjunction with the E-Prime developed task, is a proprietary file type (e.g., *.gazedata* file extension) that logs both gaze data and E-prime data in a single output table. These gazedata files can be opened using the E-Data Aid software provided with the EET system or third-party software such as Microsoft Excel. Although E-Data Aid proved to be a useful tool in fleshing out some of the gross data points such as reaction times and user input accuracy, the complexity of the TOMM task paradigm effectively resulted in 200 individual tasks (with multiple associated gaze data measures) for each subject.

The completed TOMM task produced a massive gazedata output table. The size of these tables, including markers for input accuracy and oculomotor events occurring across two trial types (i.e., stimuli presentation and forced-choice), exceeded the capacity of E-Data Aid and

Excel to compress and refine the raw data. As a result, a more powerful data management software package, Sequential Query Language (SQL), was required to parse out these tables and refine the raw data into a useable form for statistical analyses in SPSS. However, before detailing the process used to refine these data, it is important to define the component data points of the original gazedata file.

Section 3.2.4 – Tobii TX-300 Eye Tracking System: Equipment Calibration & Data Validation

Proper hardware configuration and calibration of the Tobii TX-300 Eye Tracker ensures consistent functionality and assures confidence in the validity of gaze data obtained. In order for the TX-300's infrared cameras to accurately obtain precise coordinate locations of gaze fixations by tracking the pupils of a participant's eyes, calibration of the device is necessary at the start of each testing procedure in which gaze data will be sampled. This calibration sequence is initiated via Tobii Technologies proprietary software, Tobii Studio. This software package is run on a dedicated computer whose primary purpose is to initiate calibration, provide calibration feedback, activate and terminate blocked recordings of gaze data, capture raw video of in-vivo oculomotor tracking, and store these recordings. Tobii Studio is also capable of rendering simple tracking tasks and produce output concerning oculomotor variables of interest (e.g., fixations in areas of interest); however, the software is limited in the scope of the tasks it can create and was thus not used in this study. Rather, E-Prime 2.0 was used to render the digital performance validity task (e.g., TOMM) as this software provided greater refinement in terms of task transitions based on participant response. E-Prime 2.0 tasks were run on a dedicated computer that was integrated with the TX-300 using E-Prime Extensions for Tobii (EET), a joint production of Psychology Software Tools, Inc. and Tobii Technologies.

Per Tobii Technologies, the calibration system is designed to assure in-vivo sampling characteristics capable of determining the gaze accuracy and gaze precision of data obtained by the eye tracker. Accuracy provides information about the angular average distance from the actual gaze point to the one measured, whereas precision assesses the spatial variation between successive samples of a subject's fixation on a specific stimuli point. These characteristics can be applied in either monocular or binocular recording settings, with the latter being used in the present study given that under ideal conditions the degree of accuracy is refined from 5° to 4°, globally. In order to accommodate "ideal conditions" to the best extent possible, lab was designed in accordance with Tobii published recommendations. Namely, the lab environment maintained constant luminance, hardware was assembled per Tobii TX-300 manualized instructions, and participants were calibrated per standardized instructions.

Outside of these primary measures of gaze accuracy and precision, the validity of obtained samples is also contingent on secondary measures. First, the system is designed to sample at a rate of 300hz, otherwise stated as one sample every 3ms. Per the manufacturer's specifications, there is an anticipated sampling variability rate of 0.3% when run at the maximum 300hz. In order to accommodate this variability, post hoc analyses of the raw gaze data measured the average sampling rate of each of the 200 test items individually, thereby producing a distinct sampling rate for samples obtained during a particular test item. Samples deemed valid (to be addressed in greater detail below) were converted, when appropriate to the variable of interest, into a measure of duration (i.e., time in milliseconds) by multiplying the number of samples by the idiosyncratic sampling rate obtained for those samples. Second, because eye blinks are a natural occurrence, we utilized the system's built in algorithmic filter that allows immediate recovery of gaze position following a blink. When gaze position was completely lost (e.g., the

subject moved outside of the max gaze angle, distance, or adjusted their head angle beyond the limits of the tracker), the system specifies that tracking recovery would be re-established within 10 to 165ms.

At the start of a recording session, Tobii Studio initiates a calibration sequence advertised to provide "stable and reliable eye tracking calibrations [which] eliminate the need for recalibration" (Tobii Technologies product website: http://www.tobiipro.com/product-listing/tobii-pro-tx300/). Once the test participant had been seated in a comfortable position in front of the integrated TX-300 monitor (a 27" LED high-definition monitor upon which the infrared cameras are mounted, see Figure 1), the examiner initiated a pre-calibration procedure causing Tobii Studio to display a screen showing whether both pupils have been located (visualized by two white dots in the middle of a black box sitting atop a smaller colored bar) as well as distance of the participant's eyes from the infrared cameras (visualized by vertical colored bar along which a white arrow moves in response to the participant distance, see Figure 2). The examiner explained these visualizations to the participant, first describing the white dots as representative of the participant's left and right eye. The participant was asked to move their head up and down and left to right to demonstrate how the white dots move in accordance to the participant's movements. Next, the participant was asked to close one eye and then the other, which results in the corresponding dot to disappear and reappear, which aided the participant in understanding how the camera system was tracking their eyes. Aside from the visualization of the white dots, the colored bar beneath the black box also provided information about the camera's ability to register the participant's pupils, changing from green if both pupils were found, to yellow if only the left or right pupil was located, and red if neither pupil could be captured. The examiner was able to use this metric to determine if the participant had any ocular

problems that may interfere with capturing their gaze (e.g., if the participant wore glasses, the prescriptive strength would at times cause refractions that occluded the pupil from the camera). In these cases, the participant would be excluded from the study.

Once the participant had an adequate understanding of how the cameras were capturing their pupil and gained a cursory understanding of the degree of head movement they could make before the system lost one or both pupils, attention was focused on adjusting the participant's distance from the screen. Seating distance from the screen was adjusted by explaining the movement of a white arrow along the vertical colored bar that bordered the right side of the black box in which the white dots appeared. This bar is given a color gradient, ranging from red to green to red (see Figure 2). The participant was instructed to move their face towards and away from the screen, watching how the white arrow would move up or down the bar, respectively. Alongside this arrow a precise measure of distance, in centimeters, was reported. Ideal distance is 65cm, as specified in the Tobii TX-300 User Manual, which corresponded to the centermost section of the colored bar. Once the participant understood how the distance of their face from the screen was being registered, they were asked to adjust their seating position so that the white arrow was as near to the center of the bar as was comfortable for them. They were asked to try and not move their seating position for the remainder of the test. Although they were not told to remain perfectly still, they were asked to be cognizant of their general posture and asked not to drastically lean in or away from the screen during a test session. Gaze precision was maximized by utilizing the system's built-in Stampe Filter (Stampe, 1993), which reduces the effects of changing distance across the course of sampling. As a result, we increased our confidence that should a participant alter their distance from the cameras by a range of 50 to 80 cm, precision estimates would remain under 0.18° between samples obtained.

When the cameras adequately captured both pupils and seating position was established, the examiner provided instructions to the participant that they would next see a screen with nine dots (each containing a smaller black dot at its center). They were informed that a red circle would move about the screen, stopping at each of the larger dots, and that they were to follow this circle with their eyes. Each time the circle stopped on one of the nine dots, they were to try and fixate their eyes on the smaller black dot. Once instructions were understood, the examiner began the calibration sequence. Following calibration, the TX-300 monitor would go blank and the Tobii Studio monitor would relay feedback to the examiner. This feedback included two versions of the screen the participant had seen, one corresponding to the left eye movement and the other to the right eye. However, the feedback screen also provided small green lines extending from the center of the nine dots. Good calibration showed short green lines extending out from the center of the dots, indicating that the point of gaze was very near to the measured point of gaze; the longer the line, the greater the offset of the measured gaze to the supposed point of gaze. If no line was present at one of the nine dots, indicating that the TX-300 lost the participant's gaze at that quadrant, then calibration was repeated. If calibration could not be completed with all nine dots being registered by both eyes, the participant was excluded from the study.

Following successful calibration, the participant was introduced to the PVT task (e.g., TOMM). All oculomotor recordings and gaze sampling gathered during this task was automated using the EET's built in server (Tobii Eye Tracker Server; TET), thereby synchronizing the start and end of gaze recording of the TX-300 (via Tobii Studio) to the TOMM's task demands as defined by E-Prime 2.0 programming. Per Tobii TX-300 specifications, use of the TET server keeps processing latency between E-Prime and Tobii Studio to 1.0 – 3.3ms and guarantees that

total system latency remains below 10ms. Given these specifications, we are able to approach resulting data with a high degree of confidence. This is especially true for stimuli presentation items, which lasted exactly 3000ms, meaning that data loss due to system latency issues would be equal to or less than 0.3% when sampling oculomotor behavior during these items. The degree of confidence that latency issues interfered with data validity during forced choice tasks, whose duration is dependent on participant reaction time, is slightly less than during stimuli presentation items. For example, if a participant responded to a forced choice item within 500ms (a low end estimate), it is possible given the TX-300 specifications that data loss due to latency issues may approach 2%. However, given the generally practiced convention that 95% confidence is admissible for statistical significance, even a 2% loss (if it occurred) would fall within the confines of being considered reasonably reliable and valid. Provided the numerous characteristics built into the TX-300 Eye Tracker system (whereby "system" is meant to include the entire network between the TX-300, E-Prime programming, and Tobii Studio), we are reasonably assured that any data deemed valid by the system output can be accepted with confidence.

With a system that samples at a rate of 300hz, the number of samples obtained across the course of one test for one participant is contingent on the length of the test itself. With the TOMM typically lasting approximately 10 minutes, this equates to roughly 600,000 samples per participant. Although numerous validity characteristics are in place, the feasibility of checking these characteristics for each sample manually would be impossible. As a result, E-Prime Extensions for Tobii (EET) provides in its output a coded system for the validity of each sample, for each eye. This coding, as defined by the EET manual, states that a sample given a value of "0" indicates that the "system is certain that it has recorded all relevant data for the particular

eye, and that the data recorded belongs to the particular eye (no risk of confusing left eye with right eye by the system)" (Psychology Software Tools, Inc., 2009). Following from the same source, a validity value of 1 is specified as meaning "The system has only recorded one eye, and has made some assumptions and estimations regarding if the recording if the recorded eye is left or right. However, it is still highly probable that the estimations done are correct. The validity code on the other eye is in this case always set to 3." A value of 2 suggests, "The system has only recorded one eye, and has no way of determining if this is the left or the right eye." A value of 3 indicates that the "system is fairly confident that the actual gaze data is actually incorrect or corrupted. The other eye will always have a validity code of 1." Lastly, a validity value of 4 means that the "actual gaze data is missing or definitely incorrect." Furthermore, the TX-300 user manual specifies that any sample that contains a validity code of 2 or greater should be discarded due to the general lack of confidence regarding the reliability of the associated data and from which eye it originated. However, the manual also suggests that in the case that should the validity value of one eye be 0 and the other eye greater than 2, one may choose to use this data, though it is a less conservative approach. For the sake of this study, particularly in light of the vast amount of data accumulated for each participant across the PVT, we have opted to use only the most rigorous validity standards. Hence, any data that obtained a validity value of 2 or greater on either eye was discarded.

Section 3.3 – Measures

Section 3.3.1 – Injury Severity

The motor subscale of the Glasgow Coma Scale (GCS) will be employed as a measure of TBI severity. Specifically, brain injury severity will be represented by the time required to follow commands, as indicated by the number of days needed to twice obtain a score of 6 on the GCS

motor subscale within a 24-hour period (Dikmen, Machamer, Winn, & Temkin, 1995; Rohling, Meyers, & Millis, 2003).

Section 3.3.2 – Premorbid Intelligence

The Wechsler Test of Adult Reading (WTAR) (The Psychological Corporation, 2001) is a word reading test that consists of 50 irregular words to pronounce aloud. Recognition reading vocabulary is relatively robust to neurologic impairment and has been shown to be an excellent estimate of overall intellectual ability, or Full Scale IQ (Johnstone, Hexum, & Ashkanazi, 1995). Past research has used the WTAR to generate estimates of intellectual functioning among people with TBI (Green et al., 2008).

Section 3.3.3 – Neuropsychological Battery

California Verbal Learning Test – 2nd Edition (CVLT-II) (Delis, Kramer, Kaplan, & Ober, 2000). This list-learning task presents 16 words orally and requires examinees to recall the words over the course of five trials. This latter trial is associated with attention and learning efficiency. Following the five learning trials, a distracter set is introduced and the examinee is administered a short-delay free recall trial. Another free recall trial is administered following a 20-minute delay to assess long-term retention. A final 10-minute delay proceeds a forced-choice recognition task in which the examinee must choose between a word from the original list and a novel foil.

Trailmaking Tests (Reitan & Wolfson, 1985) Trailmaking Test–Part A (Trails A) is a graphomotor attention task in which participants must connect dots labeled 1 through 25 in numerical sequence. Trailmaking Test–Part B (Trails B) follows a similar format, but it requires participants to switch between numerical and alphabetical sequences in ascending order. Scoring for this measure is based upon completion time in seconds. Trails B involves greater

visuoperceptual processing requirements than Trails A and is also sensitive to executive dysfunction and brain damage (Spreen & Strauss, 1998).

Digit Span Test (Wechsler, 2008) This task was developed as a subtest within the WAIS-III. Examinees are read strings of digits that must be recalled in either the same order (Digits Forward), backwards (Digits Backwards), or in sequence of lowest to highest digit (Digit Sequencing). The measure provides information pertaining to simple attention (Digits Forward) as well as working memory (Digits Backwards).

Symbol Digit Modalities Test (SDMT; Smith, 1973): This stand-alone neuropsychological measure provides sentivity to the presence of brain damage (i.e., cognitive impariment). The 90-second measure requires the use of a reference key to pair numbers with specific geometric shapes. By assessing the efficiency in which symbols are coded with their respective numbers, this test provides useful information regarding examinee visual search, attention, and working memory efficiency.

Section 3.3.4 – Effort: Memory Specific Performance Validity Measures

Test of Memory Malingering (TOMM; Tombaugh, 1996) This 50-item, forced-choice measure uses visual recognition of drawings to assess an examinee's level of effort and is commonly used in psychological assessment batteries. The test consists of two learning trials, both of which present the same 50, hand-drawn stimulus items in different orders. Each trial is followed by a forced-choice task that presents a previously shown item alongside a novel foil item, and the patient is asked to choose the item they remember having seen previously. An optional retention trial is also included following the prior two trials. Totaling the correct responses in each trial derives two continuous scores that can be compared to statistically-derived (below chance) cut scores for each trial. Typically, effort research relies on examining

the performance on Trial 2, with an obtained score of less than 45 signifying inadequate effort. Although the TOMM has shown adequate specificity in detecting feigned neurocognitive impairment (Gierok & Dickson, 2000; Rees, Tombaugh, Gansler, & Moczynski, 1998; Teichner, Wagner, & Newman, 2000), research also indicates that the level of sensitivity it provides may be too low to use alone (Greve, Ord, Curtis, Bianchini, & Brennan, 2008). For the purposes of this study, transformation of the analog TOMM into a digital program was required. E-Prime 2.0 Professional software will be used to generate exact duplicates of the images, which will be superimposed onto a black screen. Parameters of the visual field will be restricted to mimic the spatial area produced by the test booklets. The program will be set to show each item in the learning trials in the same order as they appear in the analogue version. Each image will be presented for exactly 3 s, as stipulated in the manual (Tombaugh, 1996). During forced choice trials, each target image will be shown adjacent to the same foil image found in the analogue test. Participants will be instructed to press the "A" key on the computer keyboard if they wish to select stimulus image A or the "B" key if they wish to select stimulus image B. Following their response, one of two screens will be presented for 2000ms. Correct responses will be followed by a grey screen with the word "Correct" at its center, whereas incorrect responses will be followed by a screen with the phrase "No, that's not right" in the top center and the stimulus image of the correct response centered below this phrase. The phrase "It was this one" will be centered below the correct stimulus image. Upon completion of the first trial, instructions for the second trial will be immediately presented. Trial 2 will follow the same procedure as the first trial, although answer feedback screens will not be provided and stimulus images will be changed to correspond with the paper-based version of Trial 2.

Section 3.3.5 – Oculomotor Variables and Qualities of the Gazedata File

Timing Variables. Timing variables provide information about the runtime clocks (i.e., timestamps) that synchronize the TX-300 and E-Prime via the TET server. The gazedata output provides timestamps in three metrics: seconds, milliseconds, and microseconds. The most fundamental timing variable found within the gazedata file is the "Timestampsec" variable. This running value provides a gross log of the time in which the task began, in seconds, and runs throughout the course of the task until completion. Derived from the preliminary timestamp is the "TETTime" variable. This running value, which is assigned to each sample of the gazedata file, provides a timestamp from the Tobii hardware (e.g., TX-300) that is connected to the TET server, yet refines the timestamp by converting it into milliseconds. An alternative version of TETTime is provided by the "TimeStampMicroSec" variable, which provides the same information in a microsecond metric (i.e., one millionth of a second). Given that the TX-300 can generate samples at various rates, ranging from 60hz to 300hz, it is important to utilize the metric for the timestamp that best reflects the events being logged. Having chosen the most refined sampling rate (i.e., 300hz), the most appropriate timestamp metric was either milliseconds or microseconds. However, operating with data at the millionth of a second level was visually taxing; therefore, TETTime was selected as the primary log of the runtime clock.

Alongside the runtime clocks, a metric of the number of raw samples was obtained for each participant, termed "TotRows." This variable provides an estimate of the time a participant took to complete the task, given that samples are obtained at a consistent rate (i.e., TotRows multiplied by the sampling rate). Lastly, the time the TET server took to retrieve, buffer, and display the stimuli images within the SlideStates was gathered into the "OnsetBuffer" variable. Generally, the time to buffer the retrieved image files was consistent between each item on the

task and between subjects. However, this variable enables quick identification of cases in which the TET server showed lag, which can ultimately skew interpretation of two variables of interest: time to first fixation and total time to complete forced-choice items.

Total Validity Index – (Validity): Percentage of all TOMM samples obtained with right and left eye validity scored 0 or 1. As recommended by the Tobii TX-300 user manual, scores above 1 are to be considered unstable or unreliable, and data associated with these samples should be discarded. For a further explanation of the validity scores and procedures, see Section 3.2.4 on the study's validity methodology.

Raw Coordinate Variables. Eye tracking fundamentally involves locating the trajectory of the subject's eyes' gaze on a two-dimensional Cartesian plane. The TX-300, which relies on binocular, dark-pupil image capture, utilizes multiple infrared cameras that locate the darkest part of each eye and algorithmically triangulates the convergence of the eyes' gaze on the monitor. The digital monitor is assigned x and y coordinate positions based on the resolution of the screen. The TX-300 built-in display uses a 1080p HD system at a 16:9 aspect ratio (i.e., y-axis is 1080 pixels in height and x-axis is 1920 pixels in width). The TX-300 relays triangulation data to Tobii Studio, which assigns the specific coordinate location of the pixel upon which the gaze was determined to exist.

The gazedata file provides information about the triangulated location of each eye's gaze position along the x and y axes via four coordinate location variables: XGazePosLeft, XGazePosRight, YGazePosLeft, and YGazePosRight. These positions are recorded on a normalized scale, where the 0 point of the x-axis is the left-most pixel on the display, whereas the furthest pixel on the right side of the screen is scored as 1. The y-axis is scaled with the topmost pixel labeled as the 0 coordinate, and the bottom-most pixel the 1 coordinate. Logged

coordinate positions are expressed to the millionth of a decimal place, thereby allowing absolute refinement of coordinate position, limited only by the resolution of the display itself.

The TX-300 infrared cameras are also capable of calculating distance of the dark pupil from the display itself. Again, based on system-generated algorithms, the gazedata file provides precise measures of this distance via the "DistanceLeftEye" and "DistanceRightEye" variables.

E-Prime Extension for Tobii Variables. All oculomotor variables are directly dependent on one fundamental variable: "Gaze." Gaze is the triangulated location of the converged trajectory of both the right and left eye upon a scaled coordinate pixel display. Each sample locates the pixel upon which both eyes have converged. Gaze becomes a usable variable when individual or groups of pixels are defined into meaningful areas within the stimulus projected upon the display.

Stimulus Image SlideStates (StimImage, StimPres). Using E-Prime's built-in toolbox to develop slides that incorporate multilayered image files and coordinate-grouping boxes, multiple *areas of interest* (AOIs) were defined within each SlideState. Two distinct SlideStates were created to meet the task demands of the two types of stimuli necessary to replicate the TOMM task structure. Consistency of coordinate grouping was achieved by relying on the same two SlideStates, and their defined AOIs, being populated by jpeg image files retrieved by the TET server. The first SlideState, termed the *StimImage* SlideState, incorporated a SlideImage Sub-Object populated by a blank, white image jpeg file that occupied the entire screen. All pixels that constituted this white image were assigned the title of "*Background*." Layered on top of this background image, another SlideImage Sub-Object was programmed to populate a jpeg image scanned from the TOMM stimuli presentation items (i.e., presentation of TOMM Trial 1 items). Using E-Prime's BlockList procedure, these images were called up in the same order seen during

the manual presentation of the TOMM test. Pixels assigned to create these stimuli image files were grouped into an AOI labeled as "*StimPres*." Similar to the StimImage SlideState, the forced-choice (FC) SlideState was created by grouping pixels into three distinct AOIs: *Background*, *Astim*, and *Bstim*. Astim is the AOI associated with the top (A-labeled) image seen on the TOMM and Bstim the bottom (B-labeled) image.

Stimulus response. User input accuracy variables were also logged into E-Prime and, using the TET server, relayed information from a stimbox to indicate which item on the screen the participant chose. The gazedata output file tracked the following variables: *correct response*, *actual response*, *accuracy of the response*, and *response time* (time taken to make the response). Furthermore, the TET server populated variables for each sample regarding the trial identifier (TrialID) and the image that was being displayed on the screen at the time the sample was taken (OnScreen).

Scan Path. Each sample recorded by the TX-300 locates the coordinate position of the eyes, and by overlaying the grouped pixel areas (AOIs) defined by E-Prime and the TET, logs the AOI to which these particular coordinates belong. Within the gazedata file, a variable termed "AOI" logs the coordinates upon which the gaze was triangulated. Stimulus presentation trials log only Background and StimPres AOIs. Forced-choice trials log Background, Astim, or Bstim. The complete log of this AOI variable constitutes the scan path for the item.

Transitions. In order to fully understand transitions, the events that mark the start and end of a transition must be clearly defined. The oculomotor events that demarcate a transition are "gazes" or "fixations". Any triangulated oculomotor position logged within the visual field (i.e., coordinate plane) is considered a gaze. However, as a gaze remains within a specified area (e.g., AOI) for a prolonged period of time, it adopts a quantitatively new definition: a fixation.

Fixations are defined as a gaze that lasts within the same coordinate field of a specified AOI for at least 150ms. Therefore, all fixations are in essence a form of a gaze, though not all gazes are fixations. A temporal threshold must be met to categorize a gaze event as a fixation event.

A transition begins when a gaze or a fixation ends (i.e., the triangulated oculomotor position leaves the circumscribed coordinate points of the AOI it was initially located within). The transition ends when the oculomotor position is logged as a new gaze or fixation in another AOI, distinct from that which it had just left. In other words, a transition is recorded when a gaze's (or fixation's) coordinate position changes from one AOI to another. For example, if a sample by the TX-300 identifies the triangulated coordinate location of a gaze within the Background AOI, and a subsequent sample logs the gaze within another AOI (e.g., StimPres AOI), then one transition has occurred. Transitions can be defined to occur between gazes at a sample-by-sample level, or between fixations, which span multiple samples based on the length of the fixation. Furthermore, a transition can begin when a gaze ends and a fixation begins in a new AOI, or when a fixation ends and a gaze begins in a new AOI. The classification of the oculomotor event (i.e., gaze vs. fixation) is irrelevant to the creation of a transition as a transition is based on location, whereas the gaze/fixation distinction is based solely on duration.

Gaze Transitions – (Global, Stimulus Trial, Forced-Choice Trial): This variable reflects the number of gaze scan path transitions that occurred. A *scan path* is constituted by the complete log of gazes that were recorded across the various AOIs, regardless of time spent in each AOI. Seven gaze transition variables were created for the present study, reflecting the component sub-tests of the complete (i.e., global) TOMM test. These include TOMM Trial 1 – Stimulus Presentation (T1stim) and TOMM Trial 1 – Forced-Choice (T1FC), and TOMM Trial 2 – Stimulus Presentation (T2stim) and TOMM2 – Forced-Choice (T2FC):

Global (GzTrans.tot)	Total gaze transitions that occurred across the entire task.
Stimulus Trials (GzTrans.stim.tot)	Sum of gaze transitions that occurred across both stimuli presentation trials (T1stim and T2stim).
Stimulus Trial 1 (GzTrans.Stim1)	Sum of gaze transitions that occurred during the first stimuli presentation trial (i.e., T1stim).
Stimulus Trial 2 (GzTrans.stim3)	Sum of gaze transitions that occurred across the second stimuli presentation trial (i.e., T2stim).
Forced-Choice Trials (GzTrans.FC.tot)	Sum of gaze transitions that occurred across both forced-choice trials (T1FC and T2FC).
Forced-Choice Trial 2 (GzTrans.FC2)	Sum of gaze transitions that occurred across the first-forced-choice trial (T2FC).
Forced-Choice Trial 4 (GzTrans.FC4)	Sum of gaze transitions that occurred across the second forced-choice trial (T2FC).

Fixation Transitions – (Global, Stimulus Trial, Forced-Choice Trial): This variable reflects the number of fixation transitions that occurred between discrete fixations. For example, if the first fixation were located on the stimulus image, followed by another fixation on the background, and a third fixation on background, this process would count as two fixation transitions. Parallel to Gaze Transitions, seven fixation transition variables were created for the present study:

Global (TotTrans.global)	Total fixation transitions that occurred across the entire task.
Stimulus Trial (TotTrans.stim.tot)	Sum of fixation transitions that occurred across both stimuli presentation trials (T1stim and T2stim).
Stimulus Trial 1 (TotTrans.stim1)	Sum of fixation transitions that occurred during the first stimuli presentation trial (T1stim).
Stimulus Trial 2 (TotTrans.stim3)	Sum of fixation transitions that occurred across the second stimuli presentation trial (T2stim).

Forced-Choice Trial (TotTrans.FC.tot)	Sum of fixation transitions that occurred across both forced-choice trials (T1FC and T2FC).
Forced-Choice Trial 1 (TotTrans.FC2)	Sum of fixation transitions that occurred across the first forced-choice trial (T1FC).
Forced-Choice Trial 2 (TotTrans.FC4)	Sum of fixation transitions that occurred across the second forced-choice trial (T2FC).

Fixation Variables. A fixation is defined as a gaze that remains within an AOI for a prescribed period of time. The prototypical length of time used to define a fixation is 150ms or longer. Using this criteria, the TET server was set to log a fixation when a gaze remained in any of the trial's possible AOIs for 150ms or longer. Seven fixation variables were created for the present study:

Global (TotFix.global)	Total fixations that occurred across the entire task.
Stimulus Trial (TotFix.stim.tot)	Sum of fixations that occurred across both stimuli presentation trials (T1stim and T2stim).
Stimulus Trial 1 (TotFix.stim1)	Sum of fixations that occurred across the first stimuli presentation trial (T1stim).
Stimulus Trial 2 (TotFix.stim3)	Sum of fixations that occurred across the second stimuli presentation trial (T2stim).
Forced-Choice Trial (TotFix.FC.tot)	Sum of fixations that occurred across both forced-choice trials (T1FC and T2FC).
Forced-Choice Trial 1 (TotFix.FC2)	Sum of fixations that occurred across the first forced-choice trial (T1FC).
Forced-Choice Trial 2 (TotFix.FC4)	Sum of fixations that occurred across the second force- choice trial (T2FC).

Location Variables. Beyond the frequency of gazes and fixations that occurred throughout the task, variables reflecting *where* (i.e., in which AOI) and *when* these oculomotor events occurred was vital to parsing out the visual behavior of the participants. As noted, discrete AOIs were created for each of the trials of the TOMM. The two stimuli presentation trials required the creation of two AOIs, one covering the background and another covering the

stimulus image: Background and StimPres, respectively (see Figure XXX). The forced-choice trials required the creation of three AOIs, one covering the background, another covering the top image choice, and another covering the bottom image choice (see Figure XXX). Coding of these AOIs was consistent between all location variables:

AOI Location	Variable Coding
Background	0
Stimulus Images	1
Top Image Choice (Stimulus A)	2
Bottom Image Choice (Stimulus B)	3

Two variables were created to identify where a gaze or fixation occurred at the start of a task:

Initial Gaze Location (intGZ_Loc) — AOI in which the first valid gaze was located at the start of an item.

Initial Fixation Location (intFIX_Loc) — AOI in which the first fixation occurred at the start of an item.

Similarly, two variables were created to identify where a gaze or fixation occurred at the end of a task:

Final Gaze Location (endAOI_Loc) — AOI in which the last valid gaze was located at the end of an item.

Final Fixation Location (endFIX_Loc) — AOI in which the last fixation occurred at the end of an item.

Automatic Fixation Variables. In some cases, a participant may not have any transitions, but merely fixate on an AOI for the duration of the item. Hence, a variable was created to identify whether the first recorded oculomotor event was an immediate fixation. Distinguishing between immediate fixations versus immediate gazes is theoretically important regarding the attentional behavior of the subject in response to the stimuli. A score of 1 indicates that the first oculomotor event recorded was a complete fixation, whereas a score of 0 indicates that the participant scanned the image quickly (i.e., represented by darting gazes) prior to focusing their visual attention long enough to register as a fixation. Seven variables were created,

parsing out the frequency of automatic fixations for the global task, as well as its component parts.

Auto-Fixation – Global (autoFIX.global)	Frequency of automatic fixations occurring across the entire TOMM task.
Auto-Fixation – Stimuli Presentation Trials (autoFIX.Stim.tot)	Frequency of automatic fixations occurring across both stimuli presentation trials (T1stim and T2stim).
Auto-Fixation – Stimuli Presentation Trial 1 (autoFIX.Stim1)	Frequency of automatic fixations occurring across the first stimuli presentation trial (T1stim).
Auto-Fixation – Stimuli Presentation Trial 2 (autoFIX.Stim3)	Frequency of automatic fixations occurring across the second stimuli presentation trial (T2stim).
Auto-Fixation – Forced-Choice Trials (autoFIX.FC.tot)	Frequency of automatic fixations occurring across both forced-choice trials (T1FC and T2FC).
Auto-Fixation – Forced-Choice Trial 1 (autoFIX.FC2)	Frequency of automatic fixations occurring across the first forced-choice trial (T1FC).
Auto-Fixation – Forced-Choice Trial 2 (autoFIX.FC4)	Frequency of automatic fixations occurring across the second forced-choice trial (T2FC).

Fixation Onset Variables. In other cases, a participant may not immediately fixate on an AOI. Rather, they may scan the stimuli field, resulting in a period of time in which gazes form a scan path prior to an initial fixation. Seven variables were created to track the length of time before the first fixation occurred, parsed globally and by component elements of the task:

Time Until Initial Fixation Onset - Global (intFIX_Onset.global)	Average time taken before the first fixation occurs, across the entire test.
Time Until Initial Fixation Onset – Stimuli Presentation Trials (intFIX_Onset.Stim.tot)	Average time taken before the first fixation occurs, across both stimuli presentation trials (T1stim and T2stim).

Time Until Initial Fixation Onset – Stimuli Presentation Trial 1 (intFIX_Onset.Stim1)	Average time taken before the first fixation occurs, across the first stimuli presentation trial (T1stim).
Time Until Initial Fixation Onset – Stimuli Presentation Trial 2 (intFIX_Onset.Stim3)	Average time taken before the first fixation occurs, across the second stimuli presentation trial (T2stim).
Time Until Initial Fixation Onset – Forced-choice Trials (intFIX_Onset.FC.tot)	Average time taken before the first fixation occurs, across both forced-choice trials. (T1FC and T2FC).
Time Until Initial Fixation Onset – Forced-choice Trial 1 (intFIX_Onset.FC2)	Average time taken before the first fixation occurs, across the first forced-choice trials (T1FC).
Time Until Initial Fixation Onset – Forced-choice Trial 2 (intFIX_Onset.FC4)	Average time taken before the first fixation occurs, across the second forced-choice trials (T2FC).

Duration Variables. Numerous variables were created to reflect the length of time spent gazing or fixating on the areas of interest throughout the TOMM trials. All duration variables were measured in milliseconds. Given that all fixations begin as a gaze and only qualify as a fixation once that gaze has remained within the same AOI for at least 150ms, it is important to recognize that the first created variable will be equal to the second variable if the participant approached the item with an immediate fixation (e.g., autoFIX = 1). These 14 variables were created to parse out the task, ranging from the global TOMM task to the component trials of the stimuli presentation and forced-choice trials.

Initial Gaze Duration - Global (intGZ_Dur.global)	Average duration of the first gaze before a transition to a new AOI occurred, across the entire task.
Initial Gaze Duration – Forced-choice Trials (intGZ_Dur.FC.tot)	Average duration of the first gaze before a transition to a new AOI occurred, across both forced-choice trials (T1FC and T2FC).
Initial Gaze Duration – Forced-choice 1	Average duration of the first gaze before a transition to a new AOI occurred, across the first forced-choice trial (T1FC).

(intGZ_Dur.FC2)	
Initial Gaze Duration – Forced-choice 2 (intGZ_Dur.FC4)	Average duration of the first gaze before a transition to a new AOI occurred, across the second forced-choice trial (T2FC).
Initial Gaze Duration – Stimuli Presentation Trials (intGZ_Dur.Stim.tot)	Average duration of the first gaze before a transition to a new AOI occurred, across both stimuli presentation trials (T1stim and T2stim).
Initial Gaze Duration – Stimuli Presentation Trials 1 (intGZ_Dur.Stim1)	Average duration of the first gaze before a transition to a new AOI occurred, across the first stimuli presentation trial (T1stim).
Initial Gaze Duration – Stimuli Presentation Trials 2 (intGZ_Dur.Stim3)	Average duration of the first gaze before a transition to a new AOI occurred, across the second stimuli presentation trial (T2stim).
Initial Fixation Duration - Global (intFIX_Dur.global)	Average duration of the first fixation before a transition to a new AOI occurred, across the entire task.
Initial Fixation Duration – Forced-choice Trials (intFIX_Dur.FC.tot)	Average duration of the first fixation before a transition to a new AOI occurred, across both forced-choice trials (T1FC and T2FC).
Initial Fixation Duration – Forced-choice 1 (intFIX_Dur.FC2)	Average duration of the first fixation before a transition to a new AOI occurred, across the first forced-choice trial (T1FC).
Initial Fixation Duration – Forced-choice 2 (intFIX_Dur.FC4)	Average duration of the first fixation before a transition to a new AOI occurred, across the second forced-choice trial (T2FC).
Initial Fixation Duration – Stimuli Presentation Trials (intFIX_Dur.Stim.tot)	Average duration of the first fixation before a transition to a new AOI occurred, across both stimuli presentation trials (T1stim and T2stim).
Initial Fixation Duration – Stimuli Presentation Trial 1 (intFIX_Dur.Stim1)	Average duration of the first fixation before a transition to a new AOI occurred, across the first stimuli presentation trial (T1stim).
Initial Fixation Duration –	Average duration of the first fixation before a transition to a new

Stimuli Presentation Trial 2 (intFIX_Dur.Stim3) AOI occurred, across the second stimuli presentation trial (T2stim).

Fixation Duration Variables. The number of fixations that occur during an item can vary depending on the oculomotor behavior of the participant. Regardless of the number of fixations that occurred during an item, seven variables were created to be able to measure the *average duration of time spent fixating on any of the available AOIs*. Seven more, similar variables were created that reflect the *average amount of time spent gazing during an item*.

Total Fixation Duration - Global (totFIX_Dur.global) Average duration of all fixations that occurred across the entire TOMM test.

Total Fixation Duration – Stimuli Presentation (totFIX_Dur.Stim.tot) Average duration of all fixations that occurred across both stimuli presentation trials (T1stim and T2stim).

Total Fixation Duration – Stimuli Presentation Trial 1 (totFIX_Dur.Stim1) Average duration of all fixations that occurred across the first stimuli presentation trial (T1stim).

Total Fixation Duration – Stimuli Presentation Trial 2 (totFIX_Dur.Stim3) Average duration of all fixations that occurred across the second stimuli presentation trial (T2stim).

Total Fixation Duration – Forced-choice Trials (totFIX_Dur.FC.tot) Average duration of all fixations that occurred across both of the forced-choice trials (T1FC and T2FC).

Total Fixation Duration – Forced-choice Trial 1 (totFIX_Dur.FC2) Average duration of all fixations that occurred across the first forced-choice trial (T1FC).

Total Fixation Duration – Forced-choice Trial 2 (totFIX_Dur.FC4) Average duration of all fixations that occurred across the second forced-choice trial (T2FC).

Total Gaze Duration – Global (totGZ_Dur.global) Average duration of all gaze behaviors that occurred across the entire TOMM test.

Total Gaze Duration – Average duration of all gaze behaviors that occurred across both

Stimuli Presentation Trials (totGZ_Dur.Stim.tot)	stimuli presentation trials (T1stim and T2stim).
Total Gaze Duration – Stimuli Presentation Trial 1 (totGZ_Dur.Stim1)	Average duration of all gaze behaviors that occurred across the first stimuli presentation trial (T1stim).
Total Gaze Duration – Stimuli Presentation Trial 2 (totGZ_Dur)	Average duration of all gaze behaviors that occurred across the second stimuli presentation trial (T2stim).
Total Gaze Duration – Forced-choice Trials (totGZ_Dur.FC.tot)	Average duration of all gaze behaviors that occurred across both forced-choice trials (T1FC and T2FC).
Total Gaze Duration – Forced-choice Trial 1 (totGZ_Dur.FC2)	Average duration of all gaze behaviors that occurred across the first forced-choice trial (T1FC).
Total Gaze Duration – Forced-choice Trial 2 (totGZ_Dur.FC4)	Average duration of all gaze behaviors that occurred across the second forced-choice trial (T2FC).

Six variables were created to differentiate the time spent looking at particular AOIs across the trials.

Duration of Fixations within the Stimulus Image (stimFIX_Dur)	The total duration of time spent fixating on the stimulus image during the stimuli presentation trials.
Duration of Fixations within the Background Image (backFIX_Dur)	The total duration of time spent fixating on the background image during the stimuli presentation or forced-choice trials.
Duration of Fixations within the Top Choice Image (Astim_Dur)	The total duration of time spent fixating on the top choice image (Stimulus A) during the forced-choice trials.

Duration of Fixations within the Bottom Choice Image (Bstim_Dur)	The total duration of time spent fixating on the bottom choice image (Stimulus B) during the forced-choice trials.
Duration of Fixations within the Correct AOI (DurCorrect.FC)	The total duration of time spent fixating on the correct forced-choice stimuli image (AOI) for the trial.
Duration of Fixations within the Incorrect AOI (DurIncorrect.FC)	The total duration of time fixating on the incorrect forced-choice stimuli image (AOI) for the trial.

One variable was created to compare the relative ratio of time spent looking at one AOI over another. This ratio variable attends to the proportion of time the participant spent looking at the correct stimulus image during a forced-choice test as opposed to all other AOIs.

Correct to Incorrect AOI Ratio (CORRECTratio)	Ratio of time spent looking (i.e. gaze or fixation) at the correct stimulus image during a forced-choice trial as opposed to looking (i.e., gaze or fixation) at the incorrect stimulus image.

Lastly, two variables were created to identify whether the scanpath recorded for the participant indicated correct focus on the appropriate stimulus AOI.

Focus Right – Stimulus Trials (FocusRightStim13)	During stimuli presentation trials, the target AOI is the image and the foil is the background (i.e., empty space). This variable calculates the location of the AOI in which the initial fixation occurred and determines if this location is the target or foil AOI (e.g., Background Image). If more than one fixation transition occurs (i.e., the gaze moved from one AOI to another), this variable computes whether the participant's gaze returns to target AOI by the end of the trial.
Focus Right – Forced-Choice Trials **(**FocusRightFC24**)**	Given that the forced-choice trials present two stimuli images simultaneously, there exists a 50% chance that the participant's initial fixation may land on the target image or the foil. This variable calculates the location of the AOI in which the initial fixation occurred and determines if this location is the target or foil AOI. If

more than one fixation transition occurs (i.e., the gaze moved from one AOI to another), this variable computes whether the participant's gaze returns to target AOI by the end of the trial.

Prior to statistical analyses, the raw oculomotor data yielded 4,200 variables. In order to obtain a manageable set of variables, oculomotor variables at the item level of the TOMM were summed or averaged across the entire test to construct global variables. This process resulted in the creation of the following 14 core oculomotor variables of interest: Gaze Transitions, Global Gaze Duration, Fixation Transitions, Fixation Durations, Background Gaze Duration, Autofixations, Initial Fixation Duration, A-Stimulus Gaze Duration, B-Stimulus Gaze Duration, Correct Stimulus Gaze Duration, Incorrect Stimulus Gaze Duration, Correct to Incorrect Gaze time Ratio, Correct Focus (during stimulus trials), and Correct Focus (during forced-choice trials).

Section 3.4 – Procedure

Section 3.4.1 – Laboratory

The experimental lab was housed at our research space on Wayne State University's main campus and in a research lab at the Rehabilitation Institute of Michigan. Testing occurred in a windowless room. Lighting was arranged strategically, and luminance regularly measured, to ensure the optimal functioning of the tracking software. Participants were seated in an adjustable office chair to accommodate the need for a consistent gaze length, despite variability in participant height. The eye tracking camera and stimuli display monitor were mounted to a table in front of the participant (see Figure 3). Tobii Studio's calibration sequence, relying on infrared cameras, provided a built in measure of gaze distance for each participant; hence, optimal viewing distance was set prior to task onset. Preparing each participant required only a brief, non-invasive set of minor adjustments to ensure visual field consistency (see "Calibration"

below). Two tower computers were peripherally connected to the monitor and stored in non-intrusive locations away from the table.

Precision and accuracy are vital components in determining the validity of the obtained data. To attain the temporal resolution necessary to capture the refined temporal events of interest (e.g., reaction time, dwell time, micro-saccades, etc.), the tracking system was set up to keep latency (i.e., the end-to-end delay between actual eye movement and the computer registering movement) as low as possible. To accomplish this goal, two dedicated processors were incorporated (see Figure 4); one to render the task stimuli and the other to sample, analyze, and transform movement into data points. E-Prime operated on one of the PCs, while Tobii Studio operated on the other. The PCs were networked via serial bus, allowing simultaneous data time-stamps to be generated. By adding this safeguard, all raw data were time-stamped, thereby enabling offline filtering to correct for any unexpected, yet measurable, lag (Helmquist et al., 2011). Furthermore, a StimTracker apparatus was calibrated with the eye-tracking monitor. Using a 3mm optic sensor attached to the stimulus monitor, the StimTracker read signals from the monitor signaling changes in stimulus display. This added measure increased the validity of oculomotor data synchronization with each stimulus trial.

Section 3.4.2 – Calibration

Once participants were positioned in a manner acceptable to the equipment, a Tobii programmed calibration sequence was activated. This calibration sequence directed viewer gaze to a central marker within a 9” x 9” grid pattern. The sequence directed the viewer to move their gaze between various grid cells and fixate on a new marker. This process took10 - 30s.

Section 3.4.3 – Group Assignment and Instructions

Bona Fide Traumatic Brain Injury group (TBI). Informed consent procedures were

completed per institutional review board guidelines. Participants enrolled in the SEMTBIS project were notified of this research opportunity. Those expressing interest were informed of the opportunity to participate in a research project aimed at studying the use of a new psychological assessment test. Testing was completed in a single session.

Upon arrival, participants were brought to a dedicated room where they will complete their consent agreement. The use of eye tracking equipment was discussed, followed by a brief educational introduction and an outline of the seating/positioning requirements (i.e., possible frequent adjustments) of the study. At this point, the WTAR was administered. Participant height and gaze length were measured, and adjustments were made to maintain lab standardization and fulfill requirements of the tracking system. TBI participants were instructed to put forth their full effort on all measures administered, including the initial calibration sequence.

Healthy Comparison group (HC). Participants in the HC group were recruited from the Southeastern Michigan area via newspaper advertisements, online postings, and flyers posted throughout the Wayne State University campus and screened for eligibility via telephone. Informed consent procedures were completed with HC participants per institutional review board guidelines. The instructional procedure outlined for the TBI groups was duplicated for the HC group. In total, 92 healthy adults were included in the present sample. Fifty of these individuals were assigned to give full effort during testing (HC group), whereas 39 were assigned to the simulation (SIM) group. Participants were not made aware of the existence of any other groups but their own.

Traumatic Brain Injury Simulators (SIM). To gain an accurate estimate of intellectual functioning for SIM participants, they were instructed to put forth full effort for the WTAR. After completing the WTAR, SIM participants were told that the remainder of the assessment

would focus on the ability of a new memory measure to assess the level of effort put forth during testing. SIM Group participants were then presented with a scenario indicating his or her involvement in litigation following a motor vehicle accident that resulted in a TBI. The scenario was read from a script that has been used successfully in prior research on simulation with designs similar to that of this study (DenBoer & Hall, 2007; Tombaugh, 1997). Consistent with recommendations by Suhr and Gunstad (2007) regarding simulation research designs, SIM participants were provided with a pamphlet summarizing the nature of a TBI and the symptoms commonly associated with this type of injury such as slowed thinking, memory dysfunction, etc. (Coleman, Rapport, Millis, Ricker, & Farchione, 1998; Rapport, Farchione, Coleman, & Axelrod, 1998). Each participant was given as much time as needed to read over these materials.

All participants received $30 compensation.

CHAPTER 4 RESULTS

Section 4.1 – Intercorrelations of Oculomotor Variables

Section 4.1.1 – Identifying redundant oculomotor variables

Initial analyses compared the intercorrelations among this set of core variables, as well as correlations between the demographic and neuropsychological measures for the complete sample. The primary aim of calculating the core variable intercorrelations was to identify statistical and theoretical redundancies between these variables. Due to the heavily skewed distribution among most of the variables, nonparametric Spearman's rho correlations were employed. Exceedingly high intercorrelations were observed between Global Gaze Duration and Gaze Transitions (r_s = .96), A and B Stimulus Gaze Duration and Correct and Incorrect Stimulus Gaze Duration (r_s = .86 and .87, respectively), and Correct Focus (stimulus trials) with both Initial Fixation Duration (r_s = .73) and Initial Gaze Duration (r_s = .75). Given the overly convergent status of these variables, it was determined that the constructs measured by them was redundant. Based on theoretical implications, Gaze Transitions was retained, as it is determined that a transition requires more conscious effort than maintain a gaze for any length of time; Gaze Duration was excluded from further analyses. Similarly, A and B Stimulus Gaze Durations were excluded in lieu of the more theoretically refined Correct and Incorrect Stimulus Gaze Durations, given that these latter two variables specifically tap duration of gazes occurring within stimuli AOIs. Additionally, they are of theoretically greater interest because they reflect whether the gaze occurred in the item's correct or incorrect AOI, respectively. Lastly, Focus Right (stimulus trials) and Focus Right (forced-choice trials) were retained, whereas Initial Fixation and Initial Gaze Duration variables were excluded. The former is a more theoretically refined measure of effortful behavior that taps fixation on the appropriate stimulus AOI, whereas the latter can be

predominantly influenced by chance viewing behavior (i.e., there is a 50% chance that the initial gaze and/or fixation will occur on either of the two AOIs). Focus Correct accounts for initial chance by attending to the importance of final gaze and/or fixation occurring on the "correct" stimulus AOI).

Section 4.1.2 – Intercorrelations among core oculomotor variables

Tables 3a – 3c present the intercorrelations for the HC, SIM, and TBI groups, respectively. A notable and consistent correlation across the three groups was the inverse relation between frequency of fixating on the stimulus AOI during stimulus trials (Focus Right-Stimulus) and the time spent gazing at the background (Background Gaze). Among all three groups, Background Gaze time (ms) shows strong inverse correlation (r_s -.73 to .79) with Focus Right for Stimulus trials (i.e., frequency of trials with fixations in the AOI).

Correlations that stand out for one group and not the others may provide meaningful insight into which variables will facilitate accurate group discrimination. For example, Gaze Transitions and Fixation Transitions (frequency variables) are strongly correlated in the HC group (r_s = .61), but only modestly correlated for SIM (r_s = .36), and weakly correlated for TBI participants (r_s = .22). Total Fixation time (ms), which theoretically reflects purposeful visual search and effortful comprehension, showed medium-large correlation with gaze time in Correct and Incorrect AOI among HC (r_s .59 and .64) and TBI (r_s .42 and .49), and very strong correlation with gaze time in Correct and Incorrect AOI among SIM (r_s .89 and 91). Of note, Focus Right for stimulus trials also showed medium correlation to Total Fixation time for HC and TBI groups (r_s .40 and .44, respectively) but weak correlation for the SIM group (r_s .17).

All three groups showed strong positive correlation between time in Correct Stimulus and Incorrect Stimulus AOIs. However, among SIM and TBI groups, Correct/Incorrect Ratio showed

strong inverse correlation to gaze time spent in the Incorrect Stimulus AOI (r_s -.51 and -.60), which indicates that the ratio is predominated by time spent in the Incorrect Stimulus AOI. In contrast, among HC, Correct/Incorrect Ratio showed positive correlation to gaze time in Correct and Incorrect AOI (r_s .27 Correct and .35 Incorrect), which indicates that gaze time in the Correct AOI predominated.

Section 4.2 – Oculomotor and Neuropsychological Variable Correlations

Correlations between the core oculomotor variables and the neuropsychological measures were assessed. Results of the Spearman's rho correlations are presented in Tables 3a – 3c separately for each group. Results of the Spearman's rho correlations between the oculomotor measures and TOMM Forced-Choice Trials 1 and 2 for the entire sample are presented in Table 3d.

Table 3a presents correlations for the HC group, who, being instructed to put forth good effort, provide the ideal baseline for variable comparisons. The HC group showed the strongest correlations between education and gaze duration in the correct stimulus AOI (r_s = .44). Estimated IQ (e.g., WTAR) showed moderate inverse relation to global fixation durations (r_s = -.40), number of fixation transitions (r_s = -.29) and gaze durations in empty space (r_s = -.41). Much the same, high scores on Trials 1 – 5 on the CVLT, which suggest intact attentional capacity and learning efficiency, were inversely related to Fixation Transitions (r_s = -.34); as well as correct stimulus gaze duration (r_s = -.28). Similarly, Digit Span Forward (r_s = -.40), which taps simple attention, and Digit Span Backward, which taps working memory (r_s = -.33), also showed moderate inverse correlation with background gaze duration. This result suggests that attentional capacity is inversely related to gaze durations to empty space. Moreover, Digit Span Forward (r_s = .40) and Digit Span Backward (r_s = .26) were positively related to correct

AOI focus during stimulus trials (Focus Right-Stimulus) and inversely related forced-choice trials (Focus Right-FC). This pattern would be expected if effortful attention was mobilized during the task. Also, as attention increased, fixation transitions decreased (r_s = -.26 and -.30, Digits Forward and Backward, respectively). Trails A time showed minimal correlations with any oculomotor variables; however, Trails B time (increases with poor performance) was associated with total Gaze Transitions (r_s = .34), Fixation transitions (r_s = .34), Background Gaze duration (r_s = .26), and Incorrect Stimulus Gaze duration (r_s = .25). Symbol Digit had the weakest correlations with the oculomotor variables, showing low to modest, inverse correlations between duration of gazes in the correct (r_s = -.26) and incorrect (r_s = -.28) AOI locations during forced-choice trials.

All correlations among the core oculomotor and neuropsychological variables for the TBI group can be found in Table 3c. Unlike the HC group, who showed no significant associations between age and gaze behaviors, the TBI group had a moderate correlation between age and the ratio of gazing at correct to incorrect AOIs (r_s = .49). Education was inversely related to correct focus behavior during forced-choice trials (r_s = -.38) and the number of fixation transitions that occurred across the test (r_s = -.38). Similar to the HC group, the TBI group showed a general pattern of inverse correlations between WTAR, CVLT-II, Digit Span (Forward and Backward) and Trails times (high times reflect poor performance) with Gaze Transitions, Fixation Transitions, and Background Gaze time. CVLT-II was also inversely related to Correct/Incorrect Ratio (r_s = -.29) and Focus Right – FC (r_s = -.28). Symbol Digit also was negatively related with total task fixation durations (r_s = -.44). Results for both TBI and HC groups also suggest a pattern of positive correlations between neuropsychological indexes (especially Digit Spans) with Focus Right-Stimulus, and inverse correlations with Focus Right-

FC.

The SIM group, being coached to feign cognitive impairment, would be expected to have neuropsychological scores that correlate with oculomotor variables in patterns either similar to the TBI group (i.e., if successful), or uniquely to their own strategies of feigning impairment. All correlations between these variables for the SIM group can be found in Table 3b.

Unlike both the HC and TBI groups, the SIM group tended to view incorrect AOIs for longer periods of time the younger they were (r_s = -.27). Like the TBI group, the number of gaze transitions that occurred across the test (r_s = -.28) decreased as their education increased Contrary to the HC and TBI groups, estimated IQ (WTAR) was positively correlated with fixation transitions (r_s = .43), global fixation duration (r_s = .38), correct stimulus gaze (r_s = .39), and incorrect stimulus gaze (r_s = .38). The SIM group also showed some unique associations between Digit Span Forward scores and the oculomotor variables as compared to the HC and TBI groups. Namely, the SIM group showed nearly no associations between oculomotor measures and the CVLT-II; though, the directions of the correlations were all positive whereas most correlations for the HC and TBI groups were inversely related. Additionally, the HC group had little relationship between Digit Forward score and duration of time spent gazing at incorrect stimuli, yet the SIM group tended to decrease the time gazing at incorrect stimuli as their Digit Scores went up (r_s = -.33). The same pattern was evident for the SIM group on Digit Span Backwards. In fact, Focus Right-Stimulus trials showed inverse correlation with Digit Span Backward (r_s = -.35). Trails A completion time was positively associated with frequency of fixation transitions (r_s = .34), much the same as the HC group. Symbol Digit scores were not significantly correlated with any neuropsychological measure for the SIM group.

Table 3d provides the relationship between the oculomotor variables and TOMM

outcome scores, as it would be used clinically, for the entire group. The pattern of directionality of these correlations provides unique insight into how these variables tend to relate to successful passing of the TOMM. Namely, almost all measures of visual behavior showed medium to large *inverse* correlations with both forced-choice trials. Only Correct/Incorrect Ratio and Focus Right – Stimulus variables were positively correlated with TOMM 1 (r_s = .60 and r_s = .26, respectively) and TOMM 2 (r_s = .63 and r_s = .27, respectively) outcome scores. That Correct/Incorrect Ratio was positively related for all groups, yet the component variables of this measure (i.e., correct stimulus gaze and incorrect stimulus gaze) were negatively correlated, is of special note. It would appear that Correct/Incorrect Ratio is perhaps tapping a unique element of visual behavior that is unrecognized by the correct and incorrect gaze durations in isolation.

Section 4.3 – One-Way Mean Rank Comparisons of Oculomotor Variables

Table 2 presents the descriptive statistics for TOMM performance and associated oculomotor variables for each group, including mean, standard deviation and median values. Because several of the oculomotor variables showed unequal variance across the groups, nonparametric analyses were required to compare the core variables between the three groups. One-way comparisons of mean ranks (e.g., Kruskal-Wallis test) were conducted for each of the global variables (i.e., total task sums or means), including the traditional accuracy scores for TOMM forced-choice trials 1 and 2. Table 4a presents the mean ranks of each of the global variables for each group. Also presented are the Kruskal-Wallis chi-square statistics and summary of the Mann-Whitney post hoc contrasts. Table 4b presents the detailed statistics for the Mann-Whitney contrasts for all combinations of group mean comparisons across the global variables (i.e., HC-SIM, SIM-TBI, HC-TBI). Included in Table 4b are the Mann-Whitney U statistics and z scores used to calculate effect sizes in Cohen's d for each of the variables.

Analyses revealed that each of the oculomotor indexes showed significant group differences except Initial Fixation Duration (X^2 = 1.66, p = .436) and Focus Right Forced-Choice (X^2 = 3.10, p = .214). Significant contrasts of mean ranks for all variables were compared using the Mann-Whitney post hoc tests. The traditional TOMM accuracy scores significantly differentiated all three groups. Furthermore, the following four oculomotor variables produced mean values that significantly differentiated all three groups: Fixation Transitions (p < .001; SIM > TBI > HC), Background Gaze Duration (ms) (p < .001; SIM > TBI > HC), Correct Stimulus Gaze (ms) (p = .001; SIM > TBI > HC), and Incorrect Stimulus Gaze (ms) (p < .001; SIM > TBI > HC). Although Correct/Incorrect Gaze Ratio was not significantly different between HC and TBI groups, TBI and SIM were significantly differentiated (p < .001; HC = TBI > SIM). A similar finding was observed for Fixation Duration (p = .009; SIM > HC = TBI).

Following the identification of global variables that successfully differentiated groups, the component variables comprised in the global variables were assessed using the same nonparametric tests (i.e., Kruskal-Wallis with Mann-Whitney post hoc tests). Table 5a and 5b present the results of the four components that compose the global variables (i.e., the four presentations of the stimuli during the TOMM task): TOMM Trial 1 (stimulus presentation), TOMM Trial 1 (forced-choice), TOMM Trial 2 (stimulus presentation), TOMM Trial 2 (forced-choice). Additionally, averaged scores for the stimulus presentations of TOMM Trials 1 and 2 combined (Stimulus TOMM 1 & 2), and forced-choice (Forced-Choice TOMM 1 & 2) are tested. These analyses of the component variables were conducted to identify which aspect of the global variable was driving group differentiation.

The combination variable for Fixation Transitions Forced-choice Trials 1 & 2 was significantly different between the groups (X^2 = 24.21, p < .001). At the trial level, the first

forced-choice trial (Forced-Choice TOMM 1) significantly differentiated all three groups, whereas the second forced-choice trial showed significant differences between HC-SIM and SIM-TBI, with a trend (p = .057) for HC-TBI. The combined scores for Background Gaze Duration Forced-choice Trials 1 & 2 significantly differentiated each group (X^2 = 22.69, p < .001); though, the trial level variables only produced significant differences between the HC and SIM groups. Individually, Correct Stimulus Gaze Forced-Choice Trials 1 and 2 both significantly differentiated the HC group from the SIM group (X^2 = 10.37, p = .006 & X^2 = 14.56, p = .001, respectively). Alternatively, only the Trial 1 component score differentiated HC from TBI (p = .043) whereas only the Trial 2 component score differentiated SIM from TBI (p = .014). Nearly identical results were found for the first and second forced-choice trials in regards to the Incorrect Stimulus Gaze variable; however, in the case of these component variables, both the Forced-Choice Trial 1 and Forced-Choice Trial 2 variables significantly differentiated the SIM group from the TBI group.

Section 4.4 – Test Performance Based on Published Cut Scores

Classification accuracy statistics predicting group status were examined for the traditional TOMM and each oculomotor variable. The TOMM was tested using the dichotomous pass/fail classification based on the cutoff score indicated in the published manual. Phi coefficient reflecting the association between group membership and TOMM pass/fail status demonstrated that the TOMM was significantly associated with group membership, with a large effect size (φ = .80, p < .001). Based on dichotomous pass/fail scores, as the test would be used in a clinical setting, 100% of the HC group passed and 95% of the TBI passed, demonstrating appropriate classification. However, only 23% of the SIM group failed the task, indicating that 77% of the SIM group avoided detection when traditional cut-scores were implemented.

Traditional binary logistic regression models and ROC curve analyses also were used to assess classification accuracy. Due to extreme homogeneity of variance for the HC group (i.e., resulting in perfect classification, therefore, zero cases in one of the necessary cells for this analysis), models including HC were unstable and could not be interpreted for HC-SIM or HC-TBI comparisons. For the initial analysis, the logistic regression used group membership (e.g., SIM versus TBI) as the outcome variable and the TOMM Trial 2 (dichotomous pass/fail score) as the predictor. Following, each of the oculomotor variables were examined as the predictors in single-variable logistic regression models, with group membership as the outcome. These single-variable logistic regression models were assessed via model significance (χ^2), odds ratio, and Nagelkerke R^2, as well as ROC curve analyses.

A strong indicator of a logistic regression model's ability to discriminate between groups (i.e., model fit) is the AUC produced by the model. This statistic, derived by calculating the area under the Receiver Operating Characteristic curve, provides information about how well the predicted probabilities created by the regression model match the observed probabilities over the entire range of values. Essentially, the model tests the power of classification accuracy by plotting the dynamic tradeoff of Sensitivity against 1 – Specificity for all possible values of the test. In other words, it acts as a graphical representation of how well the model correctly classifies those cases with or without a condition of interest. Larger AUC values represent better discrimination. AUC values at 0.50 offer no discrimination. AUC values between 0.70 and 0.79 are "acceptable," 0.80 to 0.89 are "excellent," and values greater than 0.90 are considered "outstanding" (Hosmer & Lemeshow, 2000). Despite the utility of AUC models in showing discrimination capability, this statistic can be relatively insensitive to changes in model fit when multiple covariates (i.e., predictors) are entered into the model, regardless of the apparent (i.e.,

via sensitivity, specificity, and associated classification accuracy statistics) predicative strength of any one of the added covariates. As a result, supplementing the AUC with other tests of model fit is beneficial.

Table 6 provides the chi-square statistics testing the significance (reliability) of the logistic regression models, the odds ratios for the model, Nagelkerke R^2 from the logistic regression, and ROC area under the curve (AUC and AUC Confidence Interval). Logistic regression indicated that the TOMM pass/fail score was a significant predictor of group membership, $\chi^2 = 51.54$, $p < .001$. Nagelkerke R^2 for the model was .61. Area under the curve (AUC) for the TOMM was .86, 95% CI [.05, .23], which is classified as excellent discrimination (Metz, 1978). Six of the core oculomotor variables were not significant predictors of group membership. These included the frequency of gaze transitions, the frequency of autofixations, the duration of the initial fixation, duration of gazes located in empty background space, focusing correctly on stimulus trials, and focusing correctly on the forced-choice trials. All other models were significant at $p = .005$ or lower. Of note, the model for Correct/Incorrect Gaze Ratio was unstable, producing extreme odds ratios likely due to restricted variance (empty cells) in the low end of the variable distribution as compared to the SIM group. A stable model was produced by recoding and reducing the Correct/Incorrect Gaze Ratio variable to four groups, with cutpoints < 1.0, 1.1, 1.2 and > 1.2. The reduced variable stabilizes the model by effectively ensuring that there are no weak cells in either group. The new variable (Gaze Ratio-grouping) is interpretable as ratios < 1.0 (i.e., predominated by gaze at incorrect stimuli) and various degrees of increased dominance of gaze at correct versus incorrect stimuli.

AUC for the significant models varied moderately, ranging from .53 for Initial Fixation (ms) to .76 for the ratio of correct to incorrect gaze duration. Incorrect Stimulus Gaze (AUC .75)

and Gaze Ratio-grouping (AUC .81) surpass the "acceptable" criterion, and Fixation Transitions (AUC .69) showed a (heartbreaking) strong positive trend in this regard.

Section 4.5 – Two-Variable Logistic Regression Models

Those variables that proved to be significant individual predictors of group membership were tested in combined models that included the TOMM pass/fail score as a covariate on Step 1 and the oculomotor variable on Step 2. Table 7 presents the results of the two-variable models, including the χ^2 statistics for the Total Model and the second step on which the oculomotor variable was added, Wald statistic for the oculomotor covariate added on Step 2, Nagelkerke R^2 for the total model, and AUC statistics from the ROC of the combined model.

The model including frequency of transitions occurring between fixations as a covariate (Fixation Transitions) was significant ($\chi^2 = 48.22$, $p < .001$); Nagelkerke R^2 was .61 and AUC for the total model was .92 (outstanding). The covariate itself added significantly to the model's predicative ability beyond that produced by TOMM pass/fail, increasing Nagelkerke R^2 from .62 to .68. In the present analyses, the Hosmer-Lemeshow chi-square test for model calibration was also examined. A model is better calibrated when the observed and expected frequencies of group membership (as based on the predicted probabilities) are similar; therefore, nonsignificant (i.e., $p \geq .05$) differences are desired and indicate good fit of the model. The TOMM*Fixation Transitions model produced a non-significant Hosmer-Lemeshow chi-square test ($\chi^2 = 8.40$, $p = .395$), indicating good calibration of the model. Two other two-variable models presented in Table 7 are noteworthy. The model testing Incorrect Stimulus Gaze added unique variance on the step ($p = .041$), with a Wald statistic = 3.5, $p = .059$. Nagelkerke R^2 increased from .60 to .65. Hosmer-Lemeshow was nonsignificant ($p = .247$), indicating adequate calibration. As shown in Tables 6 and 7, the AUC for the variable Incorrect Stimulus Gaze was a respectable .75, and the

combined model improved the AUC of TOMM Accuracy alone (.86) to .89. Wald is a very conservative statistic and can underestimate the contributions of individual predictors. For example, the Backward Likelihood Ratio of removing Incorrect Stimulus Gaze from the model is significant (change in -2 Log Likelihood = 4.12, p = .041), which indicates that the model is significantly diminished without the covariate. Lastly, the model with Gaze Ratio (group) also shows promise, increasing Nagelkerke R^2 increased from .60 to .62 and AUC from .86 to .89. Hosmer-Lemeshow for the model was nonsignificant (p = .341), indicating adequate calibration.

CHAPTER 5 DISCUSSION

The findings of this study demonstrate that mulitple measures of oculomotor behavior show great promise in their capacity to improve discrimination and classification accuracy of feigned and bona fide TBI. Moreover, many of the oculomotor indexes assessed demonstrate meaningful associations with cognitive constructs engaged during the performance of the TOMM. As predicted by theory, convergent and construct validity became apparent via the interrelationships seen among the oculomotor measures and their relationships with neuropsychological tests designed to assess constructs such as attention, visual scanning, and processing speed (Neuman, Assaf, & Israeli, 2015; Orquin & Mueller, 2013, Poplun, Ritter, & Velichkovsky, 1996). Most important, some of these eye-tracking indexes proved capable of not only discriminating between bona fide and feigned neurocognitive impairment on their own, but demonstrated improvements upon the discriminative ability of a "gold standard" PVT (i.e., the TOMM) as it is used clinically. Overall, the findings yield excellent support for the broad aim of this study: that computerized technology and biomarkers such as eye tracking can add significantly to the clinical utility of neuropsychological assessment. Proof of concept has been well established by means of empirically demonstrated incremental improvements in classifying clinical groups of interest when these measures are put to use.

The first step in this exploratory study was to determine which measures of visual behavior would be assessed. The number of oculomotor measures that can be operationalized when combining theory with the data capturing capacity of modern eye-tracking technologies is staggering. Fortunately, the eye-tracking literature has provided ample evidence that a large assortment of cognitive processes can be inferred from even a few genres of oculomotor measures. For the purposes of this study, three of these genres were operationalized as potential

measures of the cognitive behaviors anticipated within a clinical administration of the TOMM: oculomotor frequencies, durations, and scanpath ratios. Frequencies were proposed to assess immediate attentional processing (Orquin & Mueller, 2013; Jacob & Karn, 2003; Goldberg & Katvol, 1999; Just & Carpenter, 1976) and the attention orienting properties of the stimuli (Foulsham & Underwood, 2008; Byrne et al., 1999). Durations, or dwell time, are suggested to tap into information processing, comprehension, and encoding (Velichkovsky, Rothert, Kopf, Dornhofer, & Joos, 2002). Scanpath ratios are considered indexes of visual scanning regularity, efficiency, and recognition (Orquin & Mueller, 2013; Glöckner & Hebold, 2011; Poole & Ball, 2005; Jacob & Karn, 2003; Goldberg & Kotval, 1999; Russo & Rosen, 1979).

Redundant indexes were identified, and the oculomotor measures that were hierarchically or theoretically most refined were retained in lieu of less precise oculomotor measures. Based on statistical (i.e., correlational) evaluations of convergent and discriminant validity among the indexes, the number of oculomotor measures was reduced from 14 to 11. These redundancies made theoretical sense given the qualitative similarities between those oculomotor behaviors showing strong intercorrelations. For example, *gaze transition* frequency was retained because a change in viewing location requires effortful processes to initiate saccadic shift and assumes greater variability than *gaze duration* (Glöckner & Habold, 2011). The two indexes shared more than 80 percent of their variance in the present study, so only one index should be retained; however, theoretically, frequencies can vary more than time, in a time-limited paradigm such as the TOMM. Similarly, duration measures that provided information about the location and accuracy of a gaze (e.g., Correct Stimulus Gaze) replaced measures that assessed location only. This process of refinement emphasized the need for diligence in deciphering which oculomotor

behaviors are theoretically subsumed by others. Although multiple levels of visual behaviors can be obtained, it is unsound to assume they all tap distinct cognitive constructs.

Striking patterns were observed among the remaining oculomotor indexes, especially when stratified by the groups producing them. Before discussing the visual behaviors unique to each group, however, attending to consistencies is warranted. Theory would presume that good effort during a stimulus presentation trial requires greater frequency of fixating on the salient image as opposed to time spent gazing at empty space (Pomplun, Ritter, & Velichkovsky, 1996; Yarbus, 1967). Orquin and Mueller (2013) summed up this theoretical expectation well, stating "the effect of saliency on attention capture should also interact with task demands, in that decision makers are more likely to attend to salient stimuli that share features with goal-related objects" (p. 192). As expected, there was a consistent, inverse relationship between time spent gazing at the background and the frequency in which the final fixation of a trial landed on the target stimuli during the stimulus presentation trials of the TOMM. Although this finding was true for all three groups, the nature of these measures' interrelationship supplies evidence that unique pairing of oculomotor behaviors yields theoretically congruent information about cognitive processes, such as efficient attention and stimuli-salient transitional movements (Orquin & Mueller, 2013).

More useful, however, is to evaluate how the relationships among the oculomotor indexes differ between groups. Given that fixation patterns are assumed to demonstrate effortful (yet efficient) comprehension and increasing levels of processing and encoding (Velichkovsky et al., 2002), efficient attempts at engaging the TOMM stimulus presentation trials would likely find that fixations are focused on the salient image (Yarbus, 1967). Interestingly, the relationship between the number of fixations made and the frequency of correctly focusing on the stimulus

image was relatively weak for the TBI simulating group, as compared to the full effort groups of health adults and adults with TBI. On the other hand, efficient engagement in the forced-choice trials would likely be demonstrated by minimal oculomotor behaviors, given the ease of the task (Orquin & Mueller, 2013). In other words, once the correct stimulus was identified, likely by memory as opposed to comparing multi-level perceptual features of all stimuli presented, few additional eye movements would be needed. Theory suggests that fixations can act as "external memory space" (Droll, Hayhoe, Triesch, & Sullivan, 2005) and the visual system, in conjunction with working memory, "strives to minimize processing demands in general" (Orquin & Mueller, 2013); to fixate and encode all available visual information would be cognitively inconvenient. If it is more convenient to retrieve information from memory (as would likely be the case in a task such as the TOMM), scanning the entire visual environment can be considered an inefficient process. Rather, the use of *a just-in-time* fixation strategy (Ballard et al., 2007) is expected, whereby utilizing only the salient and easily available stimulus cues required to retrieve information from memory decreases working memory load. Curiously, the total time spent fixating was very strongly related to time spent gazing at both the correct and incorrect stimuli for the SIM group (i.e., a seemingly inefficient process), yet only modestly related for the other two groups. Additionally, a unique between-group distinction was found in the relationship between the times spent looking at the incorrect stimulus and the *proportion* of time spent looking at the correct versus incorrect stimuli. Healthy adults providing full effort showed a proclivity to spend most of their fixation time focused on the correct stimulus, whereas adults with TBI and those feigning TBI generally fixated more on the incorrect stimulus. Taken together, it appears that these measures are empirically distinct in terms of the constructs they are measuring. As distinct indexes, they may be useful in distinguishing oculomotor characteristics

of a purposeful simulator from bona fide TBI patients and healthy adults instructed to put forth full effort. However, in order to truly understand the underlying processes of how the groups are distinctly engaging the task, it is imperative that the cognitive constructs behind these oculomotor characteristics are identified.

The process of assessing construct validity required evaluating the relation of the core oculomotor measures to concurrent neuropsychological measures known to tap the very constructs the visual behaviors are presumed to capture. As Franko-Watkins and Johnson (2011) eloquently summarize, "combining multiple sources of data is a useful tool for providing convergence in understanding the dynamic processes (i.e., constructs; *parentheses mine*) associated with the acquisition and use of visual information in decision making" (pp. 861). Following psychometric theory, moderate relationships were anticipated between measures that tapped into anticipated cognitive constructs, such as attention (Digit Span), visual search (Symbol Digit), and processing (Trails A and B). Given that convergence between these variables would be expected if the oculomotor behaviors are tapping similar cognitive functions, it was expected that these correlations would remain relatively stable among groups that performed in a manner reflective of good effort (i.e., appropriate use of cognitive functions needed to complete the task). Conversely, lower or different correlations between cognitive variables and associated oculomotor indexes were anticipated in the context of attempts to underperform on these tasks.

Healthy adults were expected to engage the TOMM in a straightforward manner; hence, the relationships between measures of their visual patterns and the neuropsychological indexes were considered an ideal baseline in assessing construct validity. Findings showed that as IQ increased, the global frequencies and durations of gazes and fixations decreased, as did time

spent looking at empty space. As stipulated by theory, learning effects (moderated by intellectual ability) are suggested to increase visual decision efficiency as demonstrated by more frequent fixations on task-salient stimuli, fewer fixations on task-irrelevant stimuli, and quicker stimuli processing (Orquin & Mueller, 2013; Glöckner & Hebold, 2011; Pomplun et al., 1996). The pattern observed among healthy adults putting forth full effort supposes cognitive efficiency on the task: High IQ would suggest intact cognitive functioning, improved learning of task demands, and thus, increases in oculomotor efficiency (e.g., fewer fixations, transitions, and gazes directed towards irrelevant stimuli). Furthermore, a measure of simple attention was inversely related to time spent looking at empty space, indicating that strong attention yields less time attending to non-salient stimuli. Additionally bolstering this finding was that Digit Span Forward and Backward were positively related to fixating on the correct AOI during stimulus trials. As Trails B time increases, oculomotor scanning increases and more time is spent in the incorrect stimulus AOI. This pattern reflects cognitive inefficiency on the task: Trials B is a complex visual scanning and processing task that taps executive control, speed and attention; thus, the direction of this correlation is as expected. Although visual search efficiency as measured by Symbol Digits had the lowest association with oculomotor measures, these findings are in the expected direction. However, this trend again reflects cognitive efficiency on the task, given that strong performance on Symbol Digit requires speed in conjunction with working memory to avoid spending time returning the gaze to the symbol-digit legend. Overall, it appears that performance on the TOMM by cognitively healthy individuals is generally marked by decreases in oculomotor behaviors, which is likely a sign of visual and cognitive efficiency, all of which would be expected of a healthy individual as specified by the extant research regarding decision making and its correlates with visual patterns.

Similar to healthy adults, the adults with TBI were anticipated to put forth as much effort as their capacity allowed. Comparisons of oculomotor variable correlations to neuropsychological variables were anticipated to be in the similar direction as the HC group. As expected, estimated IQ, Trails time, CVLT-II Trials 1-5 scores, and Digit Span were similarly related to core oculomotor measures reported for the HC group. Overall, among participant groups expected to put forth full effort (HC and TBI), little evidence of working hard on the task (i.e., numerous gazes and fixations, or viewing all stimuli in the visual field) was found. Rather, cognitive efficiency characterized participants who demonstrated the adequate cognitive functions to complete the task as directed. Additionally, the Focus Right indexes, which were designed to tap attention, appear to converge as predicted: Attentional effort during the initial stimulus presentations of the task (Focus Right-Stimulus) is positively related to Digit Span (i.e., strong attention is associated with high frequency of trials focused on the correct stimulus AOI), which then reaps a benefit observed in inverse correlation to the forced-choice trials (i.e., needing fewer fixations to know the correct answer).

Generally, the pattern of oculomotor and neuropsychological correlations for TBI simulators was weaker and less consistent than that observed for the full effort healthy adults and TBI group. One notable difference between the patterns observed is that the TBI simulators show substantial *positive* relation between estimated IQ (WTAR) and oculomotor indices including Fixation Transitions, Fixation Duration, Correct Stimulus Gaze, and Incorrect Stimulus Gaze. Most strikingly, and in direct contrast to proposed theory concerning duration sequence and two-choice gaze bias (Glaholt & Reingold, 2011; Glaholt & Reingold, 2012), was that the TBI simulators showed a unique tendency to decrease the frequency of focusing correctly on stimulus trials as their measure of attention (i.e., Digit Span) improved. A finding such as this is not only

contrary to that seen in both of the full effort groups, but suggests that the TBI simulators purposefully (and inefficiently) employed attentional capacity by fixating on aspects other than the salient image on the screen. Overall, these findings suggest that the TBI simulators are working harder on the task (i.e., numerous gazes and fixations, viewing background in addition to stimuli) than it actually demands. Furthermore, increases in oculomotor activity (i.e., visual effort) were positively associated with intelligence and cognitive function: a result that is consistent with the hypothesis that the TBI simulators are using their intelligence in an attempt to thwart the test (Bashem et al., 2014; Rapport, Farchione, Coleman, & Axelrod, 1998).

A final, and important finding, regarding the relationship of the oculomotor variables and the neuropsychological indexes, involves the visual behaviors and TOMM Forced-Choice Trials 1 and 2 accuracy scores. The findings for the entire sample generally demonstrate that as oculomotor efficiency increases (i.e., decreased frequency and duration of visual behaviors), so too does TOMM accuracy. This holds true for almost all oculomotor variables: Gaze transitions, fixation transitions, fixation durations, correct stimulus gaze, and incorrect stimulus gaze are all inversely related to TOMM outcome. At first, this would appear to be counterintuitive, especially in terms of the duration of gaze time spent looking at the correct stimulus item during a forced-choice trial. However, correct focus during the stimulus trial is positively correlated with TOMM accuracy, as is the Correct/Incorrect Ratio. Taken together, it seems that there is strong evidence that cognitive efficiency as a whole is linked to successful completion of the TOMM. Moreover, the ratio of time spent gazing at correct and incorrect stimuli provides unique insight into how absolute values of duration can be misleading, especially when considering that TBI participants are typically reacting slower in general due to the sequelae of their injury. In other words, an increase in simple gaze time to correct or incorrect stimuli taps how much effort someone puts in

because they are either feigning (i.e., demonstrating cognitive and visual inefficiency) or their processing capacity and speed are truly impaired. However, because the ratio of these two indexes is positively related to the outcome, we can gather that it is tapping something unique. It would appear that the ratio controls for the TBI participants' general slowness by assessing the proportion of time spent looking at the correct stimuli versus the incorrect stimuli, regardless of the actual duration. The significant difference here is that the full effort TBI and healthy adult groups both tend to look at the correct stimuli for a greater proportion of the time, whereas the TBI simulators group tends to look at the incorrect stimulus for a greater proportion of the time. Following from this, it would appear that TBI simulators spend a disproportionate amount of time observing non-accurate information, substantially more so than adults with verified moderate to severe TBI. Consistent with the pattern of *disproportionate disability* described in prior malingering literature (Coleman, Rapport, Millis, Ricker, & Falchion, 1998), the simulators are trying to feign so badly they end up looking worse than bona fide TBI.

Following successful demonstration that the core oculomotor variables were distinctly tapping many of the cognitive constructs they were purported to assess, group behaviors were compared to identify which of these indexes would prove to reliably differentiate three groups. The findings showed that all three groups were differentiated by the global frequency of fixations produced, the global duration of time spent looking at the background, and the time spent focusing on the stimulus presentation images. The global duration of fixations and the proportion of time spent gazing at the correct versus the incorrect forced-choice stimulus images successfully differentiated TBI simulators from the other two groups. At the component level of these variables, group differentiation appeared to be strongest in terms of oculomotor behaviors occurring during the forced-choice trials as opposed to the stimulus trials.

It has now become apparent that many of the distinct oculomotor measures are capable of capturing unique visual behaviors that successfully differentiate the groups. However, a pivotal next step was to test the clinical utility of these measures is their ability to predict group membership. All of the oculomotor indexes were tested as predictors of group membership, and six of the eleven were not capable of reliably identifying group membership. However, five indexes did reliably differentiate the groups. These indexes were tested in comparison to the standard clinical pass/fail scores of the TOMM, which was an exceedingly strong predictor of group membership. The predicative strength of the TOMM pass/fail scores likely grew out of two important factors: 1) the healthy adults demonstrated an extreme level of homogeneity in their TOMM accuracy, and 2) the simulators tended to score so poorly that the clinical cut score for the TOMM easily identified most of the members (77%). Resulting, this scenario set an extremely high bar for the oculomotor predictors to pass in terms of offering incremental predictive utility above and beyond that provided by the TOMM's clinical cut point. Despite this rigorous test, the frequency of fixation transitions occurring globally did in fact add significant incremental predictive value to the TOMM pass/fail score. This finding provides strong evidence that the frequency of fixation transitions is a useful index for predicting simulated neurocognitive deficits on the TOMM. This index, which taps effortful (yet unconscious) cognitive behavior, occurred more frequently among TBI simulators than the among full effort healthy adults or adults with bona fide TBI. This finding demonstrates a vital piece of information about the cognitive behavior of TBI simulators: They tend to put in more effort to try and understand the test, and if biometric markers are recording this effort via oculomotor patterns, their extra effort actually renders them more susceptible to being identified as simulators!

Section 5.1 – Conclusions

State-of-the-science, eye-tracking technology was integrated into a multimodal neuropsychological assessment battery to examine the incremental clinical utility of this novel computer technology. Large effects were observed for a majority of the eye-tracking behaviors evaluated, which demonstrated that the inclusion of biomarkers in neuropsychological assessments could significantly improve detection of feigned neurocognitive deficits. One oculomotor variable accounted for unique predictive value in identifying clinical status beyond that produced by the published pass/fail cut scores for the well-performing TOMM performance validity test. Even those variables that did not provide evidence for improving the predicative accuracy of this PVT, specifically, did demonstrate construct convergence with neuropsychological measures of cognition and had predicative power based on their individual merit. As such, this study presents strong evidence that adopting biometric markers within neuropsychological assessments (i.e., assuming the correct variables are identified and incorporated into appropriate PVTs) can significantly improve predicative accuracy. Furthermore, these findings support the assertion that further research investigating how biometric technologies may evolve neuropsychological assessment is both needed and warranted.

Previous studies on malingering suggested that poor performance on PVTs may result for a myriad of reasons, both conscious and unconscious (Lynch, 2004). Fortunately, it is correct that unconscious motivators are at play, making eye tracking a unique method of tapping into such unconscious behaviors such as covert attention and decision making (Franko-Watkins & Johnson, 2011; Glöckner & Hebold, 2011; Rayner, 1998). That the oculomotor measures operationalized and assessed demonstrated unique abilities to tap into cognitive processes

provides support for the embodied cognition theory: Cognitive processes are deeply rooted in the body's interactions with the world, which provides insight into perception and action (Wilson, 2002). The findings of this study also lend support to prior research indicating that effortful employment of intelligence (i.e., increased cognitive processing) is a consistent strategy of healthy adults instructed to simulate brain injury. These results demonstrated that malingering on the TOMM actually entails *more* effort, as opposed to suboptimal effort (a previous label for malingering). This finding is also congruent with one of the primary tenants of JDM theory; namely, the *Subjective Expected Utility Theory*, which stipulates that humans are utility maximizers who, given sufficient reasoning abilities, should aim to decide on the normative option regardless of the surrounding circumstances. This pattern is exactly what we observed for the two groups expected to engage the TOMM as instructed. They utilized their cognitive abilities (via visual behaviors) in a manner that maximized efficiency. In fact, one of the hypotheses generated from JDM theory regarding risk aversion (Baumeister et al., 2001), was found to be correct in light of the obtained results. It was suggested that the TBI simulator will likely perceive the correct choice as aversive (i.e., correct responding when attempting to feign disability is antithetical to their goal of appearing impaired); thus, it would be predicted that unconscious, oculomotor movements would focus on the foil (e.g., via quicker saccadic fixation, longer gaze duration, or an increased frequency of regressive transitions towards the foil).

Taken together, the simulators generally went against the normative behaviors needed to successfully complete a task structured like the TOMM. In a an effort to deceive it, they ended up giving themselves up by working too hard when enaging the test. The simulators were not guilty of suboptimal or poor effort, they were actually guilty of providing more effort than was needed by even a bona fide survivor of brain injury.

Section 5.2 – Limitations and Future Directions

The process of developing discriminatively valid oculomotor variables that could successfully tap into cognitive constructs, as assessed by convergent validity with known neuropsychological measures was guided heavily by theory. Due to the exploratory nature of this study, there are several limitations that must be addressed. A primary limiation of this study was the modest size of the three groups, in combination with the volume of statistical tests run, which substantially increased the chance of Type I (chance) error. Despite observing considerably strong effect sizes and a pattern of results that converged in a manner predicted by theory, it remains critical that these findings are replicated in a larger and independent sample for the results to be generalized. This limitation is emphasized given that successful generalization is at foundational to developing novel biometric indexes that may prove clinically useful.

Second, the nature of the phenomena yields heterogeneity of variance across the groups: Among the hallmark behaviors of TBI simulators is that their responses are considerably more variable than examinees who put forth full effort. Therefore, core assumptions of the parametric model are violated, and nonparametric statistics must be employed, which also limits statistical power and design (e.g., factorial designs). The inclusion criteria for the healthy adult population may have been too stringent, resulting in skew regarding estimated IQ and education; both of which may have contributed to the extremely low variability in their TOMM outcome scores. None of the healthy adults in the full effort condition failed the TOMM. This very high level of performance on the TOMM undermined exploration of clinical group prediction using some statistical models of choice (i.e., logistic regression) due to violations of model assumptions that require a certain number of observations in each cell. Future research with larger samples, and perhaps relaxing the inclusion criteria for healthy adults, would likely address this problem. On

the other hand, the simulator group appeared to simulate brain injury in an exceptionally unsophisticated manner, as indicated by a 77% fail rate on the TOMM alone. Given the very powerful accuracy of the standard TOMM cut score in identifying the simulators, this situation ultimately highlights how remarkable it was to find that some oculomotor indexes were able to account for unique variance. In the future, it would be wise to attempt to increase the sophistication of the simulator group by refining the methods of coaching.

Lastly, two of the oculomotor measures performed below expectations, likely due to oversights in how they were developed and calculated. For one, the Focus Right – Forced Choice variable was less powerful a predictor than was expected. Although its relationship with cognitive processes such as attention (as measured by Digit Span) was in the anticipated direction, its lack of predicative ability was likely due to the frequency score underrepresenting the construct it was designed to measure: correct focusing of attention. This variable was created to track whether a participant's gaze transitioned to the correct stimulus in situations where they chose the correct stimulus. However, built into the operationalized equation was a requirement that the participant earn a correct focus score if the trial included at least one transition. Due to the nature of the forced-choice paradigm, there was a 50% chance that the initial fixation would land on the incorrect stimulus image, thus requiring at least one transition to the correct stimulus before choosing the correct answer. However, the other 50% of the time, the initial fixation likely landed on the correct stimulus image, and was immediately followed by a correct response. Given that no transition was necessary, individuals whose first fixation started on the correct stimuli were unfairly deprived of earning a focus right score. In the future, it is suggested that the Autofixation variable and Focus Right – Forced-Choice be integrated to better capture the construct originally intended.

Another variable that showed strong promise, but was limited by a lack of variability within the TBI group (i.e., low scores), was Correct/Incorrect Gaze Ratio. Low scores (i.e., < 1) indicate predominance of gaze at incorrect stimuli, whereas high scores (> 1) indicate predominance of gaze at correct stimuli. Similar to the problem introduced by the high-performing healthy adults on the TOMM, as it was originally designed, this ratio index produced major model instability due to violations of distributional assumptions (i.e., too few participants with TBI produced low scores indicating predominance of gaze at incorrect stimuli). Logistic regression is typically touted for its very limited distributional assumptions, which makes it a preferred model for many scenarios like this one; however, the present sample nonetheless produced an unstable model. This problem was remedied by dividing the continuous scores into a smaller number of ranked categories that allowed the models to run (i.e., ensuring the minimum number of observations in each cell). However, reducing a continuous variable reduces power and effect size. Subsequently, although the revised index differentiated the groups reliably with a large effect size, the *incremental* predictive power to add to the already efficient TOMM accuracy score then did not reach significance (albeit heartbreakingly close to the .05 criterion). This index demonstrated strong abilities in discriminating TBI simulators from the other two groups as it captured the proportion of time that they gazed at the incorrect stimulus versus the correct stimulus. Furthermore, this index had the unique ability to bypass the confounding variable of slowed processing time in the TBI group, as this is a hallmark deficit for people who sustain this type of injury. It is recommended that future studies do not underestimate the power of ratio variables such as this one, and it is anticipated that with greater samples sizes the original operationalization of this variable will be successful.

APPENDIX A

TABLES

Table 1. *Descriptive Statistics Comparing Health Adult (HC), Simulator (SIM), and Traumatic Brain Injury (TBI) Groups*

	HC			SIM			TBI			
Variable	*M*	*SD*	*median*	*M*	*SD*	*median*	*M*	*SD*	*median*	Range
Age	49.1	(15.7)	51.0	44.4	(16.9)	47.0	45.3	(12.8)	42.0	18 – 78
Education	14.3	(2.4)	14.0	14.5	(2.0)	15.0	12.2	(2.1)	12.0	8 – 20
WTAR Standard Score	101.2	(13.7)	102.0	105.3	(11.9)	107.0	84.6	(11.7)	83.5	66 – 126
Digit Span Forward Raw	10.0	(2.2)	10.0	7.0	(2.6)	2.1	9.0	(2.5)	9.0	0 – 16
Digit Span Backward Raw	7.5	(2.1)	7.0	6.0	(2.3)	6.0	7.0	(2.5)	6.0	0 – 14
Digit Span Reliable Digit	9.0	(1.9)	9.0	7.0	(2.6)	7.0	8.5	(2.4)	8.0	0 – 16
Trails A Raw (sec)	28.5	(9.7)	27.0	57.6	(43.7)	43.0	40.3	(17.2)	34.5	15 – 264
Trails B Raw (sec)	76.7	(40.6)	70	102.4	(43.8)	100.5	124.8	(71.9)	98.0	22 – 311
Symbol Digit Total Correct	51.5	(11.0)	51.0	31.1	(12.3)	30.0	37.7	(10.9)	39.0	0 – 1879
CVLT-Trials 1-5	47.2	(10.9)	46.5	34.9	(11.3)	36.0	34.5	(10.6)	32.0	10 – 72

Note. WTAR = Wechsler Test of Adult Reading; CVLT-Trials 1-5, California Verbal Learning Test-II Total Trials 1-5.

Table 2. *Descriptive Statistics of TOMM Performance for HC (n = 50), SIM (n = 42) and TBI (n = 39) Groups.*

	HC			SIM			TBI			
Variable	*M*	*SD*	*median*	*M*	*SD*	*median*	*M*	*SD*	*median*	Range
TOMM1 Correct	47.8	(2.5)	49.0	32.9	(7.7)	33	43.6	(5.4)	44.0	17.0 – 50.0
TOMM2 Correct	49.8	(0.4)	50.0	35.2	(11.2)	35.0	48.5	(4.4)	50.0	8.0 – 50.0
Gaze Transitions[1]	5.7	(2.7)	5.0	9.2	(4.6)	8.4	8.6	(4.4)	7.7	1.7 – 68.4
Fixation Transitions	1.5	(0.5)	1.5	2.1	(0.7)	2.1	1.7	(0.4)	1.7	0.7 – 4.0
Fixation Duration (ms)	1702	(264)	1755	1991	(548)	1899	1706	(278)	1691	657 – 3173
Autofixations	0.83	(0.1)	0.76	0.77	(0.1)	0.77	0.74	(0.1)	0.76	0.2 – 1.0
Initial Fixation (ms)	894	(318)	844	822	(297)	777	803	(250)	759	323 – 1659
Background Gaze Duration (ms)	212	(121)	191	370	(193)	332	285	(146)	281	24 – 2128
Correct Stimulus Gaze (ms)	553	(120)	545	794	(345)	692	621	(153)	625	0 – 1879
Incorrect Stimulus Gaze (ms)	449	(107)	454	826	(388)	677	513	(138)	506	0 – 2129
Correct/Incorrect Gaze Ratio	1.2	(0.2)	1.2	1.0	(0.2)	1.0	1.2	(0.2)	1.2	0.6 – 2.2
Focus Right-Stimulus Trials	68.5	(19.4)	70.5	53.2	(21.0)	49.5	57.1	(20.6)	55.0	9.0 – 98.0
Focus Right-Forced-Choice Trials	14.8	(8.4)	13.5	16.8	(6.6)	18.0	17.2	(8.5)	18.0	2.0 – 38.0

Note. TOMM1 = Test of Memory Malingering–Trial 1; TOMM2 = Test of Memory Malingering–Trial 2; Autofixation = first oculomotor event was an immediate fixation; Focus Right = First and final fixations are on the stimulus image.

1. All oculomotor variables reflect events per trial.

Table 3a. *Spearman Rho correlations – Healthy (Full Effort) Group (n = 50): TOMM Oculomotor and Neuropsychological Test Indexes.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Gaze Transitions	--															
2. Fixation Transitions	.61**	--														
3. Fixation Duration Total[1]	-.14	.12	--													
4. Background Gaze[1]	.46**	.78**	-.05**	--												
5. Correct Stimulus Gaze[1]	.31**	.40**	.64**	.14	--											
6. Incorrect Stimulus Gaze[1]	.29*	.36**	.59**	.07	.76**	--										
7. Correct/Incorrect Ratio[1]	-.00	.00	.11	-.01	.27*	.35**	--									
8. Focus Right-Stimulus	-.45**	-.54**	.40**	-.79**	.03	.03	.19	--								
9. Focus Right-FC	.11	-.04	-.02	-.08	.31**	.08	.16	-.14	--							
10. WTAR	-.29*	-.40**	.22	-.41**	.14	.05	.09	.26*	-.03	--						
11. Digits Forward	-.19	-.26*	.14	-.40**	.04	-.05	.15	.40**	-.24	.54**	--					
12. Digits Backward	-.24	-.30*	.19	-.33*	-.13	-.07	-.01	.26*	-.26*	.50**	.43**	--				
13. Trails A (time)	.19	.21	.00	.20	.18	.22	.04	-.17	.06	-.22	-.22	-.20	--			
14. Trails B (time)	.34**	.34**	-.12	.25*	.19	.26*	-.02	-.18	.04	-.44**	-.33*	-.46**	.53**	--		
15. Symbol Digit	-.22	-.22	-.10	-.12	-.26*	-.28*	.00	.04	-.07	.26*	.25*	.27*	-.40**	-.42**	--	
16. CVLT-Trials 1-5	-.12	-.34**	-.04	-.12	-.28*	-.25*	-.13	.06	-.07	.33*	.11	.27*	-.05	-.26*	.26*	--
17. Age	.07	.07	-.08	.08	.00	-.13	.20	.02	-.14	-.00	-.00	-.14	.30*	.26*	-.27*	.12
18. Education	-.04	-.01	.39**	-.11	.44**	.31*	.24	.29*	-.15	.54**	.27*	.17	.02	.00	.02	.14

Note. WTAR = Wechsler Test of Adult Reading; CVLT-Trials 1-5, California Verbal Learning Test-II Total Trials 1-5; Correct/Incorrect Ratio = (gaze duration correct stimulus / incorrect stimulus).
1. Duration indexes (ms).
*$p < .05$, **$p < .01$.

Table 3b. *Spearman Rho correlations –Simulator Group (n = 42): TOMM Oculomotor and Neuropsychological Test Indexes.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Gaze Transitions	--															
2. Fixation Transitions	.36**	--														
3. Fixation Duration Total[1]	.19	.55**	--													
4. Background Gaze[1]	.11	.34*	.31*	--												
5. Correct Stimulus Gaze[1]	.28*	.58**	.89**	.20	--											
6. Incorrect Stimulus Gaze[1]	.29*	.55**	.91**	.21	.90**	--										
7. Correct/Incorrect Ratio[1]	-.12	-.24	-.32**	-.13	-.13	-.51**	--									
8. Focus Right-Stimulus	-.17	-.06	.17	-.73**	.15	.17	-.06	--								
9. Focus Right-FC	.28*	-.11	-.15	-.03	-.06	-.08	.05	-.20	--							
10. WTAR	-.12	.43**	.38**	.05	.39**	.38**	-.03	.33*	.02	--						
11. Digits Forward	-.06	-.16	-.22	.25	-.22	-.33*	.32*	-.35*	-.02	-.08	--					
12. Digits Backward	-.06	-.03	-.20	-.00	-.23	-.26*	.17	-.05	-.00	.08	.58**	--				
13. Trails A (time)	-.01	.34*	.21	.17	.16	.22	-.22	-.07	.15	.22	-.35*	-.16	--			
14. Trails B (time)	.23	.44**	.28*	.08	.27*	.30*	-.17	.07	-.01	.21	-.28*	-.18	.74**	--		
15. Symbol Digit	.01	.12	.19	.00	.14	.08	.02	.04	-.06	-.02	.19	.21	-.43**	-.42**	--	
16. CVLT-Trials 1-5	.05	.17	.00	.25	-.08	.01	-.14	-.15	.10	.29*	.23	.36**	-.15	-.25	.21	--
17. Age	-.03	-.04	-.22	-.10	-.24	-.27*	.16	.17	-.02	-.06	-.02	.07	-.10	.02	.19	-.25
18. Education	-.28*	.16	.15	-.05	.12	.10	-.13	.26*	.03	.11	-.17	-.13	.09	-.00	-.06	-.09

Note. WTAR = Wechsler Test of Adult Reading; CVLT-Trials 1-5, California Verbal Learning Test-II Total Trials 1-5; Correct/Incorrect Ratio = (gaze duration correct stimulus / incorrect stimulus).

1. Duration indexes (ms).

*$p < .05$, **$p < .01$.

Table 3c. *Spearman Rho correlations – TBI Group (n = 39): TOMM Oculomotor and Neuropsychological Test Indexes.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Gaze Transitions	--															
2. Fixation Transitions	.22	--														
3. Fixation Duration Total[1]	-.28*	.16	--													
4. Background Gaze[1]	.10	.40**	.00	--												
5. Correct Stimulus Gaze[1]	.02	.32*	.49**	-.09	--											
6. Incorrect Stimulus Gaze[1]	.07	.33*	.42**	-.30*	.79**	--										
7. Correct/Incorrect Ratio[1]	-.10	-.14	-.04	.31*	-.01	-.60**	--									
8. Focus Right-Stimulus	-.31*	-.28*	.44**	-.75**	.13	.27	-.18	--								
9. Focus Right-FC	.78**	.11	-.17	-.02	.00	.10	-.16	-.18	--							
10. WTAR	-.22	-.20	.05	-.18	.19	.22	-.02	.07	-.22	--						
11. Digits Forward	-.39**	-.09	.36*	-.18	.21	.25	.00	.22	-.27	.52**	--					
12. Digits Backward	-.37*	-.23	.33*	-.28	.02	.07	.02	.33*	-.39**	.53**	.57**	--				
13. Trails A (time)	.49**	.35*	.26	.23	.36*	.25	.04	-.01	.40**	-.17	-.06	-.19	--			
14. Trails B (time)	.53**	.23	.20	.22	.17	.12	.01	-.02	.46**	-.43**	-.24	-.39**	..69**	--		
15. Symbol Digit	-.15	-.10	-.44**	-.16	-.25	-.08	-.23	-.13	-.14	.22	-.07	.15	-.66**	-.59**	--	
16. CVLT-Trials 1-5	-.38**	-.37*	.01	-.16	-.09	-.26	.29*	.23	-.28*	.20	.23	.32*	-.17	-.38**	.30	--
17. Age	.17	.15	.06	.16	.21	-.09	.49**	-.05	.12	.06	-.03	-.02	.33*	.32*	-.28*	-.14
18. Education	-.38**	-.04	.12	-.07	.16	.09	.16	.09	-.38**	.53**	.38**	.61**	-.23	-.48**	.11	.32*

Note. WTAR = Wechsler Test of Adult Reading; CVLT-Trials 1-5, California Verbal Learning Test-II Total Trials 1-5; Correct/Incorrect Ratio = (gaze duration correct stimulus / incorrect stimulus).

1. Duration indexes (ms).

*$p < .05$, **$p < .01$.

Table 3d. *Spearman Rho correlations – Total Sample (n = 131): TOMM Forced-Choice Trials Scores and Oculomotor Indexes.*

		1	2
1.	TOMM Trial 1 Correct	--	
2.	TOMM Trial 2 Correct	.82**	--
3.	Gaze Transitions	-.37**	-.26**
4.	Fixation Transitions	-.41**	-.31**
5.	Fixation Duration Total[1]	-.21**	-.22**
6.	Background Gaze[1]	-.32**	-.34**
7.	Correct Stimulus Gaze[1]	-.30**	-.21**
8.	Incorrect Stimulus Gaze	-.56**	-.49**
9.	Correct/Incorrect Ratio[1]	.59**	.63**
10.	Focus Right-Stimulus	.26**	.27**
11.	Focus Right - FC	-.30**	-.14**

1. Duration indexes (ms).
*$p < .05$, **$p < .01$.

Table 4a. *Kruskal-Wallis Group Comparisons of TOMM Performance for HC (n = 50), SIM (n = 42) and TBI (n = 39) Groups*: *Global Scores*

	HC	*SIM*	*TBI*				*Kruskal-Wallis*		
Variable	*Mean Rank*	*Mean Rank*	*Mean Rank*	*M*	*SD*	*Range*	$X^2(2)$	*p*	Mann-Whitney Contrasts[2]
TOMM1 Forced-Choice Correct	93.2	25.9	66.3	42.0	8.3	17.0 – 50.0	72.62	< .001	HC > TBI > SIM
TOMM2 Forced-Choice Correct	86.5	28.5	72.3	45.0	9.3	8.0 – 50.0	67.20	< .001	HC > TBI > SIM
Gaze Transitions[1]	47.2	80.2	74.6	8.2	6.9	1.7 – 68.4	19.81	< .001	SIM = TBI > HC
Fixation Transitions	48.9	84.6	62.9	1.8	0.6	0.7 – 4.0	20.70	< .001	SIM > TBI > HC
Fixation Duration (ms)	58.2	79.2	56.8	1795	412	657 – 3173	9.44	.009	SIM > HC = TBI
Autofixations	79.6	60.7	54.3	0.78	0.13	0.22 – 0.99	10.88	.004	HC > SIM = TBI
Initial Fixation (ms)	69.8	62.1	60.3	847	299	323 – 1659	1.66	.436	HC = SIM = TBI
Background Gaze Duration (ms)	48.4	81.8	66.7	300	239	24 – 2120	18.30	< .001	SIM > TBI > HC
Correct Stimulus Gaze (ms)	51.4	80.5	65.4	652	261	0.0 – 1879	13.68	.001	SIM > TBI > HC
Incorrect Stimulus Gaze (ms)	45.9	90.8	61.1	592	307	0.0 – 2129	33.27	< .001	SIM > TBI > HC
Correct/Incorrect Gaze Ratio	79.6	34.1	79.1	1.2	0.2	0.6 – 2.2	42.00	< .001	HC = TBI > SIM
Focus Right-Stimulus Trials	80.1	53.1	59.9	16.2	8.0	2.0 – 38.0	12.88	.002	HC > TBI = SIM
Focus Right-Forced-Choice Trials	58.2	70.0	70.2	0.9	0.8	0.0 – 2.0	3.10	.214	TBI = SIM = HC

Note. TOMM1 = Test of Memory Malingering–Forced-Choice Trial 1; TOMM2 = Test of Memory Malingering–Forced-Choice Trial 2; Autofixation = first oculomotor event was an immediate fixation; Focus Right = First and final fixations are on the stimulus image.

1. All oculomotor variables reflect events per trial.
2. Mann-Whitney post hoc tests, $p < .05$ criterion.

Table 4b. *Mann-Whitney Group Comparisons of TOMM Performance for HC (n = 50), SIM (n = 42) and TBI (n = 39) Groups: Global Scores.*

	HC-SIM				**SIM-TBI**				**HC-TBI**			
Variable	*U*	*Z*	*p*	*d*	*U*	*Z*	*p*	*d*	*U*	*Z*	*p*	*d*
TOMM1 Forced-Choice Correct	42.0	-7.75	< .001	-2.88	189.0	-5.72	< .001	-1.70	474.0	-4.18	< .001	-0.99
TOMM2 Forced-Choice Correct	146.0	-7.43	< .001	-2.56	184.5	-5.90	< .001	-1.80	704.5	-2.87	.004	-0.64
Gaze Transitions[1]	519.5	-4.16	< .001	-0.96	755.0	-0.61	.545	-0.14	576.5	-3.30	.001	-0.75
Fixation Transitions	479.0	-4.26	< .001	-1.01	482.0	-2.91	.004	-0.69	693.0	-2.04	.042	-0.45
Fixation Duration (ms)	675.0	-2.67	.008	-0.59	508.0	-2.66	.008	-0.63	908.0	-0.20	.844	-0.04
Autofixations	744.0	-2.40	.016	-0.52	735.0	-0.79	.427	-0.18	603.5	-3.07	.002	-0.69
Initial Fixation (ms)	878.0	-1.03	.305	-0.22	753.0	-0.26	.799	-0.06	798.0	-1.14	.255	-0.25
Background Gaze Duration (ms)	498.0	-4.10	< .001	-0.96	578.0	-2.06	.049	-0.48	646.0	-2.44	.015	-0.54
Correct Stimulus Gaze (ms)	593.0	-3.47	.001	-0.78	584.0	-2.06	.039	-0.47	701.0	-1.97	.049	-0.43
Incorrect Stimulus Gaze (ms)	345.0	-5.45	< .001	-1.39	397.0	-3.86	< .001	-0.96	679.0	-2.16	.031	-0.48
Correct/Incorrect Gaze Ratio	288.0	-5.90	< .001	-1.57	241.0	-5.27	< .001	-1.47	904.0	-0.02	.983	-0.00
Focus Right-Stimulus Trials	624.5	-3.34	.001	-0.74	704.5	-0.90	.368	-0.20	645.0	-2.57	.010	-0.57
Focus Right-Forced-Choice Trials	852.5	-1.55	.121	-0.33	790.0	-0.08	.938	-0.02	781.0	-1.43	.154	-0.31

Note. TOMM1 = Test of Memory Malingering–Trial 1; TOMM2 = Test of Memory Malingering–Trial 2; Autofixation = first oculomotor event was an immediate fixation; Focus Right = First and final fixations are on the stimulus image.

1. All oculomotor events reflect per trial averages.

Table 5a. *Kruskal-Wallis Group Comparisons of TOMM Performance for HC (n = 50), SIM (n = 42) and TBI (n = 39) Groups: Background Gaze Duration, Correct and Incorrect Stimulus Gaze Durations, and Focus-Right Trials – Component Scores.*

	HC	*SIM*	*TBI*				*Kruskal-Wallis*		
Variable	*Mean Rank*	*Mean Rank*	*Mean Rank*	*M*	*SD*	*Range*	$X^2(2)$	*p*	Mann-Whitney Contrasts[2]
Background Gaze Duration (ms)	48.4	81.8	66.7	300	239	24 – 2120	18.30	.001	SIM > TBI > HC
Stimulus TOMM 1	53.4	72.8	66.6	425	363	12 - 2629	6.46	.040	SIM = TBI > HC
Forced-Choice TOMM 1	44.5	82.6	72.1	165	183	0 - 1594	25.36	< .001	SIM > TBI > HC
Stimulus TOMM 2	53.4	71.4	63.0	494	448	32 - 2873	5.56	.062	SIM = TBI = HC
Forced-Choice TOMM 2	48.3	78.9	65.8	131	154	0 - 1402	15.83	< .001	SIM = TBI > HC
Stimulus TOMM 1&2	54.2	75.3	67.7	458	377	22 - 2751	7.44	.024	SIM = TBI = HC
Forced-Choice TOMM 1&2	45.0	81.3	67.4	148	164	0 - 1499	22.69	< .001	SIM > TBI > HC
Correct Stimulus Gaze (ms)	51.4	80.5	65.4	652	261	0 – 1879	13.68	.001	SIM > TBI > HC
Forced-Choice TOMM 1	52.4	77.4	68.0	722	269	0 - 1654	10.37	.006	SIM = TBI > HC
Forced-Choice TOMM 2	51.0	80.3	61.0	574	286	0 - 2105	14.56	.001	SIM > TBI = HC
Incorrect Stimulus Gaze (ms)	45.9	90.8	61.1	592	307	0 – 2129	33.27	< .001	SIM > TBI > HC
Forced-Choice TOMM 1	47.6	88.1	61.9	637	298	0 - 1700	27.00	< .001	SIM > TBI > HC
Forced-Choice TOMM 2	45.0	87.6	61.9	537	333	0 - 2419	30.16	< .001	SIM > TBI > HC
Focus Right-Stimulus Trials	80.1	53.1	59.9	16.2	8.0	2 – 38.0	12.88	.002	HC > TBI = SIM
Stimulus TOMM 1	78.5	57.6	57.1	31.7	11.2	3 - 49	9.66	.008	HC > SIM = TBI
Stimulus TOMM2	79.8	50.8	63.0	28.5	12.1	3 - 49	13.77	.001	HC > TBI = SIM

Note. TOMM1 = Test of Memory Malingering–Forced-Choice Trial 1; TOMM2 = Test of Memory Malingering–Forced-Choice Trial 2; Autofixation = first oculomotor event was an immediate fixation; Focus Right = First and final fixations are on the stimulus image.

1. All oculomotor variables reflect events per trial.
2. Mann-Whitney post hoc tests, $p < .05$ criterion.

Table 5b. *Mann-Whitney Group Comparisons of TOMM Performance for HC (n = 50), SIM (n = 42) and TBI (n = 39) Groups: Background Gaze Duration, Correct and Incorrect Stimulus Gaze Durations, and Focus-Right Trials – Component Scores.*

	HC-SIM				SIM-TBI				HC-TBI			
Variable	*U*	*Z*	*p*	*d*	*U*	*Z*	*p*	*d*	*U*	*Z*	*p*	*d*
Background Gaze Duration (ms)	498.0	-4.10	< .001	-0.96	578.0	-2.06	.049	-0.48	646.0	-2.44	.015	-0.54
Stimulus TOMM 1	634.0	-2.58	.010	-0.58	701.0	-0.60	.552	-0.14	754.0	-1.55	.120	-0.34
Forced-Choice TOMM 1	430.0	-4.77	< .001	-1.16	660.0	-1.33	.184	-0.30	525.0	-3.47	.001	-0.80
Stimulus TOMM 2	690.0	-2.26	.024	-0.50	595.0	-1.12	.265	-0.26	699.0	-1.30	.194	-0.29
Forced-Choice TOMM 2	490.0	-3.91	< .001	-0.92	567.0	1.61	.108	0.38	650.0	-2.24	.025	-0.50
Stimulus TOMM 1&2	686.0	-2.58	.010	-0.57	695.0	1.01	.314	0.23	744.0	-1.78	.076	-0.39
Forced-Choice TOMM 1&2	405.0	-4.62	< .001	-1.13	557.0	-1.71	.087	-0.40	574.0	-2.90	.004	-0.66
Correct Stimulus Gaze (ms)	593.0	-3.47	.001	-0.78	584.0	-2.06	.039	-0.47	701.0	-1.97	.049	-0.43
Forced-Choice TOMM 1	649.0	-3.03	.002	-0.67	656.0	-1.37	.171	-0.31	694.0	-2.03	.043	-0.45
Forced-Choice TOMM 2	520.0	-3.66	< .001	-0.85	484.0	-2.47	.014	-0.59	742.0	-1.44	.151	-0.31
Incorrect Stimulus Gaze (ms)	345.0	-5.45	< .001	-1.39	397.0	-3.86	< .001	-0.96	679.0	-2.16	.031	-0.48
Forced-Choice TOMM 1	406.0	-4.96	< .001	-1.22	450.0	-3.35	.001	-0.81	701.0	-1.97	.049	-0.43
Forced-Choice TOMM 2	341.0	-5.16	< .001	-1.32	377.0	-3.58	< .001	-0.90	640.0	-2.32	.020	-0.52
Focus Right-Stimulus Trials	624.5	-3.34	.001	-0.74	704.5	-0.90	.368	-0.20	645.0	-2.57	.010	-0.57
Forced-Choice TOMM 1	711.5	-2.66	.008	-0.58	791.0	-0.07	.946	-0.02	639.5	-2.62	.009	-0.58
Forced-Choice TOMM2	598.0	-3.55	< .001	-0.80	631.0	-1.61	.107	-0.37	689.0	-2.20	.028	-0.48

Note. TOMM1 = Test of Memory Malingering–Trial 1; TOMM2 = Test of Memory Malingering–Trial 2; Autofixation = first oculomotor event was an immediate fixation; Focus Right = First and final fixations are on the stimulus image.

1. All oculomotor events reflect per trial averages.

Table 6. *Logistic Regressions: TOMM Predicting SIM and TBI Group Membership*.

	$X^2(1)$	*p*	*Odds Ratio*	*Nagelkerke* R^2	AUC	AUC 95% CI
Variable						
TOMM2 Forced-Choice Correct	47.69	< .001	0.02	.61	.86	[.77, .95]
Gaze Transitions[1]	1.29	.256	0.96	.02	.54	[.41, .67]
Fixation Transitions	11.33	.001	0.23	.18	.69	[.57, .81]
Fixation Duration (ms)	7.77	.005	1.00	.13	.67	[.55, .79]
Autofixations	0.47	.494	0.31	.01	.55	[.43, .68]
Initial Fixation (ms)	0.08	.778	1.00	.00	.52	[.39, .65]
Background Gaze Duration (ms)	0.63	.427	1.00	.01	.63	[.51, .75]
Correct Stimulus Gaze (ms)	8.05	.005	1.00	.13	.63	[.51, .76]
Incorrect Stimulus Gaze (ms)	21.26	< .001	1.00	.31	.75	[.65, .86]
Correct/Incorrect Gaze Ratio[1]	20.26	< .001	3.27	.40	.81	[.71, .91]
Focus Right-Stimulus Trials	0.69	.406	1.01	.01	.56	[.43, .69]
Focus Right-Forced-Choice Trials	0.00	.985	1.00	.00	.53	[.40, .66]

1. Variable was recoded into four categories (ratio < 1, to 1.1, to 1.2, > 1.2) due to model instability.

Table 7. *Two-Variable Logistic Regressions: TOMM Accuracy Predicting SIM and TBI Group Membership with Oculomotor Covariates.*

	$X^2(2)$ Total Model	$X^2(1)$ Step	*Wald*[1]	*p*[1]	*Odds Ratio Oculomotor*	*Nagelkerke* R^2	AUC *Oculomotor (Total Model)*	AUC 95% CI
Variable								
TOMM2*Fixation Transitions	46.73	7.69**	5.79	.016	0.14	.68	.69 (.92)	[.87, .98]
TOMM2*Fixation Duration (ms)	48.22	1.49	1.44	.231	1.00	.62	.67 (.86)	[.80, .97]
TOMM2*Correct Stimulus Gaze (ms)	49.71	2.98	2.65	.103	1.00	.63	.63 (.89)	[.81, .97]
TOMM2*Incorrect Stimulus Gaze (ms)	50.91	4.18*	3.56	.059	1.00	.65	.75 (.89)	[.82, .97]
TOMM2*Correct/Incorrect Gaze Ratio[2]	47.62	1.68	1.91	.153	1.63	.62	.81 (.89)	[.91, .97]

Note. TOMM2 = Test of Memory Malingering–Trial 2; Autofixation = first oculomotor event was an immediate fixation; Focus Right = First and final fixations are on the stimulus image.

1. Wald statistic for Step 2, unique variance added by the oculomotor variable.
2. Variable was recoded into four categories (ratio < 1, to 1.1, to 1.2, > 1.2) due to model instability.

*$p < .05$; **$p < .01$.

APPENDIX B

FIGURES

Figure 1. Example of stimuli trial AOI locations and categorical labels.

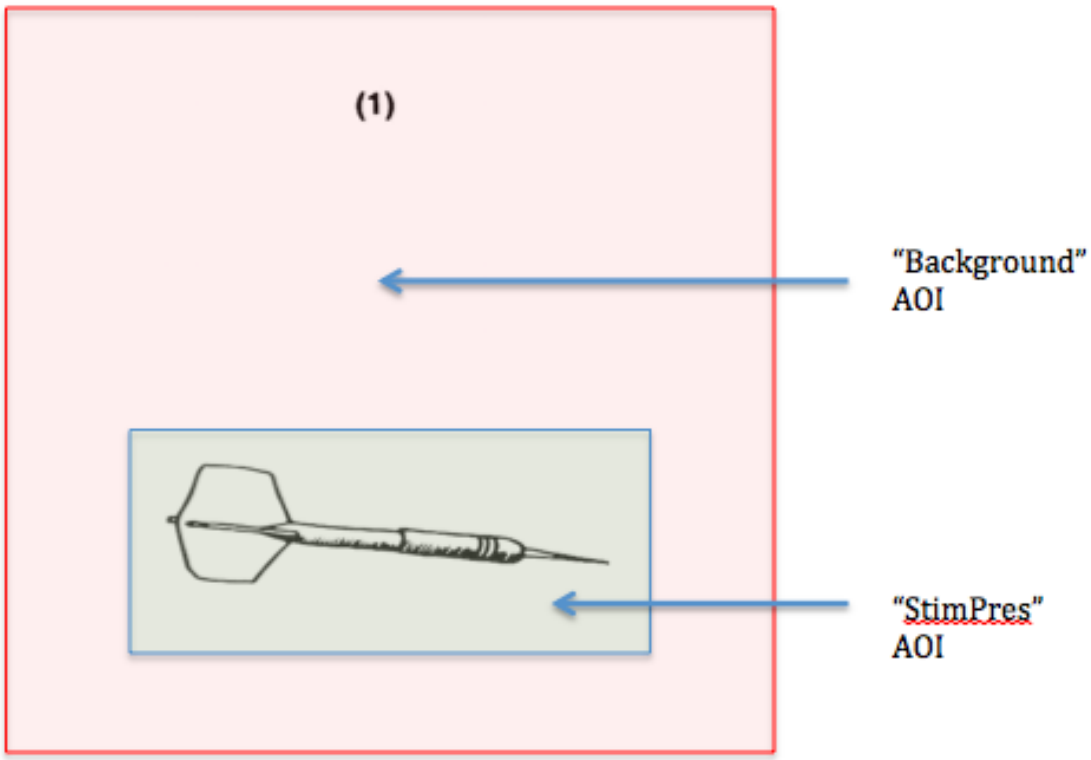


Figure 2. Example of forced-choice trial AOI locations and categorical labels..

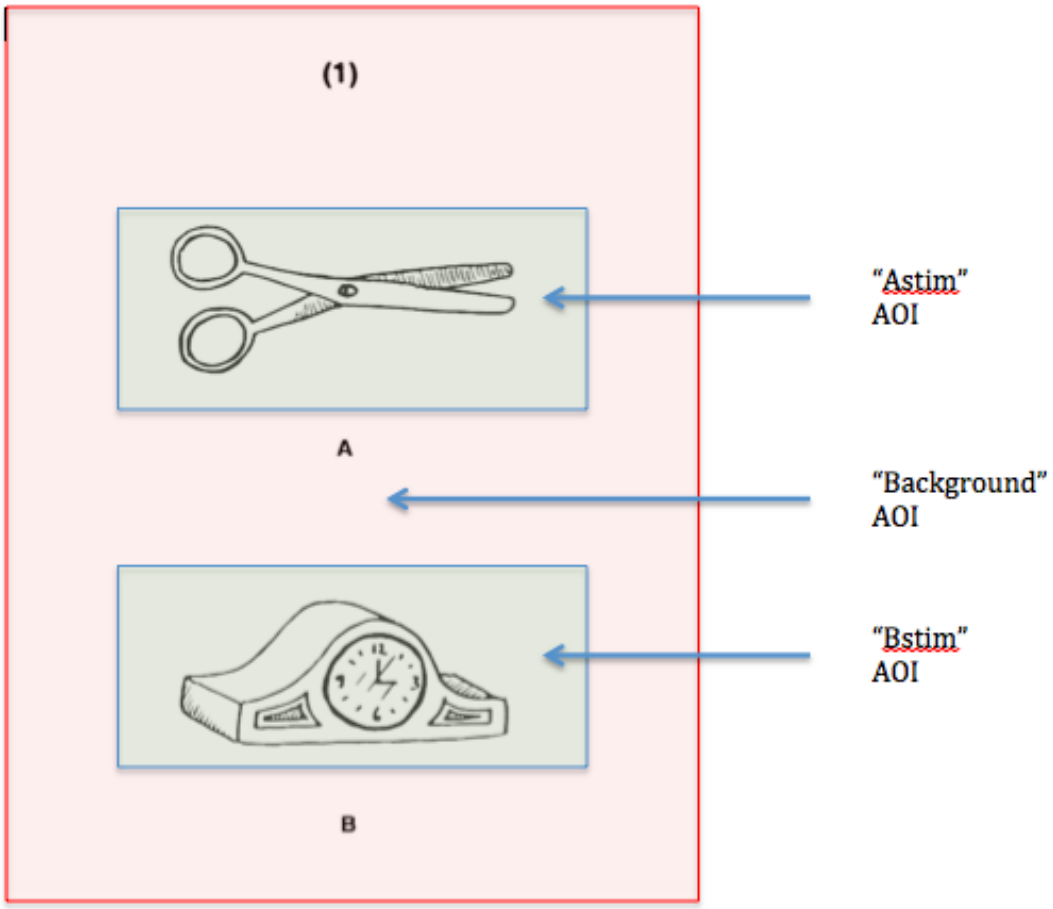


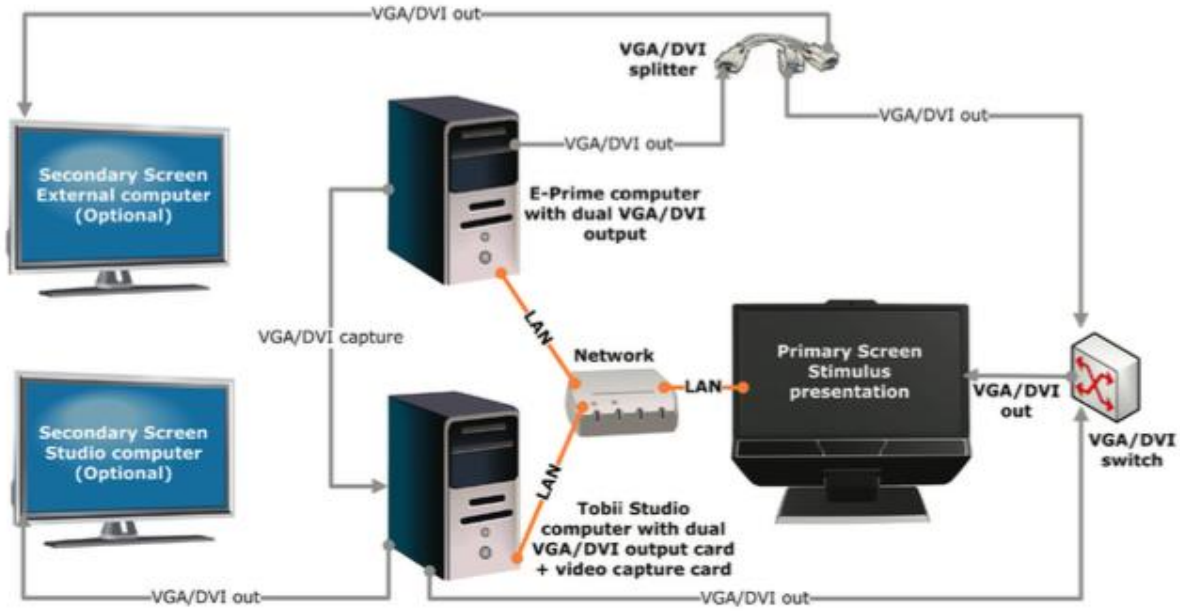
Figure 3. Integrated screen positioning.

Note: Taken from Tobii TX-300 Eye Tracker User Manual (Tobii Technologies, 2011).

Figure 4. Two-computer set up for Tobii TX-300 integration with Tobii Studio and E-Prime Extensions for Tobii.

Two-computers setup

In a two-computer setup you will use Tobii Studio to record the gaze data and E-Prime® to present the stimulus. The E-Prime® software and Tobii Studio software are run on two different computers and communicate with the Tobii Eye Tracker Server as well as between each other over a LAN network (TCP/IP protocol).



The image from the Tobii Studio computer has to displayed on the Tobii Eye Tracker's display during calibration (to display the calibration points), whereas the E-Prime® computer should be shown on the Tobii Eye Tracker's display during the actual test. Therefore, both computers have to be connected to the Tobii Eye Tracker's display. Two secondary screens can be added to the setup to enable the eye tracker operator to monitor the progress of the trial during the stimulus presentation and recording.

The image or video presented by E-Prime® on the eye tracker's display also has to be recorded by Tobii Studio and synchronized with the gaze data. The image or video recording is done via a video capture card installed on the Tobii Studio computer. As a result, the display output of the E-Prime® computer needs to be split in two connections: one to the eye tracker's display and another to the video capture card on the computer running Tobii Sudio.

Note: Taken from Tobii TX-300 Eye Tracker User Manual (Tobii Technologies, 2011).

APPENDIX C

INTRODUCTION TO THE EXPERIMENT

"Welcome to our lab. I would like to thank you for your voluntary participation in this study. As you recall from the informed consent you signed a few moments ago, we are interested in studying memory by using a number of psychological tests. However, we will also be using a video system to gather information about how you view the tests. The equipment we will be using is called an eye-tracking camera. This camera will be following your eye movements as you take the tests. In order for us to obtain the most accurate video, we will be asking you to participate in a quick calibration test that requires you to look at a few different points on the screen for about 10 to 30 seconds. Also, it's very important that you are seated in a position in which the camera can see your eyes. So, before we begin, I will be measuring the distance of your eyes from the camera and I may ask you, or help you if needed, to adjust your seat up or down. This camera is quite powerful; therefore, it allows you to move a fair bit before calibration is lost. Despite this, I would ask that you attempt to remain positioned as still as is comfortable for you. If you become tired during the tasks, please let me know so that I can pause the procedure and allow you to become more comfortable. If this request is made, we may have to recalibrate the system. At any point during the tests, the camera may lose calibration. I will be monitoring its performance on the computers located behind you. If I find that calibration is lost, I may ask you to pause what you are doing so that I can re-run the calibration process. Do you have any questions before we begin?"

APPENDIX D

SIMULATOR ACCIDENT SCENARIO (ADAPTED FROM: TOMBAUGH, 1997)

"In this study you will be asked to complete several tasks that are often used to measure a variety of changes that occur in people who have brain damage. As you take each test, I would like you to assume the role of someone who has experienced some brain damage from a car accident.

Pretend that you were involved in a head-on collision. You hit your head against the windshield and were unconscious for 15 minutes. You were hospitalized overnight for observation and then released. Gradually, over the past few months, you have started to feel normal again. However, your lawyer has informed you that you may obtain a larger settlement from the court if you look like you are still suffering from brain damage. Therefore, you should pretend that the symptoms have persisted and that they still significantly interfere with your life.

As you portray the above person, try to approach each test as you imagine this person would respond if the individual had been given the same instructions from his or her lawyer. Perform on the tests in such a way as to convince the examiner that you are truly brain damaged, keeping in mind that settlement monies depend upon your being diagnosed as cognitively impaired. Also be aware that having a lawsuit pending often raises the suspicion that people may try to exaggerate their difficulties. This means that your impairments resulting from the head injury must be believable. Major exaggerations, such as not being able to do anything, remembering absolutely nothing, or failing to respond are easy to detect."

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ABSTRACT

PERFORMANCE VALIDITY ASSESSMENT OF BONA FIDE AND MALINGERED TRAUMATIC BRAIN INJURY USING NOVEL EYE-TRACKING SYSTEMS

by

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Major: Psychology (Clinical)

Degree: Doctor of Philosophy

Purposeful presentation of neurocognitive impairment (i.e., dissimulation) in assessment of brain injury is a primary pitfall to accurate psychological assessment, especially among individuals seeking compensation. Current methods used to evaluate effort test failure (EFT; Webb et al., 2012) and dissimulation in brain injury assessment has advanced over the past few decades, but remains unacceptably inaccurate. In diagnostic decision-making, current methods identify obvious cases of purposefully poor performance, but they are considerably less accurate in subtle cases typically seen clinically; more important, they are vulnerable to coaching. Oculomotor behavior during visual tasks may be a promising avenue in the assessment of performance validity. Oculomotor patterns observed after brain injury have been well documented, and patterns characteristic of normal decision-making have been studied in healthy adults, but findings from these endeavors have not been applied to performance validity assessment. Accordingly, this study evaluated contributions of oculomotor patterns to detection of purposeful poor performance using state-of-the-science eye-tracking equipment by studying the predictive ability of a gold-standard performance validity test: The Test of Memory

Malingering (TOMM). The study examined 39 adults with moderate to severe traumatic brain injury (TBI), 42 healthy adults coached to simulate memory impairment (SIM), and 50 healthy adults providing full effort (HC). The results supported the main hypothesis: One index derived using oculomotor patterns of performance provided a reliable increase to the predicative accuracy of the TOMM in differentiating bona fide TBI from simulated TBI. Numerous other oculomotor indexes showed promise, both in their relationships to key cognitive constructs and in their ability to differentiate dissimulation from healthy adults and bona fide TBI. The predicative ability of these measures was insignificant, however, due to an underpowered sample size and violations of the assumptions of pivotal statistical models. As such, future research is needed to replicate these findings and should strive to increase sample sizes to more accurately assess those visual patterns that showed predictive potential.

AUTOBIOGRAPHICAL STATEMENT

Education

August 2012	**Master of Arts** Wayne State University, Detroit, Michigan Thesis: Detecting suboptimal effort in traumatic brain injury assessment Faculty Advisor(s): Lisa Rapport, Ph.D.
June 2005	**Bachelor of Arts** University of California, Santa Cruz, California Major: Psychology & Philosophy

Clinical Experience

September 2014 – August 2015	West Los Angeles VA Healthcare Center Pre-doctoral Internship, Neuropsychology, Rehabilitation, Health
September 2013 – July 2014	University of Michigan Department of Psychiatry Neuropsychological assessments, bariatric surgery assessments
August 2008 – July 2014	Wayne State University Psychology Clinic Individual Psychological Assessment, Individual & Group Therapy
September 2012 – August 2013	DMC Life Stress Center Psychotherapy to victims of criminal acts (VOCA)
September 2010 - August 2011	Psychology Intern, Center for Forensic Psychiatry Admissions Unit Treatment Team, psychological testing
March 2009 – April 2010	Neuropsychological Assessment of Traumatic Brain Injury Rehabilitation Institute of Michigan, Detroit, MI

Research Experience

January 2015 – August 2015	Predoctoral Intern Research Associate, Advisor: Donna Ames, MD Comprehensive Patient Rating Scale methodology & efficacy study
March 2009 – Present	Research Assistant, Advisee Lisa Rapport, Ph.D., Professor, Clinical Psychology Wayne State University, Detroit, Michigan

Competitive Funding and Awards

2013 & 2012	Association of Test Publishers Certificate of Merit
2013	Thomas C. Rumble Fellowship – Wayne State University
2012 & 2010	APA – Division 12 (Clinical Psychology) Research Travel Grant,
2011	APA Science Graduate Student Superstars – Datablitz
2011	APA Division 40 Applied Neuropsychology Student Poster Award
2008	Thomas C. Rumble Fellowship – Wayne State University