1-1-2011

Awareness of deficits and on-road driving performance among persons with acquired brain injury

Julie Ann Griffen
Wayne State University,

AWARENESS OF DEFICITS AND ON-ROAD DRIVING PERFORMANCE AMONG PERSONS WITH ACQUIRED BRAIN INJURY

by

JULIE A. GRIFFEN

DISSERTATION

Submitted to the Graduate School

of Wayne State University,

Detroit, Michigan

In partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

2011

MAJOR: PSYCHOLOGY (Clinical)

Approved by:

____
Advisor   Date

____

____

____

ACKNOWLEDGMENTS

I would like to acknowledge several individuals who were essential to the completion of this dissertation. I would like to thank my advisor, Dr. Lisa Rapport, for her dedication in assisting and guiding me through this project. She has worked tirelessly to help me and her other students meet their goals and succeed in graduate school and beyond. Also, I would like to acknowledge my committee members, Drs. Douglas Whitman, Linas Bieliauskas, Renee Bryer, and Brad Axelrod for their helpful feedback during this project. I would also like to express my appreciation to Carolyn Scott and Laura Hill, whose teamwork and assistance in data collection was invaluable. Additionally, I would like to thank Cindi Burt, the driving evaluator, for devoting many weekends to data collection and maintaining a flexible schedule. I am also deeply appreciative to all of the research participants who willingly gave of their time to promote better understanding of driving after acquired brain injury. I would like to acknowledge my family and friends for their emotional support and encouragement. My husband, Jason, and son, Gavin, have been overwhelmingly supportive and patient with me during this project, which has been greatly appreciated. Lastly, I would like to thank God for His constant strength, peace, and everlasting love which has given me the fortitude to pursue and complete this degree and project.

TABLE OF CONTENTS

Acknowledgements ii

List of Tables.. v

Chapter 1 Introduction.. 1

Assessing Fitness to Drive.. 2

On-road Evaluations.. 2

Neuropsychological Evaluations.. 4

Awareness of Deficits 7

Awareness of Deficits & Fitness to Drive 12

Compensatory Strategies 15

Summary and Purpose 17

Hypotheses... 18

Chapter 2 Methods.. 20

Participants 20

Measures 21

Barriers to Driving Questionnaire & Driving Survey 21

The Awareness Questionnaire 22

On-road Evaluation... 23

Neuropsychological Functioning... 24

Procedure 27

Chapter 3 Results... 28

Hypothesis 1a 29

Hypothesis 1b 31

Hypothesis 2a 32
Hypothesis 2b 34
Hypothesis 3 35
Hypothesis 4 38
Chapter 4 Discussion 39
Awareness of Deficits and On-Road Performance 39
Compensatory Strategies 42
Self-assessment and Predictions of Driving Performance………………........ 44
Healthy Controls and Driving Performance 47
Conclusions, Limitations, and Future Research 49
Appendix A 52
References 60
Abstract 73
Autobiographical Statement 75

LIST OF TABLES

Table 1: Descriptive Statistics: Demographics of Participants with Acquired Brain Injury... 52

Table 2: Descriptive Statistics: Characteristics of Survivors Grouped by Level of Awareness of Deficits: Hypervigilant (n = 17), Intact Awareness (n = 24), Impaired Awareness (n = 21), and Control (n = 40). 53

Table 3: Descriptive Statistics: Characteristics of Survivors Grouped by Level of Awareness of Deficits: Hypervigilant (n = 17), Intact Awareness (n = 24) and Impaired Awareness (n = 21). 54

Table 4: Pearson Correlations: Awareness of Deficits with On-road Outcomes among ABI Survivors. 55

Table 5: Pearson Correlations among all ABI Survivors (n = 62). 56

Table 6: Multiple Regression Analysis of Moderation Effect: Interaction between Awareness of Deficit and Neuropsychological Performance Predicting (Log of) On-road Driving Performance among ABI Survivors. 57

Table 7: Pearson Correlations: Neuropsychological Tests with Driving Outcomes for ABI Survivor Groups and Controls. 58

Table 8: Pearson Correlations: Ratings of Driving Ability and Self-Limitations with On-road Outcomes among ABI Survivors and Controls. 59

CHAPTER 1 INTRODUCTION

Driving a motor vehicle is essential to functional independence, as it enables access to work, shopping, health care, and social activities (Bodenheimer, Roig, Worsowicz, & Cifu, 2004; Marshall et al., 2007, O'Neill, 2000; Poole, Chaudry, & Jay, 2008; & Ragland, Satariano, & MacLeod, 2005). Most adults are understandably resistant to cease or restrict their driving because of the subsequent loss of autonomy, spontaneity, and flexibility. Driving was rated by community dwelling elderly as the second most important activity of daily living, preceded only by telephone use (Fricke & Unsworth, 2001). Driving represents cherished independence and is a sign of health and well-being, and retaining the ability to drive is an important health concern (Edwards, Perkins, Ross, & Reynolds, 2009). Approximately 40-60% of acquired brain injury (ABI) survivors, including stroke (Griffen, Rapport, Coleman Bryer, & Scott, 2009; Heikkila, Korpelainen, Turkka, Kallanranta, & Summala, 1999) and traumatic brain injury (TBI) (Coleman, Rapport, Ergh, Hanks, Ricker, & Millis, 2002; Fisk, Schneider, & Novack, 1998; Schanke & Sundet, 2000), regain their drivers' licenses and resume driving. Nearly two-thirds, however, do not complete a driver's evaluation to assess their driving abilities prior to returning to driving (Fisk, Schneider, & Novack, 1998). Even following ABI, many survivors resume driving without increased risk of injury or accident (Schultheis, Matheis, Nead, & DeLuca, 2002). Awareness of cognitive and physical limitations may invoke use of compensatory strategies to promote safe resumption of driving. Understanding the links between awareness of deficits, use of compensatory strategies, and driving performance will enable better prediction of safe drivers following ABI.

Driving is a complex task requiring the use of multiple cognitive abilities in addition to adequate visual acuity and motor function (Lister, 1999; Lundqvist & Ronnberg, 2001; Marshall et al., 2007). Cognitive functions necessary for safe driving include sustained and divided attention, visual perception, judgment, and executive control. In order to drive safely, a person must be able to make automatic motor responses with a quick response time, be flexible with different circumstances, and have quick judgment to deal appropriately with difficult traffic situations (Lundqvist & Ronnberg, 2001). Galski, Bruno, and Ehle (1992) developed a dynamic model of driving for ABI survivors that includes the interaction of sensory input, information processing, driving experience, and motor skills. When ABI results in impairments in any of these components, driving safety may be compromised. Yet, many survivors of ABI are fit to drive in spite of cognitive and perceptual impairments (Brouwer & Withaar, 1997). Awareness of these impairments may be the key to safe driving following brain injury. Because driving is an important part of independence in our society and cessation of driving is undesirable for most people, it is important to understand as much as possible about what is required for safe driving, including awareness of deficits following ABI and use of compensatory strategies.

Methods for Assessing Fitness to Drive

<u>On-road Evaluations</u>

The on-road evaluation is considered the gold standard method for assessing fitness to drive in persons with disability (Fox, Bowden, & Smith, 1998; Galski, Bruno, & Ehle, 1992; Reger, Welsh, Watson, Cholerton, Baker & Craft, 2004). On-road driving tests are the most ecologically valid assessment of driving abilities. A driving evaluator can observe the patient in a variety of driving situations, such as parking lots, residential streets, expressways, and high traffic volumes, in order to gather a well-rounded perspective on the patient's driving abilities and risky behaviors. Limitations of on-road tests include uncontrollable traffic and road conditions, as well as the cost of evaluations; however, the main limitation is the insufficient volume and inadequate design of research on the reliability, validity, and standardization of the on-road evaluation (Fox, Bowden, & Smith, 1998; Reger et al., 2004). Lundqvist, Gerdle, and Ronnberg (2000) found excellent inter-rater reliability (r =.96) for driving inspectors conducting driving evaluations. In a recent study of 100 older adults, Rasch analysis showed good evidence of inter-rater reliability and construct validity and some evidence for internal reliability of an on-road driving evaluation (Kay, Bundy, Clemson, & Jolly, 2008). Despite potential variability in on-road evaluations, they are still viewed as the optimal driving assessment and are regularly used by rehabilitation facilities because actual on-road driving is the most ecologically valid means of assessing fitness to drive.

As compared to actual on-road driving tests, driving simulators afford advantages such as standardized stimuli and control of variables such as traffic. Simulation technologies can be used to present test reaction to difficult challenges that could not be safely or consistently presented in a real-world road test (Bieliauskas, 2005). However, realistic simulation technologies are unlikely to be adopted at the clinical level in a widespread manner because they are very costly, and research on the predictive validity of simulators is very sparse.

On-road evaluations typically include assessment of pre-driving activities, including fastening seatbelt and adjusting seat and mirrors; driving activities, such as lane placement, use of turn signals, and parking; and behavior, including impulsivity and distractibility (Galski, Bruno, & Ehle, 1992). The evaluations can occur in closed courses, on city streets and highways, or a combination of these settings.

An important and surprising observation regarding research examining on-road driving evaluations is that very few studies have included a healthy control group. The studies that have included control groups have either been with very small sample sizes or on closed road courses. The inclusion of a healthy control group is valuable in that it can account for any potential rater bias towards the resumption of driving following an ABI. Additionally, a healthy control group sets normative standards and expectations for on-road driving evaluation performances.

Neuropsychological Evaluations

Neuropsychological tests have been shown to be good predictors of driving performance and driving outcomes in TBI (e.g., Coleman et al, 2002; Galski, Bruno, & Ehle, 1992), stroke (e.g., Heikkilä, et al., 1999; Lundqvist, Gerdle & Ronnberg, 2000), multiple sclerosis (MS) (Ryan et al., 2009), community-dwelling older adults (see Clay, Wadley, Edwards, Roth, Roenker, & Ball, 2005 for review), and dementia (see Reger et al., 2004 for review), as well as in studies combining mixed neurological populations (Schanke & Sundet, 2000). Type and degree of cognitive impairment, as measured by neuropsychological tests, have been shown to be better predictors of actual driving performance than are age or medical diagnosis among individuals with dementia (Fitten et al., 1995). In contrast, some studies have not found a relationship between neuropsychological test performance and driving outcomes (Bieliauskas, Roper, Trobe, Green, & Lacy, 1998; Fox, Bowden, Bashford, & Smith, 1997; Trobe, Waller, Cook-Flannagan, Teshima, & Bieliauskas, 1996; Withaar, Brouwer, & Van Zomeren, 2000).

These mixed findings regarding the utility of neuropsychological tests in predicting driving outcomes following ABI can be explained in a number of ways, including variation in test batteries utilized and driving outcomes chosen (e.g., DMV records, on-road evaluations, etc.; Coleman et al., 2002; Ryan et al., 2009). At least one study reported that when specific domains of neuropsychological functioning are used, predictions are improved as compared to using a global composite. A meta-analysis of outcomes for elderly drivers by Anstey, Wood, Lord, and Walker (2005) showed moderate to high associations for visuospatial abilities, as well as aspects of executive function and complex visual attention (e.g., UFOV), and small effects or mixed findings for other domains, including processing speed, reaction time, vision, and hearing. The most commonly implicated neuropsychological domains predictive of driving outcomes across a variety of patient populations include: visuospatial ability (Korteling & Kaptein, 1996; Meyers, Volbrecht, & Kaster-Bundgaard, 1999; Reger et al., 2004), complex visual attention (Clay et al., 2005 for review; Cushman & Cogliandro, 1999; Goode et al., 1998; Mazer, Sofer, Korner-Bitensky, Gelinas, Hanley, & Wood-Dauphinee, 2003), and executive functioning (Coleman et al., 2002; Lundqvist, Gerdle, & Ronnberg, 2000; Lundqvist, Alinder, Alm, Gerdle, Levander, & Ronnberg, 1997; Mazer, Korner-Bitensky, & Sofer, 1998; Ott, Heindel, Whelihan, Caron, Piatt, & DiCarlo, 2003; Radford & Lincoln, 2004; Schanke & Sundet, 2000).

The predictive value of neuropsychological tests on driving performance may vary depending on the type of driving outcome that has been chosen, such as non-road tests, on-road tests, and DMV records. For example, Reger et al. (2004) reported that neuropsychological tests correlated poorly with on-road tests and higher mean effect sizes were found with non-road tests in their meta-analysis of patients with dementia. They asserted that the difference may reflect that non-road tests are more standardized than the more ecologically valid on-road tests. Additionally, as participants are less familiar with non-road tests (e.g., simulators), their cognitive flexibility and executive functioning may be taxed to a greater extent than in the on-road evaluation. Thus, the authors acknowledged that the higher effect sizes could be an artifact of the failure of the dementia patients to adjust to the unfamiliar testing procedures. On-road tests are less standardized, as the driving evaluator cannot control traffic, construction, and other drivers' behaviors; yet, on-road evaluations can have adequate reliability within the context of real time driving (Kay et al., 2008; Lundqvist, Gerdle, & Ronnberg, 2000).

Another possible reason for the mixed results is the failure to account for awareness of deficits among those desiring to resume driving. The majority of studies assessing the relationship between neuropsychological performance and driving ability have focused primarily on visuospatial abilities, attention, reaction time, processing speed and memory. Despite the fact that leading theories of fitness to drive include executive functioning as an essential component, many studies fail to include this domain and its subparts, including awareness of deficits and judgment. For example, Michon (1985) proposed a theory of driving behavior including three levels of decision making involved in safe driving. The *strategic level* involves decisions regarding the planning of safe driving, which utilizes executive functioning, judgment, and memory. The *tactical level* involves decisions about present driving situations and anticipatory responses that require cognitive control and flexibility. The *operational level* consists of the basic driving skills, including automatic responses, immediate reactions, and perceptual speed. Although Michon's proposal posited that the three levels were of equal importance, most of the research has focused on the operational and tactical levels, neglecting the more complex strategic level. Studies that have included measures that require use of executive functions, such as the Trail Making Test and Stroop Test, have found significant relationships between test performance and driving abilities (Coleman et al., 2002; Heikkilä et al., 1999; Lundqvist, Gerdle, & Ronnberg, 2000; Lundqvist et al, 1997; Mazer, Korner-Bitensky, & Sofer, 1998; Ott et al., 2003; Radford & Lincoln, 2004). It is likely that the predictive value of neuropsychological tests would be improved if the patient's level of awareness of their deficits was considered.

Awareness of Deficit

Being aware of personal deficits requires executive functioning, including self-monitoring, judgment, reasoning, and ability to benefit from feedback. Prigatano and Schacter (1991) have defined self-awareness as "the capacity to perceive the 'self' in relatively 'objective' terms whilst maintaining a sense of subjectivity" (p. 13). In contrast, unawareness of deficits reflects "an impairment in the patient's ability to consciously represent (perceive and experience) a disturbance in higher cerebral functioning- a disruption in the integration of thinking and feeling" (Prigatano & Klonoff, 1998, p. 57). Unawareness of one's limitations is a common occurrence in people with ABI, including stroke, TBI, Alzheimer's disease (Prigatano, 2005), and MS (Ryan et al., 2009). This lack of insight into their current functional abilities or disabilities does not necessarily imply an indifference to or denial of their symptoms. Indifference or lack of concern is indicative of a diminished affective response to illness or injury, and denial reflects a defense or coping mechanism aimed to alleviate distress given subconscious awareness of a problem or deficit (Giacino & Cicerone, 1998; McGlynn & Schacter, 1989). Anosognosia is a term that can appropriately be interchanged with unawareness of deficit; it means “without knowledge of disease” (Hartmann-Maeir, Soroker, Oman, & Katz, 2003). “Anosognosia” was first coined by Babinski (1914; as cited in Vuilleumier, 2004) to describe an individual’s lack of knowledge, awareness, or recognition of their physical disease. Anosognosia has been defined more recently as “the condition of a patient affected by a brain dysfunction who does not recognize the presence or adequately appreciate the severity of deficits in sensory, perceptual, motor, affective, or cognitive functioning evident to clinicians and caregivers” (Orfei, Robinson, Bria, Caltagirone, & Spalletta, 2008 p. 204).

Awareness of deficit can be operationalized as the difference between a person's self-assessment and those of an accurate external criterion of the person's ability. One common method of measurement employs as the external criterion a knowledgeable informant, typically a significant other (SOs) such as a spouse, family member, or close friend (Coleman et al., 2002; Prigatano, 2005). Fordyce and Roueche (1986) have shown that caregiver reports are more predictive of ABI survivors’ functioning than are the survivors’ own self-assessments of their abilities. Furthermore, agreement tends to be greater among family and clinician ratings of the survivors’ abilities than among these sources of ratings and the survivors’ self-ratings (Sherer, Bergloff, Boake, High, & Levin, 1998a).

Practically, the behavioral pattern of anosognosia following TBI, stroke, and dementia may be similar, including a complete disavowal of symptoms or partial awareness of difficulties with causal misattribution (e.g., fatigue, arthritis, etc.), poor compliance with rehabilitation, modality specificity, such that the patient is aware of functional limitations in some areas and demonstrate unawareness in others, and graded levels of severity of unawareness. Unawareness of deficit can improve, especially during the acute phases of stroke and TBI; however, it is not uncommon in the chronic stages following these events. Unawareness of deficits following TBI has been thought to be wider reaching, including motor, cognitive, affective, and behavioral problems, than in stroke, which is often considered to be primarily a lack of awareness of physical deficits. In contrast to stroke and TBI, awareness problems often increase in severity during the course of dementia (Orfei et al., 2008). Although there are similarities in anosognosia following these conditions, variability may occur in symptom presentation both between and within these disorders.

Numerous theories have been proposed postulating various mechanisms or components involved in self-awareness. These theories distinguish between psychological and neuropsychological/cognitive factors and levels of awareness. Fleming and Strong (1995) proposed three levels of awareness, including *knowledge of deficits*, *functional implications of those deficits*, and *realistic expectations* in predicting performance. Flashman, Amador, and McAllister (1998) added the concept of an *emotional response* to the deficit in their theory of self-awareness. Similarly, Allen and Ruff (1990) proposed three levels of processing that affected accuracy in self-reporting. The first level, labeled *awareness*, requires the ability to attend to, encode, and retrieve information relating to the self, which is primarily a neuropsychological process. *Appraisal*, the second level, requires the patient to compare current information about the self to premorbid self-evaluations, utilizing both emotional and cognitive factors. The third level, *disclosure*, is the patient's willingness to report self-perceptions to someone else, also mediated by both emotional and cognitive factors. Another three factor hierarchical theory of awareness was described by Crosson et al. (1989). Intellectual awareness is the first factor, which is the ability to recognize the presence of a deficit and possible implications of this impairment. The second factor is emergent awareness, which is the recognition of moment by moment awareness of functional limitations. Anticipatory awareness, the third factor, is the ability to anticipate limitations prior to their occurrence and invoke compensatory strategies as needed. These models and theories are helpful in understanding various components of awareness problems and may lead to improving rehabilitation care, but they fail to explain actual etiologies of the impairment (Orfei et al., 2008).

Hypotheses regarding self-awareness have also focused on the relationship between anosognosia and brain dysfunction. Awareness is a complex phenomenon that requires integration from several neural networks, which have most often been cited as cortical areas including the prefrontal and parieto-temporal regions, most often in the right hemisphere but sometimes bilaterally, in association with some subcortical areas, including the thalamus (Orfei et al., 2008; Prigatano, 2005; Sherer, Hart, Whyte, Nick, & Yablon, 2005). Lesions to feedback modules in areas of the association cortex may be implicated in awareness problems that are modality or domain specific, whereas lesions to central processing areas, including the frontal lobe, may results in more generalized disturbances. Damage to the connecting white matter tracts may also interfere with adequate self-awareness (Sherer et al., 2005). Damage to subcortical circuits may lead to impaired self-monitoring processes and difficulty modifying one's beliefs and behaviors based on novel experiences (Vuilleumier, 2000). The variability seen in problems with awareness (e.g., severity, modality specificity, etc.) may be due to differences in the location of the damage in these circuits (Orfei et al., 2008). Sherer et al. (2005) found that among participants with TBIs, numbers of lesions were directly associated with severity of awareness problems. Further investigation is needed in this area to further elucidate the neuropathology associated with awareness problems.

Research has also focused on the relationship between awareness and cognitive functioning and comorbid neuropsychological deficits. The domain of executive functioning has been the primary focus. It has been theorized that there is an executive or supervisory control function that directs other subordinate cognitive skills. If this executive control function is impaired and disrupts higher order cognitive processes, including self-monitoring and cognitive flexibility, deficits in self-awareness may result (Stuss, 1991). Starkstein and colleagues (1993) found that executive functioning deficits in set-shifting and flexibility were more frequent in patients with impaired self-awareness. Furthermore, scores on executive function tasks have shown stronger correlations with awareness than tests of other neuropsychological domains (Burgess, Alderman, Evans, Emslie, & Wilson, 1998).

Although executive functioning has been shown to be related to self-awareness in some studies, the findings are not conclusive. Other studies have not found associations between measures of self-awareness and performance on other executive function tasks (Bogod, Mateer, & Macdonald, 2003; Marcel, Tegner, & Nimmo-Smith, 2004).The discrepant findings regarding the relationship between awareness and measures of executive functioning may be due to the fact that they are both complicated and multifaceted constructs that can be challenging to operationally define.

No specific neuropsychological profile has been associated with problems with awareness. Anosognosia cannot be explained by a single lesion, neurological mechanism, executive function, or a simple combination of these components (Vuilleumier, 2004). Patients with awareness problems typically exhibit global cognitive deficits, including memory impairment and reduced processing speed, and it is not always clear as to how awareness is related to these comorbid impairments (Prigatano, 2005). Yet, cognitive impairments are not a prerequisite for awareness problems (McGlynn & Schacter, 1989).

Awareness of Deficit and Fitness to Drive

The presence of cognitive and physical impairments does not necessarily imply that safe driving is unfeasible (van Zomeren, Brouwer, & Minderhoud, 1987). It is the lack of insight into these impairments that poses a serious safety risk. ABI survivors with awareness problems have a particularly difficult time accepting driving restrictions or cessation that may be imposed by caregivers or physicians (Ownsworth & Fleming, 2005; Rapport, Coleman Bryer, & Hanks, 2008). In a study by Coleman et al. (2002), 41% of TBI patients with awareness problems resumed driving. Lundqvist and Alinder (2007) found that ABI survivors who failed an on-road driving test significantly overestimated their driving performance, whereas the group who passed the on-road test had self-ratings in accordance with the test results. The authors posited that persons who passed the on-road test may have also been more aware of their cognitive capacity and had a better ability to adjust their driving behaviors as compared to those who failed the evaluation; however, this hypothesis was not tested directly.

The clinical issue is then which of the cognitively and physically impaired patients are capable of safe driving. Coleman Bryer, Rapport, and Hanks (2005) described the relationship between cognitive impairment and driver safety as a curvilinear distribution. The profoundly impaired and mildly impaired groups are considered the least risky because the former group is unlikely to resume driving and the latter group is only minimally impaired. The patients between these two groups are at the greatest risk. Awareness of deficits and the ability to self-monitor may moderate the level of risk in this group of ABI survivors. Individuals that recognize their limitations may be less likely to drive in unsafe situations and beyond their capabilities, thus lowering their risk of accident.

Schanke and Sundet (2000) investigated the relationship between neuropsychological functioning, including awareness, and on-road driving performance in a group of individuals with various neurological disorders. They found that awareness of cognitive impairment showed good predictive value in discriminating between those who passed and failed the on-road evaluation. The patients with mild to moderate cognitive impairments who demonstrated awareness of their deficits passed the on-road evaluation more successfully than did patients who were unaware of their deficits. Unfortunately, this study treated awareness of deficit simply as another domain of neuropsychological functioning, not as a moderator of the risk of cognitive impairment while driving. Thus, the results do not explain why awareness of deficit enables some individuals with mild to moderate cognitive deficits to drive safely, and they do not account for the relationship between awareness and global deficits. Having awareness of deficits is just the first step towards safe driving following brain injury. With that awareness, individuals must adjust and adapt their driving habits with the knowledge of their limitations. Awareness of deficits has been defined as a mechanism for change, allowing individuals to recognize the mismatch between their skill levels, the performances expected of them, and the environmental demands of the situation (Dixon & Backman, 1999).

Rapport et al. (1993) found that measures of executive functioning were better predictors of fall risk in an inpatient setting than were measures of physical impairment or motor ability. The authors suggested that patients with considerable physical and cognitive risk factors for accidents may be at a lower risk if they appreciate the nature of their limitations and respond appropriately. In contrast, underappreciation of even mild deficits can increase risk significantly. This relationship between awareness of deficits and fall risk can be applied to driving as well. With regards to driving, awareness of cognitive, visual, and physical limitations allows an individual to self-monitor and adapt their driving behaviors to produce safe driving (Anstey et al, 2005). Thus, ABI survivors who have cognitive and physical impairments may be fit to drive if they have the capacity to recognize their deficits and cope effectively (Lundqvist & Alinder, 2007). If survivors are unaware of their deficits, they cannot invoke the appropriate compensatory strategies to produce safe driving. Rapport, Coleman Bryer, and Hanks (2008) found that TBI survivors with cognitive impairments who rated their current abilities as unchanged and high (e.g., suggesting unawareness of deficits) drove more and had more adverse driving incidents than did survivors with adequate awareness of their cognitive impairments.

Compensatory Strategies

Compensation has been defined as “the deliberate application of a procedure that enables a patient to obtain a goal the realization of which would otherwise be prevented by impaired functioning" (Crosson et al., 1989, p.46). Unawareness of deficits may reduce use of compensatory strategies which may lead to decreased benefits from rehabilitation. In their review of the literature, Ownsworth and Clare (2006) note that several studies indicate that ABI survivors with awareness problems were less likely to benefit from rehabilitation than were individuals with accurate self-assessments. Those patients with awareness deficits may have reduced motivation for therapy, resist treatment recommendations or support, set unrealistic goals, and develop and utilize fewer compensatory strategies.

The presence of awareness of deficits can moderate driving risk in individuals with mild to moderate cognitive impairments in that they recognize the need for and are able to invoke necessary compensatory strategies. In order to adequately utilize compensatory strategies, one must recognize the need for them (Lundqvist & Alinder, 2007; Rapport, Coleman Bryer, & Hanks, 2008). Compensating for residual impairments often includes strategically limiting driving exposure, such as avoiding driving at night, on freeways, during times of heavy traffic or adverse weather conditions, on long trips, and even cease driving completely (Anstey et al., 2005; Ryan et al., 2009). Anstey et al. (2005) provided an excellent example of the use of compensatory strategies while driving. They described an older individual who was aware of his impaired reaction time and slow response to traffic situations who used this knowledge to avoid driving at peak traffic times to increase safe driving. Anstey et al. contrasted this individual to one with a lack of insight into his visual deficits who continued to drive at night despite poor vision for road signs, resulting in risky driving behavior and increased accident risk. The potential for compensatory strategies to moderate accident risk has been supported by other investigators as well (e.g., Brouwer & Ponds, 1994; Lundqvist, Gerdle, & Ronnberg, 2000; Mazer, Korner-Bitensky, & Sofer, 1998).

In a study by Schultheis et al. (2002), 14.9% of drivers with TBI independently elected to not return to driving after successfully completing a comprehensive driving evaluation. The authors suggested that these results demonstrate some drivers with TBI are capable of recognizing their difficulties with resuming driving safely and subsequently invoke compensatory strategies, including elective cessation of driving. Likewise, 37.5% of the TBI survivors who did resume driving reported imposing self-limitations on their post-injury driving. van Zomeren, Brouwer, Rothengatter and Snoek (1988) also reported that the majority of their patients who had resumed driving following severe head injury stated that since their injuries they drove more carefully, including driving slower and avoiding driving at night and for long distances, in order to compensate for their assumed limitations.

Ryan et al. (2009) found substantial inverse relationships between awareness of deficit and reported use of compensatory strategies among patients with MS, meaning that drivers who were more aware of their functional deficits were more likely to utilize compensatory strategies. Interestingly, the more MS patients reported using compensatory strategies, the fewer miles they drove per week and the fewer driving incidents they experienced. This study demonstrates that awareness moderated driving outcomes (DMV records) through a relationship with compensatory strategies and driving safety among MS patients. Patients who are unaware of their deficits perceive less need to engage in compensatory strategies, which can in turn lead to increased risk for accidents.

Summary and Purpose

Driving is a complex task that requires integration of multiple cognitive and physical abilities. Assessing fitness to drive following ABI is an essential task to ensure safety on the road for both the survivor and the public. The on-road driving evaluation is considered the gold standard assessment method. Neuropsychological assessment also plays a key role in assessing fitness to drive; however, research has revealed mixed findings regarding the relationship of test performance to driving outcomes. Neuropsychological test batteries for driving assessments typically focus on measures of visual perception and complex attention, while neglecting or minimizing the domain of executive function. Awareness of deficits is one key element of executive functioning that has been found to be related to driving outcomes.

Being aware of deficits following ABI is a requisite condition for the survivor to invoke compensatory strategies in order to continue to drive safely. Conversely, a lack of awareness of cognitive or physical limitations may be the source of a false confidence and lead to risky driving behaviors. Cognitive and physical deficits do not invariably undermine fitness to drive. Awareness of these deficits may reduce or eliminate any additional risk due to these impairments by allowing the survivor to compensate accordingly.

Previous research has shown that awareness of deficit is related to driving outcomes; however, it has not been examined as a moderator in the relationship between neuropsychological test performance and on-road evaluation. Extant research includes studies using awareness of deficit as a subdomain of executive functioning or with non-road driving outcomes. As such, this study further investigated the role of awareness of deficit and use of compensatory strategies in the context of ABI disability in an on-road driving evaluation performance. Additionally, this study improved upon the current literature by including a healthy control group for purposes of comparison and addressing any possibility of methodological bias in the on-road evaluation. The following hypotheses were proposed:

1. Awareness of deficits directly affects fitness to drive:
    a. Survivors with awareness of their impairments would have more success on the on-road driving evaluation than would their counterparts with impaired awareness of deficits.
    b. Furthermore, it is predicted that cognitive and motor/sensory awareness would have greater relation to driving performance than would behavioral/affective awareness.
2. Awareness of deficits moderates fitness to drive:
    a. Among ABI survivors, awareness of deficit would moderate the relationship between neuropsychological test performance and on-road driving evaluation. Among survivors with impaired awareness of deficit, neuropsychological performance would be strongly related to on-road performance (i.e., impairments in neuropsychological functioning impair driving); among

survivors with adequate awareness of deficits, this relationship would be null or small.

b. Awareness moderates fitness to drive via invoking compensatory behaviors: Among ABI survivors, awareness of deficits would be positively correlated with use of compensatory strategies (e.g. driving limitations) and on-road driving performance. Likewise, unawareness of deficits would be inversely related to invoking compensatory strategies and subsequently to driving performance. Survivors who are aware of their deficits would report greater use of compensatory strategies, which in turn mitigates their deficits and benefits fitness to drive. In contrast, survivors unaware of their deficits would report few compensatory behaviors and would not adequately compensate for their impairments.

3. SOs would be better predictors of on-road performance for survivors with impaired awareness of their deficits than would the survivors themselves. Among survivors with intact awareness, SOs and survivors would show equivalent prediction of survivors' on-road performance.
4. It was expected that the control group would perform satisfactorily on the on-road driving evaluation and superior to the survivor group. Also, among these healthy controls, neuropsychological performance would not be related to on-road performance (i.e., due to threshold effect).

CHAPTER 2 METHODS

Participants

The sample included 62 participants with ABI and a knowledgeable informant about that person, and 40 healthy adults with no history of ABI. See Tables 1 and 2 for the demographic characteristics of the ABI survivors and healthy controls. The participants with histories of ABI including 31 stroke (50%), 11 TBI (17.7%), 8 MS (12.9%), 4 brain tumor (6.5%), and 8 mixed and other etiologies (12.9%; e.g., multiple neurological illnesses or injuries). Participants with ABI were recruited from the Driving Education and Training Center (DETC) at the Rehabilitation Institute of Michigan (RIM). Patients were referred to the DETC by their physicians for a driving evaluation prior to resumption of driving. Informant / significant others (SOs) of each of the ABI survivors were selected by the ABI survivors, were defined as individuals who knew the survivor prior to his or her ABI, and were considered to be “active” in the survivor’s life. Forty control participants were recruited from the community and from the SOs, to participate in the on-road driving evaluation and neuropsychological testing like the ABI survivors completed at the DETC. Exclusionary criteria for the control group included any history of brain injury, not having a valid driver’s license, and obtaining a score below 24 on The Mini Mental Status Exam (MMSE). No participants were excluded on the basis of these criteria. Inclusionary criteria for all participants included ability to understand English and be over 18 years old. Participants were compensated monetarily for their participation.

The significant others of the ABI survivors were 47 women (75.8%) and 15 men (24.2%) and they ranged in age from 18 to 80 years (*M* = 46.7 years, *SD* = 13.7). Level of education for the significant others ranged from 6 to 20 years (*M* = 13.8 years, *SD* = 2.5). The relationships of the significant others to the ABI survivors were 30 spouses or romantic partners (48.4%), 3 parents (4.8%), 9 adult children (14.5%), 8 other relatives (12.9%), 10 friends (16.1%), and 2 other (3.2%).

Measures

Barriers to Driving Questionnaire and Driving Survey (BDQ – DS; Rapport, Hanks, & Coleman Bryer, 2006). The BDQ is a 40-item survey that assesses difficulties associated with driving following acquired disability. Aspects of interest in the present study include ratings of current driving ability and driving safety, which are obtained via 5-point scales (e.g., *poor, worse than average, average, better than average, excellent*). Internal consistency reliabilities (coefficient alpha) for the subscales and the total score ranged from .87 to .97 (Rapport, Hanks, & Coleman Bryer, 2006).

The Driving Survey (DS) is a modified version of a questionnaire created by Marcotte et al. (2000) that assesses perceptions of participants' current levels of safety and skill as a driver. This portion was completed only by survivors who had resumed driving at the time of the present study. In addition to current driving habits, such as frequency and typical mileage, the scale obtains information on reported use of driving limitations, such as avoiding driving at night or in inclement weather. The items pertaining to driving limitations served as the measure of compensatory strategies for the present study. The DS has been shown reliable and valid among populations such as cognitively impaired persons with HIV (Marcotte et al., 2000) and TBI (Rapport, Hanks, & Coleman Bryer, 2006). The BDQ and DS have parallel versions for self-report and other-report. In the present study, both the BDQ and the DS were completed by the

ABI survivor and the SO with reference to the survivor. Reliability (coefficient alpha) for the Limitations scale in the present study was .91.

The Awareness Questionnaire (AQ; Sherer et al, 1998a; Sherer, Bergloff, Levin, High, Oden, & Nick, 1998b). This 17-item survey was designed to measure the patients' abilities to perform various tasks after injury as compared to before their injury. One form is completed by the survivor, and one form is completed by a SO informant. This interview was developed as a measure of impaired self-awareness after traumatic brain injury (Sherer et al., 1998b). Although the scale was originally designed for use among persons with traumatic brain injury, the test authors indicate that it is appropriate for use in populations with acquired brain injuries (Sherer et al., 1998), and it has been shown to be valid and reliable among populations other than TBI (Waldron-Perrine, Rapport, Ryan, & Telmet Harper, 2009). The AQ provides an index of awareness of deficit that is calculated as the discrepancy between survivors' self-report of their cognitive, behavioral, and motor functioning and SOs' perceptions of the survivors' abilities. Internal consistency for the total score was reported at .88 for both survivor and SO samples (Sherer et al, 1998a). In the present study, reliability (coefficient alpha) for the self-report scale was .82, whereas reliability for the SO-report scale was .87.

Awareness of Deficit was assessed using the AQ Difference score: The index defines unawareness in terms of the discrepancy between survivors' self-reports of their general functional abilities across a variety of domains and the external criterion of SOs' perceptions of the survivors' functional abilities (Survivor AQ – SO-rated AQ). Discrepancy scores of this nature are a widely-used, traditional approach of quantifying awareness of deficit among populations with cognitive impairment such as TBI

(Prigatano, Altman, & O'Brien, 1990; Prigatano & Fordyce, 1986) and MS (Sherman, Rapport, & Ryan, 2007; Ryan et al., 2009) Positive scores indicate that survivors rated themselves as more functionally able than did their SOs (i.e., unawareness of deficit). Negative scores indicate that survivors underrated their functional abilities as compared to significant other perceptions of the survivors' abilities (i.e., hypervigilance or hyperawareness). Scores approaching zero indicate convergence between survivor self-perceptions and perceptions of them by SOs (awareness). In the present study, reliability (coefficient alpha) for the AQ Difference score was .85.

On-road Driving Evaluation. All 62 survivors and 40 healthy controls completed a behind-the-wheel evaluation lasting 1-2 hours with a certified occupational therapist/driving instructor. The instructor rated the participants on their driving abilities in predriving behavior (e.g., seatbelt, check mirrors) and driving behavior in parking lots and on roadways, with items scored on a 0 to 2 scale. This comprehensive evaluation also included assessments of the participants' vision and upper and lower extremity motor coordination. The driving evaluator also assigned a recommended classification to the evaluation. Recommendations included an unrestricted return to independent driving as well as restrictions on driving, such as a specific restricted mileage radius from home, exclusion of rush-hour traffic, or exclusion of expressways, as well as steps for remediation required to return to independent driving, such as satisfactory completion of a specific number of remedial training hours with a certified instructor. For the purposes of this study, "pass" was considered as cases in which there were no restrictions on driving (i.e., recommendation was "return to independent driving") but included a full return with adaptive devices.

Neuropsychological Functioning. Neuropsychological functioning of a variety of cognitive domains was assessed at the time of survey completion. Healthy controls completed the neuropsychological testing at either the time of survey completion or at the time of their on-road evaluations. Neuropsychological tests included the Trail Making Tests – A & B, Symbol Digit Modalities Test, Judgment of Line Orientation, Stroop Test, Brixton Spatial Anticipation Test, and the Wechsler Adult Intelligence Scale- III Letter Number Sequencing and Matrix Reasoning subtests. The MMSE was also administered to the participants in the control group as part of exclusionary criteria. For parsimony in multivariate analyses, a composite score was calculated (NP Composite) reflecting the average Z score on the tests.

Trail Making Test Parts A and B (TMT; Reitan & Wolfson, 1988. The TMT is a well-established and sensitive test of processing speed, visual searching, sequencing, and mental flexibility. In the TMT, Part A requires the examinee to draw a line connecting 25 encircled numbers, which are randomly arranged on a page, in the proper order. For Part B, the examinee is required to draw a line connecting 25 encircled numbers and letters in alternating order. Both parts are scored separately according to the completion time. One year rest-retest reliability coefficients were .69 to .94 for Part A and .66 to .86 for Part B for various neurological groups (Goldstein & Watson, 1989). The TMT has been found to be highly sensitive to brain damage (Leninger, Gramling, & Farrell, 1990; O'Donnell, 1983), such as closed-head injury (desRosiers & Kavanagh, 1987) and alcoholism (Grant, Reed, & Adams, 1987).

Symbol Digit Modalities Test – Written Version (SDMT; Smith, 1973). The SDMT assesses visual scanning, tracking and processing speed. Examinees are presented with a series of nine geometric symbols in random order, and for each symbol in the sequence the examinee must search a key for that symbol and substitute a corresponding number. The written version requires examinees to write the numbers in the appropriate boxes below the geometric symbols according to the key provided at the top of the page. Test-retest reliability has been reported as .80 for the written version. In terms of validity, the SDMT has been found to be one of the most sensitive measures of reduced speed of processing (Smith, 1991).

Judgment of Line Orientation (JOLO; Benton, Hamsher, Varney, & Spreen, 1978; Benton, Varney, & Hamsher, 1978). The JOLO is a 30-item test measuring visuoperceptual ability, in which examinees are asked to match pairs of angled stimulus lines to two lines of matching orientation from an array of 11 numbered line segments of various angular orientations. The test has shown excellent reliability in a variety of populations. Split-half reliability among healthy adults ranges from .89 to .94, whereas 3-week retest reliability has been reported at .90 (Benton, Hamsher, Varney, & Spreen, 1978).

Modified Stroop Test (Golden, 1978). The Stroop Test measures selective attention, response inhibition, and interference control. The test examines the ease with which an examinee can shift perceptual set to conform to changing demands and suppress a habitual response in favor of an unusual one. The task requires the examinee to first read color words printed in black ink as quickly as they can (Word Score), then state the color XXXXs are printed in (Color Score), and finally name the color of the ink of words that do not correspond with the color of that ink (Color-Word Score). Stroop Color-Word Test is among the most widely used measures of interference control, and it is frequently used in driving evaluation batteries. One-month retest reliabilities range from .83 to .90 (Golden, 1978).

Brixton Spatial Anticipation Test (Burgess & Shallice, 1997). The Brixton Spatial Anticipation Test is a measure of nonverbal problem solving measuring concept attainment through rule detection. The task requires the examinee to learn and follow a pattern of a blue dot moving in various and changing patterns (e.g., moving forward, moving in reverse, moving back and forth, etc.) in a series of ten circles. The examinee is to predict where the blue dot will be on the next card, and if they are incorrect, to learn from his or her mistake and adjust their guess for the next movement in the pattern. This test is scored based on the number of errors committed. Split-half reliability for the Brixton was reported as .82 (Burgess & Shallice, 1997).

Wechsler Adult Intelligence Scale-III: Letter Number Sequencing and Matrix Reasoning subtests (Wechsler, 1997). WAIS-III Matrix Reasoning assesses visual information processing and abstract reasoning skills. It is an untimed, language-free test and requires no motor manipulation. Four types of items make up the subtest: continuous and discrete completion, classification, analogy reasoning, and serial reasoning. WAIS-III Letter-Number Sequencing assesses working memory and attention. The task requires the examinee to order sequentially a series of numbers and letters that are orally presented.

Mini Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975): The MMSE consists of 11 items that assess orientation to time and place, attention/concentration, language, constructional ability, and immediate and delayed recall. The general purpose of this test is to screen for mental impairment and to document intellectual changes occurring over time. Test-retest reliability estimates generally fall between .80 and .95 (Tombaugh & McIntyre, 1992). The MMSE has been found to be sensitive to the presence of dementia, especially moderate to severe forms of cognitive impairment (Spreen & Strauss, 1998).

Procedure

ABI survivors meeting eligibility qualifications were recruited from the Driving Education and Training Center (DETC) at the Rehabilitation Institute of Michigan (RIM) while they completed their driving evaluations. Survivors then selected an SO to complete the surveys with them (e.g. BDQ-DS, AQ). SOs and members of the community without history of acquired brain injury were recruited to participate in the on-road evaluation and neuropsychological testing. To minimize volunteer bias caused by transportation restrictions, ABI survivors were offered the option of completing the questionnaire and interview portions of the study at their homes. All participants were compensated with a monetary payment for their participation in the study.

CHAPTER 3 RESULTS

Prior to analysis, the data were screened for violations of the assumptions associated with univariate and multivariate tests. Variables with non-normal distributions that may inflate alpha were transformed to improve normality and linearity (Tabachnick & Fidell, 2006). Results of this evaluation led to the log transformation of on-road driving score, which improved normality and reduced the impact of outlying data points and skew. For the purposes of interpretation, the untransformed values are included in tables, whereas the transformed variables were used in the statistical analyses as appropriate and are noted where applicable.

Table 1 and 2 display demographic characteristics of the total sample, including ABI survivors and the Control group. Survivors and controls did not differ significantly in educational level ($F(1, 100) = 2.27$, $p = .135$) or age ($F(1, 100) = 0.506$, $p = .479$). Age and education were unrelated to the on-road total score (Age $r = -.01$; Education $r = .15$) and pass/fail results (Age *eta* = -.07; Education *eta* = .00). There was a significantly greater percentage of men in the survivor group (69%) than in the control group (40%), $X^2(1, N = 102) = 8.59$, $p = .003$, *phi* = -.29; this finding reflects the natural demographic of caregivers, who are proportionately more women than men. The AQ was used to classify the participants' awareness status by calculating a difference score based on the survivors' and significant others' responses. The sample was categorized into three groups based on the AQ results and the natural distribution of the difference scores. Twenty-one participants in the survivor group were classified as having impaired awareness (positive AQ Difference scores, range 7 to 24), which corresponded to roughly one third of the ABI sample and a natural break in the distribution of the AQ

Difference scores, 24 participants were classified as having intact awareness (AQ Difference scores near zero, range 0 to 6), and 17 participants were classified as being hypervigilant to deficits (negative AQ Difference scores, range -1 to -13). Characteristics of the survivors grouped by their level of awareness of deficit are displayed in Table 2 and 3.

Hypothesis 1a: Awareness of deficits is directly related to fitness to drive.

Hypotheses 1a predicted that ABI survivors who had awareness of their deficits would have more success on the on-road evaluation than would their counterparts with impaired awareness. Awareness of deficits was significantly correlated with on-road driving performance (r = -.28, p = .015) and evaluation recommendations (*eta* = -.24, p = .032); the direction of association indicates that impaired awareness was adversely associated with driving outcome. In the Impaired Awareness group, their level of awareness of deficits was strongly correlated with both on-road driving performance and evaluation recommendations; in contrast, among the Hypervigilant and Intact Awareness groups, awareness of deficits was not significantly and weakly related to driving outcomes (see Table 4).

Group differences between survivors designated as Hypervigilant, Intact Awareness, and with Impaired Awareness, and the Control group on the on-road evaluation were assessed using analysis of variance (ANOVA). There was a significant difference between the groups on their (log of) on-road driving performance: $F(3, 97)$ = 6.00, p = .001, partial η^2 = .16. However, Levene's test indicated heterogeneity of variance, $F(3, 97)$ = 26.54, p < .001. Therefore, Levene's corrections were adopted as appropriate in comparing the groups using independent t tests. Hedges' *g* (Hedges, 1981), was selected as the estimate of effect size, because it represents the sample statistic parallel to Cohen's d (i.e., g is the bias-corrected estimate of the population effect size d), which adjusts for cell sizes and pooled standard deviation. Hedges' g is interpreted similar to Cohen's d (Cohen, 1965), with .20 indicating a small but non-trivial effect, .50 indicating a medium effect, and .80 or larger indicating a large effect. Independent t tests conducted on (log of) on-road driving performance indicated that the Intact Awareness group (*M* = 0.86, *SD* = 0.18) performed significantly worse than did the Controls (*M* = 0.92, *SD* = 0.02), *t*(22.4) = 1.76, *p* = .047; Hedges' *g* for the group difference was .59, indicating a medium effect. Similarly, the Hypervigilant group (*M* = 0.83, *SD* = 0.16) performed worse than the Controls did, *t*(16.3) = 2.37, *p* = .015, with *g* = 1.03, a large effect. The Impaired Awareness group (*M* = 0.75, *SD* = 0.24) showed the greatest difference from the control group, *t*(20.2) = 3.31, *p* = .002, *g* = 1.22, large. The group with intact awareness did not differ significantly from the Hypervigilant group, *t*(36.8) = 0.46, *p* = .322. *g* = .14, small, but showed a strong trend toward superior performance over the Impaired Awareness group, *t*(37.2) = -1.65, *p* = .054, *g* = 0.50, medium. The Hypervigilant and Impaired Awareness groups did not differ significantly, *t*(34.8) = -1.25, *p* = .110, *g* = 0.38, a small effect.

A chi-square test indicated that the four groups differed in the proportion of participants who passed versus failed the on-road evaluation, $X^2(3, N = 102) = 22.02$, $p < .001$, *phi* = .47 (see Table 2). The pass rate for the Hypervigilant group (64.7%) was not different from the pass rate for the Intact Awareness group (58.3%), $X^2(1, N = 41) = 0.17$, *p* = .680, *phi* = -.06, or the pass rate for the Impaired Awareness group (47.6%), $X^2(1, N = 38) = 1.11$, *p* = .292, *phi* = -.17. Similarly, the pass rate for Impaired

Awareness group (47.6%) did not differ from the Intact Awareness group (58.3%), $X^2(1, N = 45) = 0.52$, $p = .472$, *phi* = -.11. The pass rate for the Control group (97.5%) differed significantly from each of the ABI survivor groups, Hypervigilant group, $X^2(1, N = 57) = 11.91$, $p < .001$, *phi* =.46; Intact Awareness group, $X^2(1, N = 64) = 16.17$, $p < .001$, phi = .50, and Impaired Awareness group, $X^2(1, N = 61) = 21.68$, $p < .001$, *phi* = .60. In sum, the Control group attained better driving outcomes than did the ABI survivor groups, with the Impaired Awareness group having driving outcomes the most discrepant from the controls.

Hypothesis 1b: Cognitive and motor/sensory awareness will have greater relation to driving performance than will behavioral/affective awareness.

Among the total sample of ABI survivors, each domain of awareness was significantly correlated with driving performance (AQ – Cognitive, $r = -.24$, $p = .030$; AQ – Motor/Sensory, $r = -.26$, $p = .022$; AQ – Behavioral/Affective, $r = -.25$, $p = .027$). Correlations were also conducted for each group separately: Among the Hypervigilant group and the Intact Awareness group, correlations between awareness domains and driving performance were small and not significant (*r*s .04 to .24). Among the survivors with impaired awareness, cognitive and motor/sensory awareness showed moderate and significant relationship to driving performance (AQ – Cognitive, $r = .42$, $p = .028$; AQ – Motor/Sensory, $r = .44$, $p = .023$); the correlation between on-road performance and behavioral/affective awareness was smaller and not significant (AQ – Behavioral/Affective, $r = .28$, $p = .107$). Table 4 displays correlations between awareness variables and on-road performances for each of the survivor groups, and Table 5 displays the correlations for all ABI survivors.

Hypothesis 2a: Among ABI survivors, awareness of deficit will moderate the relationship between neuropsychological test performance and on-road driving evaluation.

The moderating effects of awareness of deficit were tested through linear multiple regression, specifically examining the interaction of level of awareness and neuropsychological test performance on the outcomes of the on-road driving evaluation. An interaction term between awareness of deficit (AQ Difference) and the neuropsychological composite score was created; the product was centered to minimize collinearity between the interaction term and the individual variables used to create it (Baron & Kenny, 1986; Tabachnick & Fidell, 2006). Standard multiple regression tested the combined and unique predictive powers of the individual variables awareness of deficit (AQ-Difference), neuropsychological functioning (NP Composite), and the interaction of those two variables (AQ Difference * NP Composite). Table 6 displays results of the multiple regression. The overall model was significant, $F(3, 58) = 6.50$, $p = .001$, $R^2 = .25$. Results showed that the AQ Difference * NP Composite interaction explained significant portion of unique variance in the performance on the total score of the on-road evaluation ($sr^2 = .08$, $p = .05$). Thus, awareness of deficit did moderate the relationship between neuropsychological test performance and driving performance.

The moderation effect is illustrated by examining the different patterns of correlations between the three awareness groups (see Table 7). Among drivers who were hypervigilant to the possibility of deficits, the neuropsychological composite score was not significantly related to on-road outcomes ($ps \geq .10$); it showed modest relation to on-road total score and weak relation to on-road pass/fail outcomes. Among survivors aware of their deficits, neuropsychological composite scores were not related to their on-road total but were related to the pass/fail recommendation. In contrast, among drivers with impaired awareness of their deficits, the composite of neuropsychological test performance was strongly related to both driving outcomes. Fisher's r-to-z correlation comparisons indicate that the correlation for on-road total and neuropsychological composite for drivers with impaired awareness (r = -.56) was significantly larger than the correlation for on-road total and neuropsychological composite among drivers with intact awareness (r = -.09), Z = -1.68, p = .047; however, the difference between correlations for the impaired awareness and hypervigilant (r = -.37) groups was not significant, Z = 0.68, p = .25.

Table 7 also displays correlations for the individual neuropsychological tests with the driving outcomes. Among these tests, the TMT-A and SDMT showed the strongest correlations with driving outcomes among the ABI survivor groups. Measures of executive functioning and visuospatial reasoning were also significantly and moderately to strongly correlated with driving outcomes among the Impaired Awareness survivors, but these measures showed relatively weaker and nonsignificant correlations in the Hypervigilant and Intact Awareness groups.

There was a significant difference between the ABI survivor groups on their neuropsychological composite scores: $F(3, 92) = 13.66$, $p < .001$, partial $\eta^2 = .31$. However, Levene's test indicated heterogeneity of variance, $F(3, 92) = 5.01$, $p = .003$. Therefore, Levene's corrections were adopted as appropriate in comparing the groups. Independent t tests with Levene's corrections indicated that the Impaired Awareness group (M = -0.64, SD = 0.76) performed significantly worse than did the group with intact awareness (M = -0.07, SD = 0.91), $t(40.0) = 2.20$, p = .017, g = 0.66, medium.

The Hypervigilant group (*M* = -0.36, *SD* = 0.44) did not differ significantly from the Impaired Awareness group, *t*(29.6) = 1.34, *p* = .096, *g* = 0.43, small, or the Intact Awareness group, *t*(33.6) = -1.29, *p* = .103, *g* = 0.38, small.

Hypothesis 2b: *Awareness moderates fitness to drive via invoking compensatory behaviors.*

It was predicted that use of compensatory strategies would be related to successful on-road driving performance and would be more prevalent in the survivors with awareness of their deficits than in those with impaired awareness. Among the 62 ABI survivors, 39 (62.9%) reported that they were driving at the time of their participation in the study: Hypervigilant (*n* = 13), Intact Awareness (*n* =16), and Impaired Awareness (*n* = 10). Fewer than half of the participants in the Impaired Awareness group (47.6%) were driving at the time of their participation as compared to two thirds (66.7%) of the Intact Awareness group and three quarters (76.5%) of the Hypervigilant group; however, chi-square test indicated that the three groups did not differ significantly in the proportion of drivers versus non-drivers, $X^2(2, N = 62) = 3.59$, $p = .17$, *phi* = .40 (medium).

Differences between the Hypervigilant, Intact Awareness, and Impaired Awareness, and the Control groups in the use of limitations on driving was assessed using ANOVA. There was a significant difference between the groups: $F(3, 75) = 5.19$, $p = .003$, partial $\eta^2 = .17$. Levene's test indicated heterogeneity of variance, $F(3, 75) = 6.63$, $p < .001$. As such, Levene's corrections were adopted as appropriate in comparing the groups. Independent t tests with Levene's corrections revealed that the Control group (*M* = 1.9, *SD* = 1.9) imposed significantly fewer limitations on their driving than did the Hypervigilant group ($M = 4.7$, $SD = 3.7$; $t(14.2) = 2.66$, $p = .009$, $g = 1.08$, large), the Impaired Awareness group ($M = 4.5$, $SD = 3.6$; $t(10.3) = 2.23$, $p = .023$, $g = 0.99$, large), and the Intact Awareness group ($M = 3.7$, $SD = 3.2$; $t(19.5) = 2.15$, $p = .023$, $g = 0.72$, medium). There were no significant differences in use of limitations among the ABI survivors ($ps > .22$, $g < 0.3$) (see Table 2).

Among the Control group ($r = -.02$) and the participants in the Intact Awareness group who were driving at time of their participation in the study ($r = .09$), use of limitations was unrelated to driving performance. Among the Hypervigilant group drivers, there was a modest but not significant relationship between use of limitations and driving performance ($r = -.31$, $p = .15$), and among ABI survivors with impaired awareness who had resumed driving, there was a strong relationship between use of limitations and on-road performance ($r = -.71$, $p = .012$), such that as use of limitations increased, driving scores decreased (see Table 8).

Hypothesis 3: SOs will be better predictors of on-road performance for survivors with impaired awareness of their deficits than will the survivors themselves. Among survivors with awareness of their deficits, SOs and survivors will show equivalent prediction of survivors' on-road performance.

Of note, 67.2% of the ABI participants rated themselves as “better than average” or “excellent” drivers, with 29.0% rating themselves as average, and 3.2% as below average or poor. SOs rated 17.4% of the survivors as below average or poor drivers, 37.0% as average, and 45.6% as better than average. Among the Impaired Awareness group, 85.7% rated themselves as “better than average” or “excellent” drivers, 14.3% as average, and 0% rated themselves as below average or poor. Among the Intact Awareness group, 73.9% rated themselves as "better than average" or "excellent" drivers, 21.7% as average, and 4.3% rated themselves as below average or poor. Among the Hypervigilant group, 35.3% rated themselves as "better than average" or "excellent" drivers, 58.8% as average, and 5.9% rated themselves as below average or poor.

Differences between the ABI survivor groups and the control group on self-rated driving abilities (as compared the average driver) were assessed using ANOVA (see Table 2). There was a significant difference between the groups: $F(3, 97) = 5.03$, $p = .003$, partial $\eta^2 = .14$. Levene's test indicated heterogeneity of variance, $F(3, 97) = 3.60$, $p = .016$. Therefore, Levene's corrections were adopted as appropriate in comparing the groups. Independent t tests with Levene's corrections revealed that the group with impaired awareness ($M = 4.2$, $SD = 0.7$) rated their driving abilities significantly better than did the Hypervigilant group ($M = 3.4$, $SD = 0.7$; $t(31.7) = -3.20$, $p = .002$, $g = 1.12$, large) and the group with intact awareness ($M = 3.8$, $SD = 0.9$; $t(41.3) = -1.76$, $p = .043$, $g = 0.48$, small) and not significantly differently than did the Control group ($M = 4.1$, $SD = 0.5$; $t(31.8) = 0.83$, $p = .410$, $g = 0.17$). The Control group had self-ratings higher than the Hypervigilant group, $t(21.7) = -3.06$, $p = .003$, $g = 1.22$, large. The self-ratings of the group with intact awareness were not significantly different than those of the Hypervigilant group, $t(31.1) = -1.42$, $p = .083$, $g = 0.48$, small, nor the Control group, $t(31.7) = -1.38$, $p = .090$, $g = 0.44$, small.

On average (Table 3), SOs rated participants with impaired awareness as below average in driving ability ($M = 2.9$), whereas the average ratings for the intact and hypervigilant participants were above average. Differences between SO-rated driving abilities among the ABI survivor groups were assessed using ANOVA (see Table 3). The differences between the groups were not significant, $F(2, 43) = 1.45$, $p = .245$, partial $\eta^2 = .06$. SOs' ratings of the survivors' driving ability as compared to the average driver were not significantly correlated to the survivors' personal ratings of their driving ability nor to the survivors' on-road performance in the total ABI sample (*r*s = .16 to .19), as can be seen in Table 5. The correlations between SOs' ratings and survivors' self-ratings of driving ability were weak among the Intact Awareness group ($r = .20$, $p = .217$) and the Impaired Awareness group ($r = .22$, $p = .202$) and modest but not significant among the Hypervigilant group ($r = .36$, $p = .115$). As shown in Table 8, among the Hypervigilant group, the SOs' ratings were strongly correlated ($r = .60$) and the survivors' self-ratings were modestly related ($r = .36$) with on-road performance. Both the SOs' ($r = .55$) and survivors' ratings ($r = .51$) were strongly related to the survivors' on-road performance in the Intact Awareness group. In contrast, neither the SOs' nor the self-ratings of the Impaired Awareness group were related to on-road performance (*r*s = .01 to .03). The SOs' ratings were, however, significantly correlated to the Impaired Awareness group survivors' use of limitations in their driving, such that as their ratings decreased, limitations on driving increased ($r = -.81$, $p = .014$), whereas the Impaired Awareness group survivors' self-ratings of their driving ability were unrelated to their reported driving limitations ($r = .00$, $p = .500$). The correlations between SOs' ratings of survivor driving ability and the survivors' use of limitations were weaker among survivors with intact awareness ($r = -.24$, $p = .231$), whose self-ratings also were relatively unrelated to number of limitations on driving ($r = .15$, $p = .286$). Among those hypervigilant to their deficits, self-ratings of current driving ability ($r = -.57$, *p* = .022) were more strongly correlated with number of driving limitations than were SOs' ratings of the survivors' driving (*r* = -.34, *p* = .171). Neither the SOs' nor the survivors' ratings of driving abilities were related to the survivors' neuropsychological composite score (see Table 5).

Hypothesis 4: The control group will perform satisfactorily on the on-road driving evaluation and superior to the survivor group. Among the controls, neuropsychological performance will not be related to on-road performance.

ANOVA was used to examine differences between the control group and the ABI survivors on the on-road evaluation. The Control group (*M* = 0.92, *SD* = 0.02) performed significantly better than the ABI survivors (*M* = 0.81, *SD* = 0.20) on the on-road evaluation: $F(1, 99) = 12.01$, $p = .001$, partial $\eta^2 = .11$. Chi-square test indicated that the control group (97.5%) and ABI survivors (56.5%) differed in the proportion of participants who passed versus failed the on-road evaluation, $X^2(1, N = 102) = 20.57$, $p < .001$, *phi* = .45. As noted in Hypothesis 1a, the controls performed better than each of the three awareness groups on the on-road evaluation and the pass/fail rates. The Control group (*M* = 0.42, *SD* = 0.40) also obtained significantly better neuropsychological composite scores than did the ABI survivors (*M* = -0.33, *SD* = 0.79): $F(1, 94) = 30.69$, $p < .001$, partial $\eta^2 = .25$. Correlational analyses showed that among the controls, the neuropsychological composite score was correlated to on-road performance (*r* = .37, *p* = .010) but not to the pass/fail recommendation (*r* = .16, *p* = .163). Specifically, visuospatial attention and processing speed tests showed the strongest associations with driving outcomes, whereas executive functioning measures were not as significantly related (see Table 7).

CHAPTER 4 DISCUSSION

The findings indicate that awareness of deficit has a considerable influence on driving outcomes both directly and as a moderator between the relationship of neuropsychological functioning and driving performance. Adults with ABI who had awareness of their deficits had more success on the on-road driving evaluation than did their counterparts with impaired awareness, and they more accurately assessed their own fitness to drive. Furthermore, the findings indicate that awareness of deficits moderates the adverse influence of neuropsychological dysfunction on fitness to drive: Among adults with impaired awareness of their deficits, cognitive functioning was substantially related to their driving outcomes; in contrast, driving outcome showed weak relation to cognitive functioning among adults with ABI hypervigilant to or adequately aware of their impairments. More than half of the adults with ABI successfully passed the on-road driving evaluation. This finding highlights the potential for safe driving following ABI despite potential cognitive and physical impairment and is consistent with prior research (Schultheis, et al., 2002; van Zomeren, Brouwer & Minderhoud, 1987). This study also addressed an important methodological question regarding whether expectations for success in an on-road evaluation are reasonable for the average driver; in the present study healthy controls had a markedly higher pass rate and outperformed the adults with ABI in their on-road evaluations.

Awareness of Deficits and On-road Performance

Driving is a complex task that requires integration of cognitive and physical components for safe and successful navigation (Lister, 1999; Lundqvist & Ronnberg, 2001; Marshall et al., 2007). Awareness of deficit following ABI is integral to this process. As predicted, awareness of deficits was modestly associated with driving outcomes, meaning that as awareness of impairments increased, driving outcomes improved. As compared to a healthy driver, the adverse effect of having ABI with impaired awareness of deficits was large, whereas the adverse effect of ABI with intact awareness of deficits was moderate. As compared to adults with ABI who had intact awareness of their deficits, the adverse effect of impaired awareness on driving was moderate. Of special note, among those with impaired awareness of their deficits, level of awareness was strongly associated with their driving performances, such that as their awareness increased, driving performances improved. Thus, what awareness of deficit was present among this group was of utmost importance to their success on the road. Also of interest, participants who were hypervigilant to their deficits (i.e., overrated their impairments) had substantially less success than controls, also showing a large effect, albeit less large than adults with impaired awareness. Perhaps a bit surprising, although they were generally better than adults with impaired awareness in driving and neuropsychological functioning, they consistently appeared worse than those with intact awareness. In contrast to the adults with impaired awareness of deficits, adults hypervigilant to their deficits were attentive to and apparently accurate about their deficits and the related effects on their driving abilities. This observation may well explain why they passed the evaluation with higher rates despite the deficits they realistically maintained.

The predictive power of neuropsychological tests to on-road driving performance has been variable, with some studies showing strong relationships (e.g., Coleman et al, 2002, Heikkilä, et al., 1999, Ryan et al., 2009, Schanke & Sundet, 2000, etc.) and others showing no relationship (e.g., Bieliauskas, et al., 1998, Withaar, Brouwer, & Van Zomeren, 2000). One explanation for this is the possibility of a moderator, such as awareness of deficits. As expected, awareness of deficit did moderate this relationship. In the present study, global neuropsychological functioning showed modest to strong prediction of on-road performance, as did awareness of deficits specifically; however, neuropsychological impairments had proportionately more adverse influence under conditions in which adults had impaired awareness of their deficits. Among adults with impaired awareness of their deficits, neuropsychological performance was strongly related to driving performance; in contrast, this relationship was small or null among adults hypervigilant to their deficits and those with intact awareness. This finding indicates that when adults with ABI lack appreciation for their impairments, their neuropsychological status is especially important in predicting driving outcomes. Even minor deficits, if not heeded and compensated for appropriately, can increase driving risk substantially (Rapport et al., 1993; Ryan et al. 2009). Neuropsychological functions involving psychomotor and visuomotor processing speed predicted driving skills among all participants, including the healthy controls (e.g., Anstey, Windsor, Luszcz, & Andrews, 2006; Edwards et al., 2009; Korteling & Kaptein, 1996). Executive functioning and visuospatial reasoning, however, played additional substantial roles in driving performance among adults with impaired awareness of their deficits. Adults with impaired awareness of deficit demonstrated worse neuropsychological functioning than did adults with intact awareness, which is consistent with the finding that persons with awareness problems often display global cognitive deficits (Prigatano, 2005); however, in the present study, the combined effects of impaired awareness and neuropsychological impairment accounted for unique information in predicting on-road evaluation outcome.

It was predicted that awareness of cognitive and physical deficits would be more related to driving performance than would behavioral and affective awareness. Although this finding was not supported in the ABI survivor groups as a whole, among adults with impaired awareness, awareness of cognitive and motor and sensory impairments was more strongly related to driving performance than was behavioral and affective awareness. Among adults with impaired awareness, what awareness they do have for their deficits is critical for their driving safety, especially their assessment of their cognitive deficits (e.g., impaired processing speed, attention, etc.) and physical deficits (e.g., hemiplegia, visual neglect, reduced coordination, etc.). This finding indicates that awareness of deficits in cognitive and physical abilities plays a more considerable role in safe driving than does awareness of emotional deficits (e.g., increased mood lability, decreased control over emotional responses, etc.), likely because physical and cognitive health are of greater necessity in driving safety than is emotional health.

Compensatory Strategies

As compared to healthy drivers, adults with ABI who had resumed driving with impaired awareness of their deficits and those hypervigilant towards their deficits reported substantially more limitations imposed on their driving; for adults with intact awareness of their deficits, limitations on driving were moderate as compared to their healthy counterparts. Contrary to prediction and previous research (e.g., Lundqvist & Alinder, 2007; Rapport, Coleman Bryer, & Hanks, 2008; Ryan, et al., 2009), being aware of deficits was not associated with increased use of compensatory strategies, such as reducing nighttime driving or avoiding highways. Those with intact awareness of their deficits did not report greater use of limitations than did those with impaired awareness. Healthy controls implemented fewer limitations than did adults with ABI, as would be expected given they should not need to limit their driving in any way or compensate for an impairment. Unexpectedly, though, reported limitations were strongly related to worse driving performance among adults with impaired awareness and modestly related to worse driving performance among those hypervigilant to their deficits. This finding could be explained by the possibility that, especially in the case of survivors unaware of their deficits, the limitations are being imposed upon the survivor by a significant other or driving evaluator, who determines them to be necessary. Prior research has found that the caregivers “hold the keys to the car,” in that they have the most influence on whether and how much adults with ABI drive (Coleman et al., 2002; Rapport et al., 2006; Rapport et al., 2008; Scott et al., 2009). Thus, adults with ABI who are perceived to have more impairments that may adversely affect their driving abilities may actually be reporting more limitations on their driving because they are either required to by doctors or driving professionals or because their significant other enforces certain driving limitations. Therefore, the measure of compensatory strategies in the present study may not have tapped self-imposed compensation or driving limitations, but also other-imposed driving restrictions. It is not known if these adults with ABI were in fact invoking these self-reported limitations when they were driving independently and if so, how successfully they were able to do so. Furthermore, the relationship between increased use of limitations and poorer driving performance may be a reflection of a third variable, impairment level. Persons with greater impairments require more driving limitations and restrictions, which is related to their poorer driving performance.

There was not a direct relationship between use of limitations and driving performance among the adults with intact awareness or the healthy controls. It is likely that the healthy controls did not need compensations measured as limitations on driving. This explanation might apply as well to adults with intact awareness, although it is unlikely, because they showed meaningful neuropsychologic impairment relative to the healthy adults and did have impairments that needed some compensatory response. It might be these adults with intact awareness used more subtle compensations that are more difficult to self-report (e.g., allowing more time and distance to pull out or turn, more visual scanning, greater distance in following, etc.). It is also possible that these and other compensations adopted by drivers aware of their deficits were effective, and that quality rather than quantity of self-imposed limitations (i.e., selectively and effectively invoked) makes for a nonlinear relationship between compensation and driving performance. It is important to note, however, that observations regarding limitations on driving applied only to the small subset of individuals who were driving at the time of their participation; this cluster of individuals represents a selected group that likely differs from adults who were not driving.

Self-assessment and Predictions of Driving Performance

Awareness of deficits is also related to how one perceives one's ability to drive safely. Interestingly, adults with impaired awareness viewed themselves as better drivers than did those with intact awareness or hypervigilant to deficits. In fact, the survivors with impaired awareness did not view themselves differently than did the healthy adults. As predicted, the self-evaluations of driving ability of the adults with impaired awareness of deficits were not related to their on-road performance. As such, they overestimated their driving abilities, lacking a full appreciation for the effects of their impairments on this complex task. This finding provides empirical support for the many theoretical propositions regarding the importance of accurate self-assessment in fitness to drive. It is fairly consistent with the conclusions and theories of Lundqvist and Alinder (2007) who speculated that those who fail on-road evaluations are less aware of their abilities and are more likely to overestimate their abilities. Similarly, Scott, Rapport, Coleman-Bryer, Griffen, Hanks and McKay (2009) also found that stroke survivors overestimated their driving abilities as compared to the average driver. They discuss their results within the context of Groeger and Grande's (1996) theory of a "driving self," which is a stable trait like other aspects of self-concept, such that it is entrenched over time and resistant to change. Groeger and Grande argue that under most circumstances, drivers' views of their driving abilities are unlikely to adjust, especially in the case of experienced drivers. In the present study, this ability to appropriately adjust self-ratings of one's driving abilities is lacking among the adults with impaired awareness. Most adults believe that they are better than average drivers; in most circumstances, this is a benign inaccuracy, because a broad range around average is sufficient for competent, safe driving. However, in the absence of a shift in self-assessment following ABI, drivers with impairments cannot make concomitant shifts in driving behaviors necessary to compensate. Even small impairments that go without adjustment pose serious risk on the road.

As expected, the adults with awareness of or hypervigilance towards their deficits were better at predicting their driving performances than were those with impaired awareness. This finding suggests that perceptions of personal driving abilities are more accurate among those with greater awareness of their other abilities (e.g., cognitive, motor/sensory, and behavioral/affective). Thus, these adults appear to be more able to adjust their sense of a “driving self” appropriately and accordingly to their history of ABI and resulting deficits, in contrast to those with impaired awareness of their deficits (Groeger & Grande, 1996).

The significant others’ perceptions of the driving abilities of adults with intact awareness of or hypervigilance towards deficits were also strongly associated with the survivors’ driving performance. In fact, among survivors hypervigilant towards deficits, SOs were better predictors of the driving abilities than were the survivors themselves. Surprisingly, the significant others’ perceptions of the impaired awareness survivors’ driving abilities were as unrelated to the survivors’ driving outcomes as were the survivors’ self-perceptions. There was a trend with a medium-sized effect toward SOs viewing the survivors with impaired awareness worse than the other survivors. Interestingly, neither the survivors’ self-perceptions of their driving abilities nor the SOs’ perceptions of them were related to neuropsychological functioning. These findings suggest the SOs’ perceptions of the survivors are not consistently related to actual fitness to drive, as found similarly by Coleman et al. (2002), especially among survivors with impaired awareness. This is an important observation because most adults do not seek a driver evaluation, even as they age or otherwise change, including acquired brain impairment; they and their families simply assess themselves (Fisk, Schneider, & Novack, 1998).

The SOs' perceptions were substantially related to use of limitations among adults with impaired awareness of their deficits, such that the poorer the perceptions were the more limitations the survivor reported using in their driving. In contrast, the self-perceptions of the adults with impaired awareness were not related to use of limitations. This finding likely again reflects the SOs' involvement in restricting the driving of survivors with perceived awareness problems or significant impairments, such that they "hold the keys to the car" (Coleman et al., 2002; Rapport et al., 2006; Rapport et al., 2008; Scott et al., 2009). This further supports the notion that SOs determine whether and to what extent an adult drives following ABI, despite the survivors' self-perceptions and actual level of functioning. This relationship between the SOs' perceptions and use of limitations was much weaker among adults with intact awareness or hypervigilance to their deficits as compared to those with impaired awareness. In fact, the self-perceptions of adults hypervigilant to their deficits were strongly related to their use of limitations, whereas the perceptions of the SOs were modestly related to use of limitations. This finding suggests that the adults hypervigilant to their deficits may be more active in decision making regarding driving and setting restrictions than are the adults with impaired awareness of their deficits whose SOs may "hold the keys."

Healthy Controls and Driving Performance

Healthy controls were included in this on-road driving evaluation study to allow comparisons between healthy adults and those with histories of ABI. Consistent with expectations, the healthy controls were highly successful in their on-road driving performances and achieved higher scores and passing rates than did the adults with ABI as an entire group and each awareness subgroup of survivors. This finding indicates that passing an on-road evaluation is within reasonable expectations and not unduly difficult.

Contrary to prediction, neuropsychological performance was moderately associated with driving outcomes among the healthy adults. This finding indicates that even among healthy adults those with better neuropsychological functioning attained better driving scores as compared to those with relatively lower neuropsychological functioning. Specifically, it appears that psychomotor and visuomotor processing speed are important to good driving among healthy adults and adults with ABI alike. Quick information processing and reaction time are essential for safe driving, and this finding suggests that more is better. Even among healthy adults, those with faster processing speed and response times were better drivers, albeit the healthy adults had a nearly 100% success rate in passing an on-road evaluation; therefore, although some gradations of skills can be perceived among competent drivers, there is a threshold effect for adequate driving. In contrast to psychomotor and visuomotor processing speed, executive functioning was not as strongly related to driving outcomes among healthy adults and adults with intact awareness or hypervigilance towards their deficits. Among adults with impaired awareness of their deficits, however, executive functioning and visuospatial reasoning were also strongly associated with driving outcomes. This result is consistent with the discussion that what awareness, or in this case cognitive reasoning, these survivors have is of utmost importance to driving safety. This finding also suggests that safe driving requires a basic or average level of reasoning ability, but that once that threshold is attained, superior reasoning abilities do not strongly affect driving abilities; yet, if this minimum level is not attained driving performance suffers.

Conclusions, Limitations, and Future Research

Being aware of deficits that may interfere with safe driving is critical for adults with acquired brain impairments. If deficits are not adequately appreciated and the driving self-concept not appropriately adjusted, survivors overestimate their driving abilities. This overestimation may lead to a decision to resume driving prematurely, resistance to following driving restrictions, failure to engage self-imposed compensatory strategies, and engaging in risky driving behaviors. Neuropsychological and on-road evaluations are the typical methods for assessing fitness to drive. This study highlights the importance of also assessing the survivors' level of awareness of their deficits, especially those cognitive and physical in nature. The predictive value of neuropsychological assessment is of particular importance among adults with impaired awareness of their deficits.

Limitations to this study include the mixed nature of the sample, composed of a variety of neurological conditions and injuries. Although the focus of the study was on awareness of deficit and driving, not a particular illness or injury, it may be helpful to further examine these relationships within the context of one specific group in which disease characteristics are more homogenous (e.g., prognosis, specific symptoms, etc.). Additionally, the mixed nature of this sample made assessing and controlling for noncognitive severity of illness or injury difficult. The inclusion of healthy controls to an on-road research design is an improvement to the current body of literature; however, the design of the study did not allow for blind on-road evaluations. It is possible that ratings by the driving expert were affected by knowing to which group the participant belonged; yet it is noteworthy that one of the healthy adults did not pass the evaluation. The study included a variety of exploratory analyses in which subgroups were examined (e.g., among current drivers and their use of driving limitations) with small cell sizes and limited statistical power for significance tests. Replication of these findings in a larger sample is warranted. It should also be noted that these findings apply to adults with ABI who sought out or were referred by physicians for a driving evaluation and followed up in doing so to assess their fitness to drive, and thus, these results are not representative of all adults with ABI. As mentioned previously, a majority of adults with ABI do not receive an on-road evaluation, and driving safety is not adequately addressed in the healthcare system (Fisk, Schneider, & Novack, 1998). Additionally, state laws vary widely regarding the roles, expectations, and liabilities involved for healthcare workers to report driving safety issues and refer their patients for evaluations.

The present findings contribute to a limited body of research investigating awareness of deficits in the context of an on-road driving evaluation with both a clinical sample and healthy adults. As awareness of deficit has not traditionally been included in clinical driving evaluations or even research examining predictors of driving following acquired brain impairment, this study is informative about the benefits of considering self-awareness in understanding the relationship between neuropsychological test performance and driving performance. Future studies could further examine the use of compensatory strategies following acquired brain impairment, including differences between self- and other-initiated strategies and who encourages and chooses these alternative or limited driving behaviors. The role of the caregiver or significant other appears to be especially important in understanding use of compensatory strategies in survivors with impaired awareness of deficits. Future research would also be helpful in examining the relationship between awareness of deficit and driving by assessing other driving outcomes, such as driving records and performance on driving simulator tasks. A longitudinal study following adults with acquired brain impairment and assessing relationships between and changes in self-awareness, neuropsychological functioning, decision-making regarding driving, and long-term driving outcomes would be ideal and especially informative. These studies could add further evidence as to the important role of awareness of deficits as a moderator between neuropsychological status and driving ability.

APPENDIX A

Table 1. *Descriptive Statistics: Demographics of Participants with Acquired Brain Injury*.

Survivors (*n* = 62)	*M*	*SD*	Range
Age (years)	49.5	14.1	19 – 81
Education (years)	13.9	2.4	11 – 20
Time since onset of ABI (months)	30.3[1]	63.1	2 – 364
Percent Men	69.4		
Diagnosis (%)			
Stroke	50.0		
Traumatic Brain Injury	17.7		
Multiple sclerosis	12.9		
Tumor	6.5		
Other	12.9		
Percent driving[2]	62.9		

1. Median = 12 months
2. Percent of survivors driving at the time of study.

Table 2. *Descriptive Statistics: Characteristics of Survivors Grouped by Level of Awareness of Deficits: Hypervigilant (n = 17), Intact Awareness (n = 24), Impaired Awareness (n = 21), and Control (n = 40).*

	Group							
	Hypervigilant		Intact Awareness		Impaired Awareness		Control	
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	49.6	12.0	49.5	14.5	49.5	15.9	47.5	13.7
Education	13.8	2.2	13.8	2.5	14.0	2.6	14.6	2.3
NP Composite	-0.36	0.44	-0.07	0.91	-0.64	0.76	0.42	0.40
Percent Driving[1]	76.5		66.7		47.6		100.0	
Self-Limitations	4.7	3.7	3.7	3.2	4.5	3.6	1.9	1.9
Self-rated driving skill	3.4	0.7	3.8	0.9	4.2	0.7	4.1	0.5
On-road Total	1.9	0.1	1.9	0.1	1.9	0.2	2.0	0.0
Percent On-road Pass	64.7		58.3		47.6		97.5	

1. Percent of participants driving at the time of study.

Table 3. *Descriptive Statistics: Characteristics of Survivors Grouped by Level of Awareness of Deficits: Hypervigilant (n = 17), Intact Awareness (n = 24) and Impaired Awareness (n = 21).*

	Group					
	Hypervigilant		Intact Awareness		Impaired Awareness	
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*
AQ Total (Survivor)	25.4	6.7	28.7	5.2	31.2	6.1
AQ Cognitive (Survivor)	1.5	0.5	1.7	0.4	1.8	0.4
AQ Beh/Aff (Survivor)	1.5	0.5	1.8	0.4	2.0	0.6
AQ Motor/Sen (Survivor)	1.4	0.3	1.5	0.4	1.7	0.4
AQ Total (SO)	29.7	4.6	26.9	5.0	18.0	5.6
AQ Cognitive (SO)	1.6	0.4	1.6	0.4	1.0	0.4
AQ Beh/Aff (SO)	2.1	0.4	1.7	0.3	1.2	0.5
AQ Motor/Sen (SO)	1.5	0.4	1.5	0.4	1.1	0.4
Self-rated driving skill	3.4	0.7	3.8	0.9	4.2	0.7
SO-rated driving skill	3.3	0.9	3.6	1.0	2.9	1.3

Note. AQ = Awareness Questionnaire, Survivor self-report, and Significant Other (SO) report on the survivor; Beh/Aff = Behavioral/Affective; Sen = Sensory.

Table 4. *Pearson Correlations: Awareness of Deficits with On-road Outcomes among ABI Survivors.*

	Group					
	Hypervigilant (n = 17)		Intact Awareness (n = 24)		Impaired Awareness (n = 21)	
Variables	*On-road Total*[1,2]	*Pass/Fail Outcome*[2]	*On-road Total*	*Pass/Fail Outcome*	*On-road Total*	*Pass/Fail Outcome*
AQ Difference Total	.12	-.08	.26	.17	-.49*	-.51**
AQ Difference: Cognitive	.15	-.28	.23	.03	-.42*	-.41*
AQ Difference: Beh/Aff	-.08	.16	-.04	.25	-.28	-.33†
AQ Difference: Motor/Sen	.10	-.08	.24	-.05	-.44*	-.44*
AQ Total (Survivor)	.34†	.09	.36*	.54**	.51**	-.22
AQ Cognitive (Survivor)	.18	-.15	.20	.27	.56**	-.25
AQ Beh/Aff (Survivor)	.26	.16	.18	.63**	.26	-.09
AQ Motor/Sen (Survivor)	.66**	.39†	.56**	.38*	.41*	-.25
AQ Total (SO)	.45*	.19	.27	.49**	.03	.30†
AQ Cognitive (SO)	.11	.03	.10	.27	.14	.20
AQ Beh/Aff (SO)	.35†	.02	.23	.54**	.00	.26
AQ Motor/Sen (SO)	.56*	.45*	.40*	.40*	.10	.26

Note. AQ = Awareness Questionnaire, Survivor self-report, and Significant Other (SO) report on the survivor; Beh/Aff = Behavioral/Affective; Sen = Sensory; Pass/Fail = eta correlations.
1. Log transformed.
2. Positive correlation denotes propensity toward pass outcome.
$^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$

Table 5. *Pearson Correlations among all ABI Survivors (n = 62).*

	1	2	3	4	5	6	7	8	9	10
1. On-road Total[1,2]	--									
2. Pass/Fail on-road[2]	.72**	--								
3. NP Composite	.45**	.58**	--							
4. AQ Difference Total	-.28*	-.24*	-.24*	--						
5. AQ Cognitive Difference	-.24*	-.26*	-.27*	.89**	--					
6. AQ Behavioral Difference	-.25*	-.15	-.18	.92**	.69**	--				
7. AQ Motor Difference	-.26*	-.26*	-.17	.75**	.58**	.56**	--			
8. Self-Limitations[3]	-.26*	-.33**	-.28**	-.03	.03	-.16	.19	--		
9. Self-rated driving ability	.20*	.17*	.00	.43**	.34**	.39**	.37**	-.12	--	
10. SO-rated driving ability	.19†	.18†	-.08	-.23†	-.15	-.24†	-.20†	-.14	.16	--

Note. Pass/Fail = eta correlations.
1. Log transformed.
2. Positive correlation denotes propensity toward pass outcome.
3. Completed only by participants driving at time of study; $n = 39$.
$^{\dagger}p < .10$, $p < .05$, $^{**}p < .01$

Table 6. *Multiple Regression Analysis of Moderation Effect: Interaction between Awareness of Deficit and Neuropsychological Performance Predicting (Log of) On-road Driving Performance among ABI Survivors.*

Variables	R^2	Beta	sr^2	*F*	*df*	*P*
Overall Predictor Model:	.25			6.50	3, 58	.001
AQ-Difference		-.05	.00			
NP Composite		-.29*	.08			
AQ-Difference * NP Composite		-.40*	.08			

Note. AQ-Difference = Awareness Questionnaire Difference Score (Survivor – SO report on survivor); NP Composite = Neuropsychological composite score.
Note. sr^2 (unique) = squared semipartial correlation.
**p* < .05

Table 7. *Pearson Correlations: Neuropsychological Tests with Driving Outcomes for ABI Survivor Groups and Controls.*

	Group							
	Control *n* = 40		Hypervigilant *n* = 17		Intact Awareness *n* = 24		Impaired Awareness *n* = 21	
Variables	*On-road Total*[1,2]	*Pass/Fail Outcome*[2]	*On-road Total*	*Pass/Fail Outcome*	*On-road Total*	*Pass/Fail Outcome*	*On-road Total*	*Pass/Fail Outcome*
NP Composite	.37**	.16	.37†	.27	.09	.52**	.56**	.60**
TMT A	-.41**	-.44**	-.59*	-.40†	-.12	-.49**	-.29	-.51*
TMT B	-.17	-.16	-.34	-.31	.06	-.39*	-.47*	-.57**
Brixton	-.12	-.15	.05	.09	.00	-.30†	-.48*	-.27
LNS	.07	-.19	.18	.05	.05	.40*	.67**	.51*
Matrix Reasoning	.30*	.00	.13	.17	.01	.09	.51*	.37†
SDMT – Written	.29*	.29*	.73**	.61*	.05	.38*	.55**	.46*
JOLO	.17	-.13	.18	-.07	.09	.21	.27	.28
Stroop Word	.17	.15	.21	.27	.43*	.66**	.13	.04
Stroop Color	.22†	.13	.22	.21	.38†	.64**	.58*	.41†
Stroop Color Word	.23†	.15	.39†	-.05	.23	.57**	.51*	.49*

Note. NP Composite = Neuropsychological Composite score; TMT = Trail Making Test; Brixton = Brixton Spatial Anticipation Test; LNS = Letter Number Sequencing; SDMT = Symbol Digit Modality Test; JOLO = Judgment of Line Orientation; Stroop = Stroop Test. Pass/Fail = eta correlations.
1. Log transformed.
2. Positive correlation denotes propensity toward pass outcome.
†p < .10, *p < .05, **p < .01

Table 8. *Pearson Correlations: Ratings of Driving Ability and Self-Limitations with On-road Outcomes among ABI Survivors and Controls.*

	Group							
	Control (n = 40)		Intact Awareness (n = 17)		Impaired Awareness (n = 24)		Hypervigilant (n = 21)	
Variables	*On-road Total*[1,2]	*Pass/Fail Outcome*[2]	*On-road Total*	*Pass/Fail Outcome*	*On-road Total*	*Pass/Fail Outcome*	*On-road Total*	*Pass/Fail Outcome*
Self-Limitations[3]	-.02	-.01	.09	-.16	-.70**	-.54*	-.31	-.20
Self-rated ability	.18	.01	.51**	.19	.01	.01	.36†	.39†
SO-rated ability	NA	NA	.55**	.09	.03	.43*	.60*	.25

Note. Pass/Fail = eta correlations.
1. Log transformed.
2. Positive correlation denotes propensity toward pass outcome.
3. Completed only by participants driving at time of study; n = 16 Intact, n = 10 Impaired, n = 13 Hypervigilant.
†p < .10, *p < .05, **p < .01

REFERENCES

Allen, C.C., & Ruff, R.M. (1990). Self-rating versus neurophysiological performance of moderate versus severe head-injured patients. *Brain Injury*, 4, 7-17.

Anstey, K.J., Windsor, T.D., Luszcz, M.A., & Andrews, G.R. (2006). Predicting driving cessation over 5 years in older adults: psychological well-being and cognitive competence are stronger predictors than physical health. *Journal of American Geriatric Society,* 54, 121 – 126.

Anstey, K.J., Wood, J., Lord, S., & Walker, J.G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25,* 45-65.

Baron, R.M. & Kenny D.A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173 – 1182.

Benton, A., Hamsher, K., Varney, N., & Spreen, O. (1978). Contributions to neuropsychological assessment: A clinical manual. *Clinical Neuropsychologist, 10,* 80-89.

Benton, A., Varney, N., & Hamsher, H. (1978). Visuospatial judgment. A clinical test. *Archives of Neurology,* 35, 364-367.

Bieliauskas, L.A. (2005). Neuropsychological assessment of geriatric driving competence. *Brain Injury, 19*(3), 221-226.

Bieliauskas, L.A., Roper, B.R., Trobe, J., Green, P., & Lacey, M. (1998). Cognitive measures, driving safety, and Alzheimer's disease. *The Clinical Neuropsychologist, 12*(2), 206-212.

Bodenheimer, C.F., Roig, R.L., Worsowicz, G.M., & Cifu, D.X. (2004). Geriatric rehabilitation. 5. The societal aspects of disability in the older adult. *Archives of Physical Medicine and Rehabilitation, 85*(S3), 23-26.

Bogod, N.M., Mateer, C.A., & Macdonald, S.W. (2003). Self-awareness after traumatic brain injury: A comparison of measures and their relationship to executive functions. *Journal of the International Neuropsychological Society, 9*, 450-458.

Brouwer, W.H., & Ponds, R.W.H.M. (1994). Driving Competence in older persons. *Disability and Rehabilitation, 16*(3), 149-161.

Brouwer, W.H., & Withaar, F.K. (1997). Fitness to drive after traumatic brain injury. *Neuropsychological Rehabilitation, 7*, 177-193.

Burgess, P.W., & Shallice, T. (1997). Hayling and Brixton Tests manual. Suffolk, England: Thames Valley Test Company Limited.

Burgess, P.W., Alderman, N., Evans, J., Emslie, H., & Wilson, B.A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society, 4*, 547-558.

Clay, O.J., Wadley, V.G., Edwards, J.D., Roth, D.L., Roenker, D.L., & Ball, K.K. (2005). Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: Current and future implications. *Optometry and Vision Science, 82*(8), 724-731.

Cohen, J. (1965). Some statistical issues in psychological research. In: B. Wolman (Ed.), *Handbook of clinical psychology* (pp. 95-121). New York: McGraw-Hill.

Coleman, R.D., Rapport, L.J., Ergh, T.C., Hanks, R.A., Ricker, J.H., & Millis, S.R. (2002). Predictors of driving outcome after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 83*, 1415-1422.

Coleman Bryer, R., Rapport, L.J., & Hanks, R. (2005). Determining fitness to drive: neuropsychological and psychological considerations. In: Pellerito J Jr, (Ed.), *Driver rehabilitation: principles and practice* (pp. 165-84). St Louis: Mosby.

Crosson, B., Barco, P., Velozo, C.A., Bolesta, M.M., Cooper, P.V., Werts, D., & Brobeck, T.C. (1989). Awareness and compensation in postacute head injury rehabilitation. *Journal of Head Trauma Rehabilitation, 4,* 46-54.

Cushman, L.A. & Cogliandro, F.C. (1999). On-road driving post-stroke: Cognitive and other factors. *Archives of Clinical Neuropsychology. 14*(8), 799.

desRosiers, G., & Kavanagh, D. (1987). Cognitive assessments in closed head injury: Stability, validity and parallel forms for two neuropsychological measures of recovery. *International Journal of Clinical Neuropsychology, 9,* 162-173.

Dixon, R.A., & Bäckman, L. (1999). Principles of compensation in cognitive neurorehabilitation. In: D. T. Stuss, G. Winocur, & I. H. Robertson (Eds.), *Cognitive neurorehabilitation*. Cambridge: Cambridge University Press, 59−72.

Edwards, J.D., Myers, C.M., Ross, L.A., Roenker, D.L., Cissell, G.M., McLaughlin, A.M., & Ball, K.K (2009). The Longitudinal Impact of Cognitive Speed of Processing Training on Driving Mobility. *The Gerontologist, 49*(4), 485-494.

Edwards, J.D., Perkins, M., Ross, L.A., & Reynolds, S.L. (2009). Driving status and three-year mortality among community-dwelling older adults. *Journal of Gerontololoy A Biological Sciences Medical Sciences, 64A*(2), 300-305.

Fisk, G.D., Schneider, J.J., & Novack, T.A. (1998). Driving following traumatic brain injury: prevalence, exposure, advice, and evaluations. *Brain Injury, 12*(8), 683-695.

Fitten, L., Perryman, K., Wilkinson, C., Little, R., Burns, M., Pachana, N., Mervis, J., Malmgren, R., Siembieda, D., & Ganzell., S. (1995). Alzheimer and vascular dementias and driving: A prospective road and laboratory study. *Journal of the American Medical Association, 273*, 1360-1365.

Fleming, J. M., & Strong, J. (1995). Self-awareness of deficits following acquired brain injury: Considerations for rehabilitation. *British Journal of Occupational Therapy, 58,* 55-60.

Flashman, L.A., Amador, X., & McAllister, T.W. (1998). Lack of awareness of deficits in traumatic brain injury. *Seminars in Clinical Neuropsychiatry, 3,* 201-210.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). 'Mini-mental State' : A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189-198.

Fox, G., Bowden, S., Bashford, G., & Smith, D. (1997). Alzheimer's disease and driving: prediction and assessment of driving performance. *Journal of the American Geriatrics Society, 45*, 949-953.

Fox, G., Bowden, S., & Smith, M. (1998). On-road assessment of driving competence after brain impairment: review of current practice and recommendations for a standardized examination. *Archives of Physical Medicine and Rehabilitation*, 79, 1288-1296.

Fordyce, D,.J., & Roueche, J.R. (1986). Changes in perspectives of disability among patients, staff, and relatives during rehabilitation of brain injury. *Rehabilitation Psychology*, 31, 217-229.

Fricke, J. & Unsworth, C. (2001). Time use and importance of instrumental activities of daily living. *Australian Occupational Therapy Journal, 48*(3), 118-131.

Galski, T., Bruno, R.L., & Ehle, H.T. (1992). Driving after cerebral damage: a model with implications for evaluation. *American Journal of Occupational Therapy, 46*(4), 324–332.

Giacino, J.T., & Cicerone, K.D. (1998). Varieties of deficit unawareness after brain injury. *Journal of Head Trauma Rehabilitation, 13*(5), 1-15.

Golden, C. (1978). Stroop Color and Word Test Manual. Wood Dale, IL: Stoelting.

Goldstein, G., & Watson, J. (1989). Test-retest reliability of the Halstead-Reitan battery and the WAIS in a neuropsychiatric population. *The Clinical Neuropsychologist, 3,* 265-273.

Goode, K., Ball, K., Sloane, M., Roenker, D., Roth, D., Myers, R., & Owsley, C. (1998). Useful field of view and other neurocognitive indicators of crash risk in older adults. *Journal of Clinical Psychology in Medical Settings, 5*(4), 425-440.

Grant, I., Reed, R., & Adams, K. (1987). Diagnosis of intermediate-duration and subacute organic mental disorders in abstinent alcoholics. *Journal of Clinical Psychiatry, 48,* 319-323.

Griffen, J.A., Rapport, L.J., Coleman Bryer, R., & Scott, C.A. (2009). Driving Status and Community Integration after Stroke. *Topics in Stroke Rehabilitation, 16*(3), 212-221.

Groeger, J. A., & Grande, G. E. (1996). Self-preserving assessments of skill? *British Journal of Psychology, 87, 61–79.*

Hartman-Maeir, A., Soroker, N., Ring, H., & Katz, N. (2002). Awareness of deficits in stroke rehabilitation. *Journal of Rehabilitation Medicine, 34*(4), 158-164.

Hedges, L. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational Statistics, 6*(2), 107–128.

Heikkila V.M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355.

Kay, L., Bundy, A., Clemson, L., & Jolly, N. (2008). Validity and reliability of the on-road driving assessment with senior drivers. *Accident Analysis and Prevention, 40*, 751–759.

Korteling, J., & Kaptein, M. (1996). Neuropsychological driving fitness tests of brain-damaged subjects. *Archives of Physical Medicine and Rehabilitation, 77*, 138-146.

Leninger, B., Gramling, S., & Farrell, A. (1990). Neuropsychological deficits in symptomatic minor head injury patients after concussion and mild concussion. *Journal of Neurology, Neurosurgery, and Psychiatry, 53,* 293-296.

Lister, R. (1999). Loss of ability to drive following a stroke: the early experiences of three elderly people on discharge from hospital. *The British Journal of Occupational Therapy, 62*(11), 514-520.

Lundqvist, A. & Alinder, J. (2007). Driving after brain injury: self-awareness and coping at the tactical level of control. *Brain Injury, 21*(11), 1109-1117.

Lundqvist, A., Alinder, J., Alm, H., Gerdle, B., Levander, S., & Ronnberg, J. (1997). Neuropsychological aspects of driving after brain lesion: simulator study and on road driving. *Applied Neuropsychology, 4*, 220-230.

Lundqvist, A., Gerdle, B., & Ronnberg, J. (2000). Neuropsychological aspects of driving after stroke – in the simulator and on the road. *Applied Cognitive Psychology, 14,* 135-150.

Lundqvist, A., & Ronnberg, J. (2001). Driving problems and adaptive driving behaviour after brain injury: A qualitative assessment. *Neuropsychological Rehabilitation, 11*(2), 171-185.

Marcel, A.J., Tegner, R., & Nimmo-Smith, I. (2004). Anosognosia for plegia: specificity, extension, partiality and disunity of unawareness. *Cortex, 40*, 17-38.

Marcotte, T., Heaton, R., Reicks, C., Gonzalez, R., Grant, I., & HNRC Group. (2000). HIV-related neuropsychological impairment and automobile driving. *Journal of the International Neuropsychological Society,6*(2), 233.

Marshall, S.C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H.M., Lamothe, C., Korner-Bitensky, N., & Wilson, K.G. (2007). Predictors of driving ability following stroke: a systematic review. *Topics in Stroke Rehabilitation, 14*(1):98-114.

Mazer, B., Korner-Bitensky, N., & Sofer, S. (1998). Predicting ability to drive after stroke. *Archives of Physical Medicine and Rehabilitation, 79*, 743-750.

Mazer, B.L., Sofer, S., Korner-Bitensky, N., Gelinas, I., Hanley, J., & Wood-Dauphinee,

S. (2003). Effectiveness of a visual attention retraining program on the driving performance of clients with stroke. *Archives of Physical Medicine and Rehabilitation. 84*(4), 541-50.

McGlynn, S.M., & Schacter, D.L. (1989). Unawareness of deficits in neuropsychological syndromes. *Journal of Clinical and Experimental Neuropsychology, 11*, 143-205.

Meyers, J., Volbrecht, M., & Kaster-Bundgaard, J. (1999). Driving is more than pedal pushing. *Applied Neuropsychology, 6*(3), 154-164.

Michon, J. A. (1985). A critical view of driver behavior models. What do we know, what should we do? In L. Evans & R. Schwing (Eds.), *Human Behavior and Traffic Safety* (pp. 485-520). New York: Plenum Press.

O'Neill, D. (2000). Safe Mobility for older people. *Reviews in Clinical Gerontology, 40*, 181-191.

Orfei, M.D., Robinson, R.G., Bria, P., Caltagirone, C., & Spalletta, G. (2008). Unawareness of illness in neuropsychiatric disorders: phenomenological certainty versus etiopathogenic vagueness. *The Neuroscientist, 14*(2), 203-222.

Ott, B.R., Heindel, W.C., Whelihan, W.M., Caron, M.D., Piatt, A.L., & DiCarlo, M.A. (2003). Maze test performance and reported driving ability in early dementia. *Journal of Geriatric Psychiatry and Neurology, 16,* 151-155.

Ownsworth, T., & Clare, L. (2006). The association between awareness deficits and rehabilitation outcome following acquired brain injury. *Clinical Psychology Review, 26*, 783-795.

Ownsworth, T., & Fleming, J. (2005). The relative importance of metacognitive skills, emotional status, and executive function in psychosocial adjustment following acquired brain injury. *Journal of Head Trauma Rehabilitation, 20*(4), 3150-332.

Poole, D., Chaudry, F., & Jay, W.M. (2008). Stroke and driving. *Topics in Stroke Rehabilitation, 15*(1):37-41.

Prigatano, G.P. (2005). Disturbances of self-awareness and rehabilitation of patients with traumatic brain injury: a 20-year perspective. *Journal of Head Trauma Rehabilitation, 20*(1), 19-29.

Prigatano, G., Altman, I., & O'Brien, K. (1990). Behavioral limitations that brain injured patients tend to underestimate. *The Clinical Neuropsychologist, 4,* 163-76.

Prigatano, G., & Fordyce, D. (1986). Cognitive dysfunction and psychosocial adjustment after brain injury. In: *Neuropsychological rehabilitation after brain injury* (pp. 96-118). Prigatano GP, Fordyce DJ, Zeiner HK, Rouceche JR, Pepping M, Woods BC, editors. Baltimore, MD: Johns Hopkins University Press.

Prigatano, G.P., & Klonoff, P.S. (1998). A clinician's rating scale for evaluating impaired self-awareness and denial of disability after brain injury. *The Clinical Neuropsychologist, 12*(1), 56-67.

Prigatano, G.P. & Schacter, D.L. (1991). *Awareness of deficit after brain injury: Clinical and theoretical issues.* New York: Oxford University Press.

Radford, K.A., & Lincoln, N.B. (2004). Concurrent validity of the stroke drivers screening assessment. *Archives of Physical Medicine & Rehabilitation, 85*(2), 324-328.

Ragland, D.R., Satariano, W.A., & MacLeod, K.E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology, 60A*(3), 399-403.

Rapport, L.J., Coleman Bryer, R., & Hanks, R.A. (2008). Driving and community integration following traumatic brain injury. *Archives of Physical Medicine, 89*, 922-930.

Rapport, L.J., Hanks, R.A., & Coleman Bryer, R.D. (2006). Barriers to driving and community integration after traumatic brain injury. *Journal of Head Trauma Rehabilitation, 21*(1), 34-44.

Rapport, L.J., Webster, J.S., Flemming K.L., Lindberg, J.W., Brees, J.E., Godlewski, M.C., & Abadee, P.S. (1993). Predictors of falls among right-hemisphere stroke patients in the rehabilitation setting. *Archives of Physical Medicine and Rehabilitation, 74*(6), 621-626.

Reger, M.A., Welsh, R.K., Watson, G.S., Cholerton, B., Baker, L.D., & Craft, S. (2004). The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. *Neuropsychology, 18*(1), 85-93.

Reitan, R., & Wolfson, D. (1988). *The Halstead Reitan Neuropsychological Test Battery*. Tucson, AZ: Neuropsychology Press.

Ryan, K.A., Rapport, L.J., Telmet Harper, K., Fuerst, D., Bieliauskas, L.A., Khan, O., & Lisak, R. (2009). Fitness to drive in multiple sclerosis: Awareness of deficit moderates risk. *Journal of clinical and experimental Neuropsychology, 31*(1), 126-139.

Schanke, A.K. & Sundet, K. (2000). Comprehensive driving evaluation: neuropsychological testing and on-road evaluation of brain injured patients. *Scandinavian Journal of Psychology, 41*, 113-121.

Schultheis, M.T., Matheis, R.J., Nead, R., & DeLuca, J. (2002). Driving behaviors following brain injury: self-report and motor vehicle records. *Journal of Head Trauma Rehabilitation, 17*(1), 38-47.

Scott, C.A., Rapport, L.J., Coleman Bryer, R., Griffen, J., & Hanks, R. & McKay, C. (2009). Self-Assessment of driving ability and the decision to resume driving following stroke. *Journal of Clinical and Experimental Neuropsychology, 31*(3), 353-362.

Sherer, M., Bergloff, P., Boake, C., High, W., & Levin, E. (1998a). The Awareness Questionnaire: Factor structure and internal consistency. *Brain Injury, 12*, 63-68.

Sherer, M., Bergloff, P., Levin, E., High, Jr., W.M., Oden, K.E., & Nick, T.G. (1998b). Impaired awareness and employment outcome after traumatic brain injury. *Journal of Head Trauma Rehabilitation, 13*, 52-61.

Sherer, M., Hart, T., Whyte, J., Nick, T.G., & Yablon, S.A. (2005). Neuroanatomic basis of impaired self-awareness after traumatic brain injury findings from early computed tomography. *Journal of Head Trauma Rehabilitation, 20*(4), 287-300.

Sherman, T.E., Rapport, L.J., & Ryan, K.A. (2007). Awareness of deficit in multiple sclerosis. *Journal of Clinical and Experimental Neuropsychology, 12*, 1–11.

Smith, A. (1973). *Symbol Digit Modalities Test: Manual.* Los Angeles: Western Psychological Services.

Smith, A. (1991). *Symbol Digit Modalities Test.* Los Angeles: Western Psychological Services.

Spreen, O., & Strauss, E. (1998). *A Compendium of Neuropsychological Tests:*

Administration, Norms, and Commentary (Second Edition). New York: Oxford University Press.

Starkstein, S.E., Federoff, J.P., Price, T.R., Leiguarda, R. et al. (1993). Neuropsychological deficits in patients with anosognosia. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 6*, 43-48.

Stuss, D.T. (1991). Disturbance of self-awareness after frontal system damage. In G. P. Prigatano & D. L. Schacter (Eds.), *Awareness of Deficit After Brain Injury: Clinical and theoretical issues* (pp.63-83). New York: Oxford University Press.

Tabachnick, B.G., & Fidell, L.S. (2006). *Using multivariate statistics* (4th ed.). Boston, MA: Allyn and Bacon.

Tombaugh, T. N., & McIntyre, N. J. (1992). The Mini-Mental State Examination: A comprehensive review. *Journal of American Geriatric Society, 40,* 922-935.

Trobe, J., Waller, P., Cook-Flannagan, C., Teshima, S., & Bieliauskas, L. (1996). Crashes and violations among drivers with Alzheimer's disease. *Archives of Neurology, 53*(5), 411-416.

van Zomeren, A., Brouwer, W., & Minderhoud, J. (1987). Acquired brain damage and driving: a review. *Archives of Physical Medicine and Rehabilitation, 68*, 697-705.

van Zomeren, A.H., Brouwer, W.H., Rothengatter, J.A., & Snoek, J.W. (1988). Fitness to drive a car after recovery from severe head injury. *Archives of Physical Medicine and Rehabilitation, 69*, 90-96.

Vuilleumier, P. (2000). Anosognosia. In J. Bogousslavsky & J. L. Cummings (Eds.) *Behavior and mood disorders in focal brain lesions* (pp. 465-519). Cambridge, UK: Cambridge University Press.

Vuilleumier, P. (2004). Anosognosia: The neurology of beliefs and uncertainties. *Cortex, 40*, 9-17.

Waldron-Perrine, B., Rapport, L.J., Ryan, K.A., & Telmet Harper, K. (2009). Predictors of Life-Satisfaction in Caregivers of Persons with Multiple Sclerosis. *The Clinical Neuropsychologist, 23,* 462-478.

Wechsler, D. (1997). Wechsler Adult Intelligence Scale (3rd ed.). San Antonio, TX: Psychological Corporation.

Withaar, F., Brouwer, W., & Van Zomeren, A. (2000). Fitness to drive in older drivers with cognitive impairment. *Journal of International Neuropsychology, 6,* 480-490.

ABSTRACT

AWARENESS OF DEFICITS AND ON-ROAD DRIVING PERFORMANCE AMONG PERSONS WITH ACQUIRED BRAIN INJURY

by

JULIE A. GRIFFEN

August 2011

Advisor: Dr. Lisa J. Rapport

Major: Psychology (Clinical)

Degree: Doctor of Philosophy

This study examined the relationship of neuropsychological and on-road driving evaluations among adults with acquired brain injury (ABI), and the extent to which that relationship is moderated by awareness of deficit. Awareness of deficit may partly explain mixed findings regarding the relationship between cognitive function and driving outcomes, inasmuch as persons aware of their deficits attempt to compensate for them accordingly, thereby minimizing deficit-related risk.

Sixty-two pairs of adults with ABI and significant-other informants recruited from a driving evaluation center and 40 healthy controls participated. Adults with ABI and controls completed neuropsychological and on-road evaluations.

Awareness of deficit was directly related to driving outcomes and was also a moderator between the relationship of neuropsychological functioning and driving performance. Multiple regression indicated the interaction between neuropsychological test performance and awareness of deficits explained significant variance in driving performance. The moderation effect was illustrated by different relationships between

neuropsychological and on-road performances among the awareness groups: Among adults with impaired awareness (n = 21), neuropsychological functioning was substantially related to driving outcomes; in contrast, driving outcome showed weak relation to neuropsychological functioning among those with intact (n = 24) or hypervigilance (n = 17) toward their deficits. An exception was that processing speed showed modest relation to on-road outcome for all groups, including healthy controls. Adults with impaired awareness of their deficits rated their driving more highly than did adults with hypervigilance towards or intact awareness of their deficits. Significant-other ratings were strongly related to use of driving limitations among survivors with impaired awareness of their deficits, consistent with findings that the caregivers "hold the keys."

Awareness of deficit has a considerable influence on driving outcomes both directly and as a moderator between the relationship of neuropsychological functioning and driving performance. When adults with ABI lack appreciation for their impairments, their neuropsychological status is especially important in predicting driving outcomes. Even minor deficits, if not recognized and compensated for appropriately, can increase driving risk substantially.

AUTOBIOGRAPHICAL STATEMENT

Julie A. Griffen received her Bachelor's of Arts degree in psychology from Calvin College in 2003. She began graduate training towards a Ph.D. in clinical psychology at Wayne State University in 2004. Throughout graduate school, she received extensive practicum training in clinical neuropsychology, rehabilitation psychology, and general clinical psychology at the University Health Center and the Rehabilitation Institute of Michigan of the Detroit Medical Center, and Wayne State University's Psychology Clinic. She completed her Master's degree in August 2007: her Master's Thesis was titled *The Effect of Driving Status on Community Integration in Stroke Survivors. S*he has presented these findings at an international conference and published them in a peer reviewed journal. She will be beginning her APA approved internship at the University of Alabama, Birmingham Psychology Training Consortium in August 2010.