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Self-evaluation of driving simulator performance in stroke patients

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SELF-EVALUATION OF DRIVING SIMULATOR PERFORMANCE IN STROKE PATIENTS

by

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Abstract

Impaired self-awareness (ISA) of deficit has far-reaching and potentially catastrophic consequences to stroke survivors. Previous research suggests that self-awareness greatly depends on the context or nature of the task. One of the most potentially dangerous consequences of ISA manifests when stroke survivors attempt to resume driving prematurely. Despite these potential dangers, very little research has examined the manifestations of ISA and driving. The present study examined the self-awareness of driving simulator and neuropsychological performance among stroke patients, comparing them to healthy control participants. Thirty stroke survivors and 30 controls were each asked for prediction and postdiction ratings of their performance on various driving simulator and neuropsychological tasks. Self-estimates versus actual performance discrepancy scores were calculated for various simulator and neuropsychological measures. The results indicate that across all measures, the stroke survivors greatly overestimated their performance in comparison to the accuracy of self-evaluations among the controls, thus suggesting impaired self-awareness. This pattern of overestimating was observed on both novel (neuropsychological) and familiar (driving) tasks. However, there was some evidence to suggest that stroke survivors can benefit from feedback, as seen by increased accuracy in postdiction versus prediction self-evaluation scores. Additionally, both stroke survivors and controls showed greater shift toward accurate self-estimation on postdiction of driving performance than on postdiction of neuropsychological test performance. Although the temporal stability of the shift in awareness is not known, these results support the use of driving simulators as a useful and safe method of assessing and potentially improving stroke survivors' ISA.

DEDICATION

This dissertation is dedicated to my parents, John and Janis McKay, who never missed a school play, baseball game, family dinner, or rent cheque when needed. In a society where upbringing and parenting give some children no choice but failure, I benefited from a parental environment that gave me no choice but to succeed.

Thank you Mom and Dad.

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Chapter 1: Introduction

Stroke is the fourth leading cause of death in Canada; each year, between 40 000 to 50 000 Canadians will suffer a stroke, resulting in approximately 16 000 deaths per year (Heart and Stroke Foundation of Canada, 2002). As a result of stroke, individuals may experience short-term and permanent impairments in many domains, including cognition, emotion, social interaction, and general behaviour. However, many stroke survivors experience significant limitations in their self-awareness of these deficits, a pattern that can greatly hinder their activities of daily living and independence, including driving. The purpose of this study is to examine stroke survivors' self-awareness of driving ability as measured by the discrepancies between actual and estimated performance on a driving simulator task.

The probability of a stroke survivor returning to driving ranges from 30% to 75% (Mazer, Gelinas, & Benoit, 2004). In the event of driving cessation, stroke survivors experience a 42% decline in health-related quality of life (Poissant, Mayo, Wood-Dauphinee, & Clarke, 2004) which may be attributable to increased frequency of depression, less access to community activities, and limited ability to socialize (Mazer et al., 2004). Due to the large number of Canadians impacted by stroke and the potentially widespread consequences of driving cessation, accurate identification and effective retraining of driving abilities are of the utmost importance in this population. In order to do so one must understand the many facets of driving ability, how they are impacted by stroke, and the measures that can be implemented to help retrain individuals. Of these factors, one of the most important is self-awareness of deficit as it affects the implications of the distinct cognitive and physical disorders, as well as an individual's approach to rehabilitation methods.

In terms of driving resumption, there needs to be a balance between encouraging the return to functional independence and public safety. Although there are currently numerous avenues of assessment aimed at determining one's fitness to drive, one of the primary factors remains the individual's decision itself. In theory, the decision to return to driving is a complicated and multidimensional task that includes the ability to evaluate the demands of the task accurately in the context of one's ability to manage those demands. This evaluative process must occur in cognitive, emotional, and physical domains and requires accurate self-evaluation. Unfortunately, following neuropsychological deficits, such as those following stroke, an individual's self-evaluation of his/her functioning in these areas is often compromised (Prigatano & Klonoff, 1998). Therefore, it is important for clinicians to be aware of clients' self-evaluation process and how it occurs in the context of driving resumption.

The present study will investigate self-evaluation of driving performance in stroke patients. This introduction will be divided into two primary chapters. The first chapter will discuss the construct of self-awareness, including a discussion of general theories, methods of measurement, and its relationship to different domains and skills. The second chapter will then turn to a description of the literature pertaining to stroke and driving ability. This chapter will contain a discussion of general theories of normal driving ability, the clinical manifestations of driving deficits in stroke patients, self-evaluation of driving abilities, and the recent use of driving simulators as a possible procedure for improving self-awareness in stroke patients.

Impaired Self-Awareness

Definition of ISA

ISA can have devastating effects on an individual's ability to manage their environment effectively. In fact, self-awareness has been viewed as the highest form of brain activity that mediates and interacts with other brain processes (Stuss, 1991). In a clinical setting, ISA can result in lack of motivation to participate in rehabilitation, unwillingness to use assistive/compensatory devices, the decision to leave treatment prematurely, and poor choices regarding community integration. This can subsequently lead to vocational choices that exceed ability, which may result in safety risks and increased probability of long-term psychological problems. In fact, self-awareness has been identified as a powerful predictor of vocational success (Sherer, Bergloff et al., 1998) and rehabilitation outcome (Sherer, Boake et al., 1998). A recent review of the literature pertaining to rehabilitation outcome following acquired brain injury revealed that 10 of 12 empirical studies indicated a strong positive correlation between self-awareness of deficit and rehabilitation outcome (Ownsworth & Clare, 2006). At the other end of the spectrum, self-awareness has been found to predict behavioural disturbance in acquired and traumatic brain injury independent of cognitive and executive function (Bach & David, 2006). Most relevant to the current study, self-awareness also plays an essential role in self-judgment regarding fitness to drive (Coleman et al., 2002; Scott et al., 2007).

Within research, a variety of terms have been used to describe ISA, including lack of insight, anosognosia, and neglect, as well as terms such as denial, eutonia, indifference, and metacognition. Unfortunately, the true definitions of these terms do not allow for interchangeable use. For instance, although both denial and anosognosia involve the denial of deficits, the underlying mechanisms are different (i.e., denial reflects a defense mechanism to alleviate emotional upset whereas anosognosia represents a lack of awareness likely caused by brain damage). Therefore, it is important to properly define the terminology and distinguish between concepts. The terms unawareness and anosognosia (literally meaning "without knowledge of disease") are often used interchangeably in the literature (Hartmann-Maeir, Soroker, Oman, & Katz, 2003). Babinski (1914; as cited in Vuilleumier, 2004) first coined the term "anosognosia" to describe an individual's lack of knowledge, awareness, or recognition of their physical disease. By definition, anosognosia occurs in "patients with neurological impairments who appear unable to notice and acknowledge the existence of deficits, often despite blatant evidence for the handicap (e.g., hemiplegia)" (Vuilleumier, 2004, p. 9). Self-awareness has been defined as "the capacity to perceive the 'self' in relatively 'objective' terms whilst maintaining a sense of subjectivity" (Prigatano, & Schacter, 1991, p. 13). It involves the "interaction between thoughts (i.e., knowledge of the situation in an objective sense) and feelings (i.e., appreciation or unique interpretation of situation in a subjective sense)" (Prigatano & Schacter, 1991, p. 13). Conversely, ISA 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). For the purposes of this study, the terms anosognosia, unawareness of deficit, and ISA will be used interchangeably to communicate this concept.

In the context of stroke, ISA is noted most frequently in the most severe form: hemineglect. Hemineglect (particularly in terms of unawareness for hemiplegia) is also one of the most common manifestations of ISA in stroke populations as it occurs in 20 to

30% of the stroke population (Vuilleumier, 2004). Initial studies on awareness after stroke addressed this striking phenomenon of unawareness of paralysis, particularly in right-hemisphere damage (Hartmann-Maeir, Soroker, Ring, & Katz, 2002). Since then, there has been some debate as to whether self-awareness of deficit shows consistent lateralization. Some researchers have shown that it occurs at higher rates in individuals who suffer right-sided strokes (Anderson & Tranel, 1989; Hartmann-Maeir et al., 2002) whereas others have failed to find a consistent lateralization pattern (Hartmann-Maeir et al, 2003; Hibbard, Gordon, Stein, Grober, & Sliwinski, 1992). Regardless of lateralization, ISA of deficit constitutes a significant problem in stroke patients, not only in terms of the severe forms such as hemineglect, but also in its more subtle aspects, for example, ignorance of cognitive, physical, and emotional deficits. In fact, the incidence of ISA in stroke populations has been reported to be as high as 39 to 50% (Hartmann-Maeir et al., 2002; Wagner & Cushman, 1989) and in one study, 30% of the sample did not spontaneously acknowledge having a stroke at all (Hartmann-Maeir et al., 2002).

Theories of ISA

Numerous theories have proposed possible mechanisms or factors involved in self-awareness. Fleming and Strong (1995) discussed three levels of self-awareness: 1) knowledge of deficits; 2) functional implications of the deficits; and 3) realistic expectations in predicting performance. Flashman and colleagues (Flashman, Amador, & McAllister, 1998) expanded upon this theory by proposing similar cognitive dimensions (i.e., knowledge of deficit and ability to comprehend impact of deficit on daily life) and by also including the emotional response to the deficit (i.e., anger, denial, apathy) as a critical dimension related to self-awareness. Similarly, Allen and Ruff (1990) distinguished between psychological and neuropsychological/cognitive factors among three levels of processing that they believed influenced the accuracy of a patient's self-reporting. The first level, termed awareness, requires the ability to attend to, encode, and retrieve information in relation to one's self; neuropsychological factors mostly affect this level. Appraisal, the second level, occurs when the patient compares information about the current self with premorbid self-evaluations, a process mediated by both emotional and cognitive functioning. Finally, disclosure is the willingness to report one's self-perception to another person or clinician, again a process mediated by both cognitive and emotional factors.

Many other potential mechanisms have been proposed since the inception of these general theories. There are emotional and motivational theories pertaining to inaccurate self-evaluation. ISA may involve a deficient affective drive that inhibits a person's ability to respond to uncertainties about current bodily states or cognitive abilities or leads to lessened emotional impact of perceived or supposed failure (Vuilleumier, 2000). A patient with ISA may placidly accept only partial knowledge about his/her current state and fail to engage in verification processes that one would normally carry out when faced with novel or threatening challenges (Vuilleumier, 2004).

Conversely, there have also been hypotheses regarding the relationship between ISA and brain dysfunction, and other comorbid cognitive sequelae (Vuilleumier, 2000). Damage to subcortical circuits may lead to compromised self-monitoring processes and inability to modify one's beliefs and behaviours based on novel experience (Vuilleumier, 2000). General disorder theories of awareness deficits suggest there is an executive or supervising control function providing direction to other subordinate cognitive skills and therefore significant disruption of higher order cognition (e.g., monitoring, self-regulation) may lead to deficits in self-awareness (Stuss, 1991).

Recent research has begun to examine the relationship between self-awareness and other executive functions in neurological populations, including stroke. Although there seems to be a relationship between executive functioning and self-awareness, no specific neuropsychological profile is associated with ISA. Research has found that specific deficits in set-shifting and flexibility, processes usually associated with the frontal lobes, are more frequent in patients with ISA (Starkstein, Fedoroff, Price, Leiguarda et al., 1993). In some studies, scores on executive function tasks have shown stronger correlations with ISA than tests of other neuropsychological domains (Burgess, Alderman, Evans, Emslie, & Wilson, 1998). In contrast, other studies have shown measures of self-awareness to be unrelated to performance on other executive function tasks (Bogod, Mateer, & Macdonald, 2003). The discrepant findings regarding the relationship between executive functioning measures and self-awareness may stem from the fact that they are both very complicated and multifaceted constructs. Although most would agree that executive functioning comprises a vast array of distinct yet interacting abilities, self-awareness has been viewed mostly as a one-dimensional entity. Also, self-awareness has proven to be a difficult phenomenon to operationally define and measure given its complicated and intangible nature.

Measurement of ISA

The discrepancy between findings may result from how self-awareness is defined and measured. There has been a lack of uniform methodology in neuropsychological research examining this phenomenon. Approaches have used different definitions and measurements of awareness and hence given rise to different, and on occasion, divergent, awareness results (Markova & Berrios, 2006). Early research on this construct generally relied on clinical observation and rarely operationally defined unawareness of deficit with explicit criteria (Ergh, 2004). In general, there are three primary approaches to the measurement of self-awareness: the discrepancy between the patient's report and others' (e.g., significant other, therapist, doctor); the discrepancy between the patient's description of his/her abilities and the actual abilities as measured by neuropsychological tests; and a metacognitive approach employing predicted performance experiments. Most often, self-awareness is measured by comparing the patient's self-report on a questionnaire to that of their significant other or relatives. The primary advantage to this approach is that relatives often know the patient prior to the disability and spend a significant amount of time with the patient in a variety of settings, thus acting as a reliable informant (Ergh, 2004). However, although it is expected that the patient's self-report may be inaccurate, the reliance on significant others' reports as the "correct" determination of the patient's actual functioning may also lead to biased results since they may lack objectivity and are usually emotionally invested in their significant other's functioning.

In order to eliminate the potential bias resulting from others' reports, another approach that has been implemented is the use of the discrepancy between the patient's description of his/her abilities and the patient's abilities as measured by neuropsychological tests. The primary advantage to this approach is that it includes an objective measure of the patient's deficits by using standardized tests of neurocognitive performance that have normative bases. One of the most common measures used in this approach is the Awareness Interview (Anderson & Tranel, 1989), a structured interview of patients' general descriptions of their abilities (e.g., memory, attention). Using this methodology, Anderson and Tranel discovered that neurological damage resulting from stroke, TBI, and dementia was frequently accompanied by some degree of unawareness of deficits. However, this approach relies on patients' descriptions of broad domains (e.g, memory) whereas the neuropsychological tests tend to be highly specific and novel. As such, it becomes hard to determine whether the patient is reporting on the same ability that is being measured by the neuropsychological test (Trosset & Kaszniak, 1996).

A more reliable and valid evaluation of self-awareness would involve the comparison of the patient's self-rating of a particular domain to their actual test performance within that domain. This approach borrows from the metacognition literature (i.e., knowing about one's own cognitions) and implements predicted performance experiments (Ergh, 2004; McGlynn & Kaszniak, 1991; Trosset & Kaszniak, 1996). Patients predict their performance on specific cognitive tasks and awareness is measured as the discrepancy between predicted and actual performance, thus allowing for a direct comparison because the quantities are measured on the same scale (Trosset & Kaszniak, 1996). Trosset and Kaszniak (1996) introduced the basic analysis for using predicted performance experiments. Their first experiment involved examining the discrepancy between a patient's predicted performance (ppp) and a patient's actual performance (pap) on a particular task using raw scores for the estimations. In following experiments, they also asked patients to predict their caregiver's cognitive performance (ppc) in order to delineate whether an overall impairment in judgement was underlying the problem. Finally, as a means of controlling whether overprediction of personal abilities was disease-specific or just a general human tendency, Trosset and Kaszniak asked the healthy caregivers to predict his/her own performance (cpc) as well as the patient's performance (cpp) while also measuring the caregiver's actual performance (cap). From these experiments, the researchers developed a final equation entitled the "Comparative Prediction Accuracy" (CPA) which was calculated as:

$$CPA = \frac{(ppp/pap)/(ppc/cap)}{(cpc/cap)/(cpp/pap)}$$

Although this approach served as a foundation for future research, there were several methodological limitations inherent in its design. First, this approach is limited by its reliance on a person's ability to predict their performance on a task with which they are unfamiliar (Trosset & Kaszniak, 1996). Patients are typically asked to predict their performance following task instructions; however they may still find it hard to ascertain the cognitive functions tapped by the tasks. Failure to assess the cognitive abilities underlying the tasks may hinder accurate predictions. This may be partially remedied by obtaining post-task estimations from the patient, who at that time will have a better idea of what the task involved and how he/she performed. This approach also allows for an evaluation of how well a patient is able to respond to feedback.

Using this approach, Marcel, Tegner, and Nimmo-Smith (2004) conducted one of the strongest evaluations of the relationship between self-awareness and executive functioning. They examined stroke patients' ability to evaluate flexibly their performance on traditional tests of executive functioning (e.g., sorting tasks, verbal fluency) based on their pre-test expectations and actual test outcomes. Patients' predictions of task performance were compared to the patients' actual performance. Overall, stroke patients displayed a significant overestimation of their performance and the proportion of overestimation increased as severity of executive dysfunction increased. Following that, the researchers asked patients to re-evaluate their performance after the task. A hemispheric difference was observed as those individuals with left-sided injuries made a significant adjustment in their estimates whereas those with right-sided injuries showed minimal adjustment. These results were consistent with the general consensus that awareness deficits occur predominantly in right-hemisphere injuries (Ownsworth, McFarland, & Young, 2002). From these findings, the authors concluded that accurate awareness of deficit requires some form of calibration based on direct personal experience with the deficit and a special type of mental flexibility needed to adjust behaviour based on that experience. As such, they suggested that when possible, post-task estimations should also be used to obtain a more reliable index of self-awareness.

Second, this methodology involved the use of raw scores for estimation. Raw scores are meaningless by themselves and need to be placed in the context of normative expectations, particularly for patients who are unfamiliar with the task at hand (Ergh, 2004). Raw scores provide no anchor for which a person to accurately judge their performance in comparison to the normative sample, or against the "average person", nor do they include the relative impairment ranges that correspond to test performance. For example, if a patient is asked to predict how many items they will remember on a 20-item recognition memory test, they may estimate 15 assuming that it equates to an above-average performance (75% accuracy). In reality, this raw score would be indicative of impaired performance when using normative comparison data. Thus, asking patients for raw score equivalents most likely introduces more ambiguity to the measurement of unawareness of deficit.

Ergh (2004) developed an alternative measurement technique to eliminate the reliance on raw scores and their inherent ambiguity and pilot a model of metacognitive awareness of cognitive deficit for use in various populations. In the preliminary study, individuals with multiple sclerosis (MS) were asked to rate their performance compared to others their age. Instead of asking for raw scores, participants were provided choices that could be scaled to T-score equivalents with clear interpretive markings (e.g., extremely worse than other healthy people your age, much worse, worse, the same, better, much better, and extremely better)(Ergh, 2004). They were then asked to estimate their performance on the test based on the given performance ranges (patient's predicted T-score performance: pptp). The participant's neuropsychological performance was also converted to a T score based on normative data (patient's actual T-score performance: patp). By using this method, the difference score obtained was anchored in standard units. The researcher then divided the discrepancy score by a measure of dispersion (normative T-score standard deviation of 10) to anchor the result in standard deviation units, similar to a z score. Thus, the result of 1.0 was translated to the person overestimating his/her performance by 1 standard deviation (i.e., 10 T-score points). Thus, Ergh proposed and implemented "Metacognitive Discrepancy Scores" as the measure of awareness:

$$\frac{\text{patp} - \text{pptp}}{10}$$

Ergh utilized this equation for both pre- and post-test predictions. Positive scores represented unawareness of cognitive deficits, whereas negative scores represented hyperawareness (i.e., participants estimated that they performed worse than they actually did). Using this method, the findings showed that approximately one third of the MS sample demonstrated diminished awareness of their cognitive and/or functional deficits.

ISA Across Domains

Common sense suggests that ISA occurs across a wide variety of domains, including emotional, physical, cognitive, and behavioural ones. Despite this, only a small number of studies have directly compared the nature of self-awareness in different contexts or domains and the results of these studies have been contradictory. Prigatano, Altman, and O'Brien (1990) found that individuals who had suffered a traumatic brain injury showed differing levels of self-awareness across various domains. In comparison to the reports of others regarding various activities of daily living, patients overestimated their abilities in non-physical areas (i.e., social interaction, emotional control, cognition) whereas their evaluations of their physical capabilities and self-care were more accurate. Conversely, in a study examining 87 stroke patients, the largest discrepancy between patients' reports and those of their significant others occurred in the evaluation of motor activities. On cognitive and emotional aspects, patients actually rated themselves as more impaired than significant others did (Gauggel, Peleska, & Bode, 2000).

Anderson and Tranel (1989) examined ISA of cognitive and motor deficits among stroke patients. A self-report measure of awareness was administered to patients 3 to 25 days post stroke. Whereas 28% of the patients were unaware of their motor deficits, 72% of the sample showed impaired awareness for cognitive deficits. Specifically, less than one-third of patients were accurate about their abstracting abilities and 50% showed impaired awareness of their memory and language functioning.

Fischer, Trexler, and Gauggel (2004) combined a self-report method with the predicted performance method of self-awareness to examine possible domain differences. Patients in two groups, a mixed neurological sample [traumatic brain injury (TBI) and cerebrovascular accident (CVA)] and orthopaedic controls, were asked to complete test of simple motor ability (finger tapping) and cognition (list learning). There was no over-prediction of performance on simple motor tasks in any of the groups. There was a discrepancy, however, between the TBI and CVA patients in both awareness measures. Whereas the TBI group showed over-estimation in the self-report and list learning task, the CVA group only showed an over-estimation in the list learning task, and to a lesser extent than the TBI group. The authors used these results as the basis for warning against the assumption that some self-report measures that were designed initially for bilateral or diffuse injuries (i.e., TBI) would reflect self-awareness deficits observed in asymmetric or unilateral injuries, such as unilateral CVA. Instead, the authors suggested the use of the predicted performance method in CVA populations.

From these findings, it appears that self-awareness in stroke patients differs as a function of the context involved. Self-awareness for novel versus familiar tasks has not been examined. As Marcel's theory stated, self-awareness requires some form of calibration based on personal experience (Marcel et al., 2004) and an individual's ability to adjust behaviour based on this experience. As such, it is possible that self-awareness following stroke may differ depending on the amount of experience one has had with the task prior to injury; that is the degree of familiarity or habituation. Thus, individuals may show less accurate self-appraisals of activities they believe are well-learned or familiar, such as driving.

Driving After Stroke

Models of Driving Ability

Many models of driving have been proposed in attempts to describe, classify, and simplify its multidimensional nature. These models have contributed to the understanding of driving by elucidating the components of normal driving as well as aiding the determination of risk factors for unsafe driving. Models differ in their focus. Some primarily describe emotional and motivational factors, others look only at cognitive abilities, and, more recently, some have begun to describe the interaction of these variables. Within neuropsychological research, however, most emphasis has been placed on the cognitive and interactive models.

Early in the driving literature, research focused on what were considered the basic elements of driving performance. Specifically, there was an erroneous belief that psychomotor abilities such as visual scanning, reaction time, along with knowledge of driving regulations, interact to form a hypothetical construct of "driving skill". The more driving skill an individual had, the better driver they would be. Hopewell (2002) proposed that this was related to what he termed the "rehabilitation myth" (p. 52) that is, the better professionals trained a neurologically impaired driver, the more "driving skill" they would recover, a concept analogous to exercising muscles to regain physical strength and endurance. Hopewell stated that although such skills are necessary for successful driving, they were by no means sufficient for safe driving. Instead, he theorized that these skills were actually less predictive of driving risk than cognitive, executive, and personality functions.

Michon (1985) proposed a theory of driving behaviour that included both basic and higher order processes. He proposed three levels of decision-making involved in safe driving rather than focusing on basic elements of driving performance. The strategic level involved decisions concerning the planning of safe driving with regard to time and route. This level was not time-dependent and could take place both in and out of the car. Cognitively, functioning at this level was mostly memory and reasoning driven and would therefore become impaired by deficits in memory, executive functioning, or reasoning (Mazer et al., 2004). Michon's second level involved decisions regarding the basic manoeuvring and negotiation of common driving situations, decisions, and actions and was termed the tactical level. At this stage, individuals were required to make correct judgements of traffic situations and partake in anticipatory risk avoidance behaviours. Decisions were somewhat time-dependent and data driven by one's immediate driving environment. As such, performance at this level required cognitive control and flexibility, awareness of traffic demands and allocating attention appropriately. Finally, the operational level involved actual vehicle control inputs and comprised largely automatized action patterns, immediate time reactions, and perceptual speed. Michon described this level as the most basic of the three and involving what was previously termed “driving skill.”

Since the inception of Michon’s model, much research has examined performance among these levels in both neurologically intact and impaired populations. Despite Michon’s proposal stating that each of the three levels was equally important, most neuropsychological researchers and clinical practitioners have continued to focus primarily on the operational level (i.e., “driving skill” elements), and to a lesser extent, the tactical level, whereas higher order executive functioning and reasoning involved in actual driving behaviour have been left relatively unexamined. The unequal focus on operational tasks may result from the nature of the neuropsychological tests themselves. Basic cognitive skills (e.g., reaction time) are easier to separate and evaluate than more complex and multifaceted constructs such as executive functioning and reasoning. However, given the equal importance that Michon placed on higher order and strategic decision making, compared with the other two levels, examination of these variables would surely provide important information about the elucidation and prediction of driving behaviours.

Whereas Michon’s model of driving focused on the components of safe driving, Galski and colleagues (Galski, Bruno, & Ehle, 1992) proposed a Cybernetic model designed to diagnose the cause of driving problems. The authors delineated between what they termed “general” and “specific” driving programs. The general driving program consisted of the executive skills needed for driving, including complex information processing that serves as a mechanism that initiates and directs all driving-related activities. It also included dynamic memory, which was described as an expert system required to apply road knowledge in routine situations yet also maintain the capacity to adopt to new situations with the use of available information. With brain damage, individuals were hypothesized to lose some or all of their dynamic memory which could be seen in their incapacity to build upon driving experience or to apply learned information. The specific driving program was considered a volitional process that sets and implements particular driving plans once the general program determines the most effective approach.

The Cybernetic model also includes four additional systems according to Galski and colleagues (1992). The first two of these systems consist of the basic sensory input and motor output encountered in the driving environment. The third system serves to calculate, integrate, and coordinate sensory information by mechanisms such as efficient visual scanning and selective attention. It is referred to as the calculation and construction co-processor. Finally, Galski and colleagues describe the “resident diagnostic program” the most complex of the four additional systems. This system’s primary purpose is to act as a warning mechanism to the driver about potential dangers to the rest of the system. To do so, this system requires intact cognitive reasoning, executive functioning, and psychological factors.

As both Michon and the Cybernetic model suggest, driving is a complex and multifaceted task that is hindered by deficits at various levels, from basic reaction time and sensory input to complex executive functioning and reasoning. The strong theoretical foundation put forth by these researchers is, therefore, particularly important in research examining driving in neurologically impaired populations. However, despite their emphasis on higher-order and executive functioning, research has only recently begun to fully investigate the various processes involved in driving in these populations. Examination of these variables is particularly important in populations known to demonstrate various deficits in executive functioning, such as individuals with stroke.

Driving Ability Following Stroke

Many factors contribute to an individual's decision to resume driving duties following stroke, including the opinion of the clinician, need or desire to drive again, as well as the cognitive and physical limitations following stroke and the degree to which the individual perceives these restrictions to performance. Clearly, some sequelae of stroke, such as visual field deficits (e.g., homonymous hemianopia), epileptic seizures, neglect, and apraxia, strongly contradict driving resumption. The relationship between cognitive impairment and driving safety tends to follow an "inverted-U" distribution of risk versus injury severity. Those with very severe strokes will be less likely to return to driving as their level of physical and cognitive functioning clearly prevents independent functioning during even basic activities of daily living. Thus, they pose little driving risk. On the other end of the spectrum, individuals with very mild strokes will most likely exhibit very few, if any, residual deficits and will therefore show no more safety risk than the average driver. The individuals whose stroke severity falls between the very mild and very profound, however, are those who necessitate fitness to drive assessments and driving rehabilitation as they pose the greatest risks to themselves and others if they attempt to return to driving prematurely.

There is much debate as to whether stroke survivors pose an exaggerated safety risk on the road. Some studies suggest that stroke survivors show no increased risk for accidents or citations compared to normal controls (Haselkorn, Mueller, & Rivara, 1998; Katz et al., 1990) whereas others have found a history of stroke or transient ischemic attacks (TIA) to be significantly associated with accidents five years post-injury (Sims, McGwin, Allman, Ball, & Owsley, 2000). Similarly, others have argued that a strong relationship exists between stroke and driving risk but this relationship is masked by the fact that stroke is strongly correlated with decreased average mileage (Lyman, McGwin Jr., & Sims, 2001). In a review of the literature, van Zomeren and colleagues concluded "brain-damaged drivers could not, in general, be seen as risky drivers, although some individuals show decreased driving skill and risky behavior in traffic" (van Zomeren, Brouwer, & Minderhoud, 1987, p. 697). These studies differed in their evaluation of "safe" driving behaviour (e.g., number of traffic citations, self-report). These variations may contribute to the debate over stroke patients' driving safety. Therefore, a valid and comprehensive method of identifying stroke patients who are unsafe to resume driving is beneficial, if not necessary.

Neuropsychological assessment has been demonstrated to be helpful in the identification of unsafe driving performance because it examines the many facets of both stroke and driving ability, including cognitive, emotional, and behavioural functioning. Hopewell and van Zomeren (1990) proposed that five major factors account for most of the variance in driving skill and driving risk: driving and accident/violation history, general personality and attitudinal factors, pattern and severity of alcohol/substance abuse, nature and extent of psychiatric and executive disturbance, and basic psychomotor abilities. Therefore, neuropsychological assessment is helpful in this setting as it allows for the evaluation of psychiatric, executive, and psychomotor abilities, all of which are known to be potentially affected by stroke.

Although basic sensory-perceptual functions are frequently compromised after stroke, the presence of such impairment does not necessarily hinder driving ability. For example, peripheral vision and contrast sensitivity were found to be impaired in comparison to healthy controls in stroke survivors but impairments in peripheral vision or visual acuity did not distinguish between stroke survivors who did and did not resume driving (Fisk, Owsley, & Mennemeier, 2002). Similarly, Nouri and colleagues found that the results of tests of vision and visual fields were not related to driving performance (Nouri, Tinson, & Lincoln, 1987).

More complex visual abilities, however, such as visual scanning, as well as selective and divided attention, have been found to be related to driving performance in stroke patients. Specifically, the Useful Field of View (UFOV) test (Ball & Owsley, 1992) has been found to be one of the neuropsychological tests most predictive of driving performance. The test augments the assessment of simple peripheral vision by increasing the functional visual capacity under conditions of increasing cognitive load, thus requiring intact divided attention, visual search, and scanning. Myers and others (Myers, Bal, Kalina, Roth, & Goode, 2000) found that the UFOV test alone showed 86% accuracy in predicting outcome of on-road driving evaluations. This finding is consistent with other studies that revealed the UFOV to be strongly related to driving ability in both normal aging populations and stroke (Fisk et al., 2002; Whelihan, DiCarlo, & Paul, 2005). In fact, it has been proposed that the UFOV, or other measures of brief, vision-based complex attention measures always be used in fitness to drive assessments (Bieliauskas, 2005). The UFOV has also been used as a rehabilitation mechanism for driving retraining and found to result in a two-fold increase in rate of success on on-road driving evaluations (Mazer et al., 2003).

Other basic neuropsychological abilities, such as reaction time and processing speed, are consistently impaired in stroke patients when compared to matched controls (e.g., Lundqvist, Gerdle, & Ronnberg, 2000; Sundet, Goffeng, & Hofft, 1995) but their ability to predict driving performance remains unclear. Whereas simple reaction time has been cited as a significant predictor of driving performance in some studies (e.g., Lundqvist, Gerdle, & Ronnberg, 2000; Schanke & Sundet, 2000), others have failed to find a significant relationship between the two (Nouri et al., 1987). Most likely these inconsistencies arise from the nature of the reaction time measures themselves, as some utilize simple reaction time and others use complex choice reaction time tasks.

Among pre-driving neuropsychological assessments, slowed information processing speed is mentioned consistently as one of the strongest predictors of poor on-road performance (Engum, Cron, Hulse, Pendergrass, & Lambert, 1988; Gouvier et al., 1989; Schanke & Sundet, 2000; Sundet et al., 1995). Although the types of measures used to assess processing speed differ, one of the most effective is the Symbol Digit Modalities Test (SDMT; Smith, 1991). Gouvier and colleagues (1989) showed that the oral version of the SDMT accounted for 70% of the variance in an on-road driving score. Since then, the SDMT remains one of the most consistently impaired neuropsychological tests in individuals who are considered not fit to drive (Schanke & Sundet, 2000).

From these results, there appears to be a general trend: as the cognitive demand of a task increases, so does that task's relationship with driving performance. Accordingly, it is not surprising that higher order executive functions are, almost without exception, the strongest predictors of on-road driving performance. Many studies have listed specific executive functions as significant predictors of future driving success, including response disinhibition and impulsivity (Engum et al., 1988; Hopewell, 2002; Schanke & Sundet, 2000), impaired problem solving and complex reasoning (Nouri et al., 1987; Nouri & Lincoln, 1992), planning and organization (Galski, Bruno, & Ehle, 1992), and overall poor judgment (Engum et al., 1988). Cognitive flexibility, often measured by the Trail Making Test-B, is one of the executive functions most often cited as a strong predictor of driving ability (Hopewell, 2002; Schanke & Sundet, 2000). In one study, stroke patients who performed poorly on both the TMT-B and a visual-perception test were 22 times more likely to fail an on-road driving evaluation (Mazer, Korner-Bitensky, & Sofer, 1998). Similarly, using a discriminant function analysis, Sundet and others (1995) found that the TMT-B (specifically a cutoff score greater than 180 seconds) was the single most potent variable in the classification of driving status post-stroke.

The results of these neuropsychological studies lead to two conclusions. First, those who have criticized current driving training programs for focusing too much on driving skills at the operational level (i.e., handling the car) are supported by neuropsychological research that has suggested that emphasis should instead be placed on higher order cognitive skills at the tactical or strategic level. Second, although the pre-driving neuropsychological battery is useful in predicting on-road performance (e.g., TMT-B, SDMT, UFOV) there is still much variance left unaccounted for in stroke patients. This suggests that some aspects of driving behaviour remain unexamined or that there exist mediating variables affecting the relationship between neuropsychological functioning and driving performance. Self-awareness may be one such variable.

Self-Evaluation of Driving Ability in Stroke

Success of driving interventions and return to the road following stroke depend on the ability of drivers at risk to recognize problems so they are willing to undergo interventions. Self-awareness acts as a critical moderating variable in the relationship between stroke and driving safety. Individuals with intact self-awareness, regardless of extent of neurocognitive and physical limitations, are less likely to act unsafely. Individuals with intact self-awareness may compensate for residual impairments by strategically limiting their exposure to risky situations (e.g., driving at night, heavy traffic) or may cease driving completely as a successful mechanism for managing risk (Coleman, Rapport, & Hanks, 2004). Overall, some studies suggest that stroke survivors are capable of making accurate judgements about their driving ability (Golper, Rau, & Marshall, 1980) although others report the opposite (Hartje, Willmes, Pach, Hannen, & Weber, 1991). Recently, Rapport and colleagues found individuals' perceptions of barriers to driving provided unique information in the prediction of objective and subjective indices of community integration even after accounting for other potentially important variables like injury severity (Rapport, Hanks, & Bryer, 2006). Futhermore, Scott and colleagues (Scott et al., 2007) reported that stroke survivors' endorsement of only convenience/ease (while disregarding professional advice and physical functioning) as an important consideration in the decision to resume driving may reflect unawareness of their deficits and the high importance they place on the ability to drive and the independence it affords them.

Self-awareness for driving ability may be compromised in stroke populations because of several factors. First, studies of normal drivers' attitudes towards their safety and skill have revealed a seemingly universal phenomenon of self-enhancement bias in that between 60% to 90% of people claim to be better than the average driver (Delhomme, 1991). It has been shown consistently that regardless of age, gender, or actual driving record, drivers rate their own driving ability as being better than that of their peers and they estimate their risk for accidents as lower than the average driver

(Finn & Bragg, 1986; Groeger & Brown, 1989; Matthews & Moran, 1986; Svenson, 1981). Second, based on the aforementioned literature, stroke survivors demonstrate impaired levels of self-awareness in a variety of domains over and above the self-enhancement bias seen in normals. Third, stroke patients often over-estimate their abilities in novel cognitive tasks; thus, it could be hypothesized that this tendency toward over-estimation will be exacerbated in a context (i.e., driving) within which individuals feel more confident in their ability and have been found to be susceptible to general self-enhancing biases.

Finally, previous researchers have suggested that ISA is most likely to occur when the motivation to self-deceive is high and there is a lack of concrete evidence or information available by which to self-evaluate (Flashman & McAllister, 2002). Both of these scenarios are pertinent in fitness to drive assessments and self-evaluation of driving ability. For clients with neurologic impairment who already have had to face great changes in their lifestyle, driving is an integral component of successful community reintegration. Clearly, this increases one's motivation to believe that driving ability is left intact following an injury. Second, during the initial recovery process and in rehabilitation settings, most patients are rarely faced with driving situations as their cognitive deficits preclude any attempts at returning to driving duties. As such, the individual is not provided with concrete information from which to make accurate self-evaluations about driving ability. This strengthens the argument for the use of driving simulators as a potential assessment and rehabilitation tool as it provides the patient with concrete and face valid evidence regarding their driving capabilities.

A small number of studies have included self-awareness measures among pre-driving evaluations and the preliminary results strongly support the notion that self-awareness is highly related to driving ability. Heikkila et al. (1999) examined stroke patients' performance on a lab-style driving task. Although patients performed poorly on all lab measures (e.g., reaction time to signals, directional errors), they continually overestimated their abilities, particularly on attention measures. From these results, they concluded "when driving capability is being judged, one of the excluding criteria should be the obvious absence of self-criticism including merely denying the symptoms of one's disease" (p.354).

Similar to these findings, Schanke and Sundet (2000) examined the predictability of neuropsychological testing in determining rates of on-road failures in a mixed neurological population composed primarily of stroke patients. Self-awareness, as measured by the Awareness Index, was one of the most consistently impaired measures in the groups considered not suited for driving. In fact, only measures of reaction time and anosognosia significantly differentiated between the participants who passed and failed the on-road examination.

Freund and colleagues (Freund, Colgrove, Burke, & McLeod, 2005) explored whether elderly drivers of varying driving skill levels differed in their perception of their driving evaluation performance and if self-rated driving evaluation performance was related to cognitive ability. Consistent with the universal bias, 65% of drivers rated themselves as performing better on a driving test than others their age. Furthermore, as self-rated driving evaluation performance increased, there was a significantly increased risk of unsafe driving. In fact, drivers who considered themselves at least a little better than other drivers their age were over four times more likely to be unsafe drivers compared to others who believed they were comparable to or worse than other drivers their age. This pattern persisted despite the absence of a significant relationship between cognitive ability and how drivers rated themselves.

In sum, ISA is a common and potentially devastating consequence of stroke. Most theories suggest that self-awareness comprises numerous factors and processes and is highly related to other executive functions but the empirical findings remain equivocal. Previous research has implemented various techniques in hopes of reliably assessing the construct, with most studies using self-report and other-report discrepancy data. Due to the inherent limitations of these methods, recent research has shifted to the use of predictive performance methods. These results have shown that self-awareness in stroke differs depending on the domain or context assessed. One context that has not received much research attention is self-evaluation of driving ability in stroke patients. Research in this field may be particularly relevant as both theory and empirical data show that self-awareness deficits may be especially frequent in contexts involving highly automatized and emotionally-invested tasks. One promising mechanism that would allow for a more ecologically valid evaluation and possible retraining of driving skill in stroke patients is the driving simulator.

The Use of Driving Simulators in Fitness to Drive Evaluations

Although on-road tests are considered by many to the gold standard of evaluating driving ability but they are expensive, pose unnecessary safety risks, and only measure overt driving behaviour while failing to identify subtle psychological and psychomotor impairments that affect these fundamental skills (Klavora, Heslegrove, & Young, 2000). Therefore, off-road driving assessments are a safer method for clearly identifying driving capacities of stroke survivors. At the same time, off-road determinants of fitness to drive, such as medical examinations, psychological assessment, and even pre-driver neuropsychological evaluations leave much variance unexplained. Therefore, driving simulators are a beneficial alternative because ethical constraints do not always permit impaired drivers to undergo on-road driving and the predictive validity of neuropsychological pre-driver evaluations remains questionable (Galski, Ehle, & Bruno, 1990; Schanke & Sundet, 2000; van Zomeren et al., 1987).

Contrary to on-road evaluations, the use of driving simulators provides the opportunity to analyze and practice driving situations under a variety of conditions without the risk of accident whereas in on-road evaluations, it is impossible to consistently assess potentially dangerous situations using vehicles. It allows for repetition, review, and immediate feedback regarding performance. Driving simulators are superior to pen-and-paper neuropsychological tests because they provide an individual with visual information in a similar manner to that encountered in real world driving (Schultheis & Mourant, 2001). In comparison to on-road evaluations, it is less costly but still allows for the gathering of quantitative data on performance. This information can facilitate assessment and allow for monitoring and comparison over time (Mazer et al., 2004). Overall, driving simulators are useful in driving assessments as they maintain an appropriate balance between public safety and personal autonomy of people with impairments caused by cerebral injury (Haselkorn et al., 1998). Bieliauskas (2005) concluded "driving simulator-based studies are probably the best way to assess the likelihood of safe driving when faced with a challenge (i.e., an unusual situation requiring decision-making and behavioral response while driving)" (p. 224-5).

Over time, studies of the clinical utility of driving simulators have progressed across several levels of validation (Lew et al., 2005). First, at the simplest level, driving simulator performance has been examined in terms of sensitivity to different groups of drivers (e.g., neurologically impaired versus healthy controls) in order to determine its discriminant validity. Second, research has also examined convergent validity by investigating the level of agreement between driving simulators, pre-driving cognitive screenings, and on-road tests. Finally, recent research has begun to examine the ecological validity of driving simulators by looking at performance in relation to driving performance in the community.

Currently, there is a scarcity of research examining the validity of driving simulators across these various domains, particularly in stroke populations. Most research that has been completed has utilized mixed neurological populations or has only focused on the relative predictive validity of driving simulators regarding on-road driving performance. Driving simulators have been found to be valid measures of real automobile driving in healthy participants in terms of speed and positioning (Tornros, 1998). In terms of neurological populations, however, the results are less consistent.

Nouri and Tinson (1988) were the first researchers to examine the efficacy of driving simulation in determining fitness to drive. In a preliminary study, they examined the value of a driving simulator in 38 stroke patients by comparing judgments of driving fitness from simulator and road-test. Gradings based on the simulator alone were not good predictors of performance; although the simulator provided useful predictions for the majority, a significant number of participants were still misclassified in terms of their driving safety. Nouri and Tinson's study had significant technological limitations, which compromised the face validity of the driving simulator. In this experiment, the driving simulator comprised green light acceleration and braking reaction time variables only.

Very few studies have systematically examined the relationship between driving simulators and on-road driving since Nouri and Tinson's (1998) article. The studies that have examined the utility of driving simulators have revealed mixed findings. Some researchers have found small correlations between driving simulator and on-road performance (e.g., Monga, 1997; Owsley, 1997) or between driving simulator performance and subsequent traffic accidents or citations (Keller, Kesserling, & Hiltbrunner, 2003) among various populations, thus supporting Nouri and Tinson's questioning regarding the predictive validity of driving simulators. There has been an equal number of studies, however, that have found impressive results in populations such as stroke and TBI (e.g,. Galski et al., 1992; Lundqvist et al., 2000).

Galski and colleagues (1992) administered a sophisticated and multifaceted driving simulator task, a comprehensive neuropsychological battery, and an on-road evaluation to a mixed neurological sample (22 TBI, 13 CVA). Whereas 64% of on-road performance was explained by measures of visual perception, planning, organization, and executive functioning, the driving simulator performance accounted for 63% of the on-road outcome alone. From this, the authors postulated that the driving simulator was superior in predicting on-road performance because, similar to real world driving, it tapped into integrated abilities rather than separate abilities usually examined by neuropsychological measures.

Lundqvist, Gerdle, and Ronnberg (2000) asked individuals post stroke to complete a neuropsychological evaluation, driving simulator, and on-road driving evaluation. The comprehensive neuropsychological battery displayed an impressive 83% correct classification regarding on-road driving performance (pass/fail dichotomy). The driving simulator, however, independently was able to accurately classify 85% of individuals' overall driving skill. Although the results were comparable, both the time and effort put forth to complete the comprehensive neuropsychological evaluation far exceeded the driving simulator, thus supporting the utility of this procedure.

Some of the incongruence between these studies is attributable to the nature of the driving simulators themselves. With improved technology, driving simulators have become more sophisticated in terms of the number of variables included, visual output, and overall task complexity, all of which make them more comparable to real world driving. Most of the studies that failed to show a relationship between driving simulator and real-world performance implemented basic, single measures of evaluation, such as braking reaction time (Nouri & Tinson, 1988) or lane-tracking (Keller et al., 2003).

One of the few studies that have systematically examined the ecological validity of driving simulators was conducted by Lew and colleagues (Lew et al., 2005). Their study compared individuals with mixed severity TBI and controls at two phases: the baseline phase included an on-road driving test and a driving simulator test; and a 9 months post-baseline examination incorporating participants' driving records, number of infractions, and observational data. Not surprisingly, the TBI group performed worse on all the driving simulator variables than controls. In fact, within the TBI group, performance was worse on the driving simulator than the actual road-test. Driving simulator measures were significantly correlated with long-term driving outcome and showed a strong ability to predict driving skill at the 9-month follow-up (i.e., 82% prediction efficiency). The authors concluded that the driving simulator provided unique information beyond the road test because it is able to present individuals with a wider and less predictable range of driving situations than on-road tests, which may be the reason why individuals performed worse on the driving simulator. Although these results suggest promising sensitivity, they warrant some caveats regarding driving simulator specificity when the difficulty of the driving simulator test is greater than actual on-road performance.

The Driving Simulator as a Retraining Tool

A new topic of interest in research has become the utility of the driving simulator as a retraining tool. The driving simulator provides a safe yet realistic and comprehensive method for retraining neuropsychologically impaired individuals who wish to resume driving. Perhaps the greatest contribution of the simulator to driving rehabilitation, however, is the potential to elicit awareness. Self-awareness is considered one of the most critical aspects of successful rehabilitation (Hartmann-Maeir et al., 2003) and as such any instruments that serve to garner improved awareness of deficit would be of great benefit to rehabilitation outcome. Driving simulators, in theory, have potential to be efficacious rehabilitation tools as they provide patients with immediate feedback, facilitate discovery during task performance, and provide concrete evidence of capabilities. Unlike pen-and-paper neuropsychological tests, driving simulators mimic real world driving situations and are therefore more likely to elicit increased self-awareness of driving-related skills. In other words, it will be easier for a patient to come to realize they have neuropsychological deficits that preclude driving if they perform poorly on a test actually involving driving rather than on a neuropsychological test that is completely novel and non-contextual.

Very few studies have examined the driving simulator as a rehabilitation mechanism and no studies have examined the driving simulator's relationship to self-awareness. Cimolino and Balkovec (1988) reported on the use of a driving simulator in the evaluation of training disabled adolescent new drivers and adults with stroke. Unfortunately, the authors did not provide details of the training, but reported a large increase in driving simulator scores over time for the adolescents. No differences were noted for the stroke population. The improved driving simulator performance in this study is not surprising given that the outcome measure was also the training measure. Simple practice effects would lead to improved performance, although this was not true for the stroke survivors. Since this study, there has been no attempt to examine whether driving simulators are capable of improving self-awareness deficits known to impede driving resumption.

Summary and Present Study

In summary, previous research has revealed driving to be a complex and multifaceted process consisting of various levels of cognitive, emotional, and motivational factors. Despite theories that suggest their importance and superiority in predicting on-road performance, executive functions have only recently begun to be investigated. Even when tests of executive functions are included in fitness to drive assessments, the test batteries rarely, if ever, examine the full spectrum of executive functions, thus leaving some specific processes unexamined. Perhaps the most important of these is self-awareness and the ability to use feedback as a mediator for future behaviour.

In stroke populations, ISA is evident in various severities and manifestations, ranging from severe instances of hemi-neglect to more subtle over-estimations of cognitive abilities and degree of recovery. Whereas severe forms of self-awareness deficits like neglect are easy to detect and assuredly preclude a return to driving, more subtle over-estimations in cognitive abilities may be as crucial an impediment to safe driving, yet rarely are assessed in neuropsychological examinations of fitness to drive.

Previous research examining self-awareness has been limited by several methodological shortcomings. One of the most problematic has been the inconsistency in the operational definition and measurement of the construct. Previous reliance exclusively on self-report data or discrepancy analyses using raw scores led to a large amount of ambiguity. Recent research has moved toward a metacognitive approach using predicted performance experiments. This work has had promising results. Another limitation of previous research has been exclusion of control groups. This limitation is particularly troubling given the robust findings pertaining to a general human tendency to over-estimate one's personal abilities. It is possible that the tendency for individuals to over-estimate their performance is not exclusive to neurologically impaired populations. Regardless of the population being examined, self-awareness is not a unidimensional construct but can instead be considered as context-specific and fluctuating. Specifically, it is possible that self-awareness differs depending on the novelty of the task. In other words, individuals may hold different perceptions of their abilities depending on whether the task is novel and unfamiliar (such as neuropsychological tasks) or one well known to them and considered automatic (i.e., driving). Also, stroke survivors' ability to adapt their perception of their ability may differ depending on the type of feedback given to them. Therefore, implementation of mechanisms such as driving simulators may be more successful in altering individuals' perceptions of their true abilities because, unlike pen and paper neuropsychological tests, they demonstrate greater face validity to actual driving performance.

Therefore, the purpose of the present study was two-fold. First, this study compared stroke survivors' self-evaluation or awareness of driving performance to that of healthy matched controls to determine whether they provided accurate self-evaluations of driving ability. Second, it compared both control subjects and stroke survivors' self-awareness on novel and abstract neuropsychological tests and well-learned/skilled and functional driving simulator tasks to determine whether self-awareness changed as a function of the context, and if this pattern differed in healthy versus neurologically impaired populations.

It was hypothesized that stroke patients would demonstrate greater ISA than healthy controls across most measures. Specifically, the stroke patients would show larger over-estimations in their rated versus their actual performance on the neuropsychological and driving simulator measures. Furthermore, it was hypothesized that the stroke patients, as a group, would show less change in their pre- and post-test self-evaluations than the control group. Finally, within the stroke group, there would be a significant difference in self-evaluation depending on whether the task was perceived to be novel (i.e., neuropsychological) or relatively familiar (i.e., driving simulator). Specifically, it was hypothesized that the discrepancy between estimated and actual performance would be greater on the driving simulator task. Furthermore, the discrepancy between the self-evaluation of performance on novel versus familiar tasks would be significantly larger in the stroke group than the control participants.

Chapter 2: Method

Participants

Sixty-six participants (33 stroke survivors, 33 controls) were recruited from various sources including the inpatient Stroke and Neuroscience service at the Rehabilitation Institute of Michigan (RIM), the outpatient follow-up care at RIM, and the RIM Driving Education and Training Center (DETC).

Table 1

Demographic means and standard deviations of stroke and control groups.

Demographic Variable	Stroke Group (*n*=30)	Control Group (*n*=30)
Age Mean (SD)	54.3 (9.1)	48.5 (13.0)
Range	32-70	20-72
Gender (Male/Female)	15/15	12/18
Education Mean (SD)	13.9 (2.2)	13.7 (2.5)
Range	9-20	10-20
Race (Caucasian/African American)	11/19	11/19
Location of Stroke		
Left	17	
Right	9	
Bilateral	3	
Systemic	1	
Chronicity in Months Mean (SD)	46.0 (65.0)	
Range	3-280	
Driving Since Stroke? Yes/No	19/11	

Stroke survivors were at least 3 months post stroke. In those cases where it was possible, the control participants were the patient's significant other/caregiver to minimize demographic confounds. In other cases, the control participant was a close family member or friend. Inclusionary criteria for all participants included: having driven within 3 months prior to the stroke, or for healthy controls to have driven 3 months prior to testing; English as a first language; be between 20 and 70 years of age; and to be without a self-reported severe psychiatric diagnosis or history or other neurological disorders. Participants received financial compensation for their participation ($50 per participant pair). Following data screening (see results section), 60 individuals were retained for data analyses. The demographic characteristics of both the stroke and control groups can be seen in Table 1.

Materials

Doron AMOS (Advanced Mobile Operation System)-2 Driving Simulator. This state-of-the-art simulator is completely interactive and provides 240 degrees of visual field contained in a life-sized model of a typical automobile cockpit, with sensory feedback including sound, vibration, and moving air. Unlike very high-end simulators used for military and automotive training, this type of simulator is designed as an advanced clinical driving simulator specifically designed for the clinical evaluation of driving-related skills. The evaluation takes approximately 45 minutes and includes four sequences that simulate “real life” encounters: (a) residential and light business traffic; (b) rural traffic and roadways (including lane changes); (c) challenging situations that require forethought and quick response time (e.g., near collisions, emergency vehicles); and (d) a skills track module that includes assessment of brake reaction, front-end parking, and distance estimation. The specific driving scenarios were developed with consultation from RIM’s DETC evaluators and the technical consultants at Doron, who are nationally recognized as leading experts in evaluation and training of driving skills using simulator technology. The driving scenarios scores yield an overall total score, which was used for the purpose of the current study. This score is calculated by tallying the total number of correct items across all of the scenarios within several domains, including speed, stop distance, lane placement, traffic signal use, hazard avoidance, and obeying traffic signs and signals.

Trail Making Test-B (TMT-B; Reitan & Wolfson, 1985): This test examines complex attention, processing speed, sequencing and cognitive flexibility. It requires the connection, by making pencil lines, between 25 encircled numbers and letters in alternating order. Test-retest reliability ranges from .67 to .72 (Snow, Tierney, Zorzitto, Fischer, & Reid, 1988) in various neuropsychological populations. The test has been found to highly sensitive to various forms of brain damage (Spreen & Strauss, 1998). For the purposes of this study, normative data was taken from Heaton and colleagues' well-known demographically-adjusted norms for the Halstead-Reitan neuropsychological battery (Heaton, Miller, Taylor, & Grant, 2005). This test was included in the current study as a result of previous research showing it to be very sensitive to neurocognitive impairment and highly related to driving performance (Hopewell, 2002; Schanke & Sundet, 2000).

Neuropsychological Assessment Battery-Judgment subtest (NAB Judgment, White & Stern, 2001): This test assesses an individual's judgment and verbal reasoning in the context of everyday situations. It includes a series of questions about home safety, health, and medical issues likely to be encountered in everyday life. The test includes 10 questions generated from six categories: 1) home safety; 2) personal hygiene; 3) medication safety; 4) motor vehicle driving safety; 5) medical decision making; and 6) general judgment. Test-retest reliability is modest (.43), and may result from large variability of scores (White & Stern, 2001). Interrater reliability has been reported as .85

for both forms (White & Stern, 2001). Due to the relative newness of the test, the subtest's validity and sensitivity in stroke populations has yet to be determined. The current study used the normative tables provided in the test's administration manual. This test was included in the present study because, unlike some of the other measures, it is not time-dependent which allows for evaluation of executive functioning without processing speed confound. Also, it provides a verbally rather than visually-based tool.

Symbol Digit Modalities Test (SDMT; Smith, 1991): This test is used to assess visual scanning, tracking, motoric speed, and complex attention. It requires the patient to examine a series of nine meaningless geometric designs and for each symbol in the sequence, search a key for that symbol and substitute a number, either orally or in writing. Test-retest reliability has been reported as .80 for the written version and .76 for the oral version (Smith, 1991). In terms of validity, the SDMT has been found to be one of the most sensitive measures of cerebral integrity in stroke and the single best predictor of reduced speed of processing (Ponsford & Kinsella, 1992; Smith, 1991). Normative data was taken from also taken from the Heaton norms (Heaton et al., 2005). Similar to the TMT-B, the SDMT was chosen for this study due to its strong predictive abilities in terms of driving performance (Gouvier et al., 1989).

Controlled Oral Word Association Test (COWAT; Benton, Hamsher, & Sivan, 1983): This test was developed to evaluate the spontaneous production of words beginning with a given letter of the alphabet, thus assessing verbal association fluency, as well as self-initiation and organization. For letter (phonetic association) fluency, the subject is asked to produce orally as many words as possible beginning with a given letter in a limited period of time. F, A, and S are the most commonly used letters for this test, although alternate forms have also been implemented and standardized (e.g., C, F, and L; P, R, and

W). Test-retest reliability ranges from .70 to .88 (Bardi, Hamby, & Wilkins, 1995; Snow et al., 1988). In terms of validity, Mutchnick and colleagues found letter fluency to be among the five best significant discriminators between brain damaged and pseudoneurological controls (Mutchnick, Ross, & Long, 1991). The normative data for this test was also taken from the Heaton norms (Heaton et al., 2005). Again, this measure was selected because it allowed for the evaluation of verbally-based and speeded executive functioning.

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

Metacognitive Awareness of Context-Specific Cognitive Ability (Ergh, 2004): This measure borrows from the metacognitive literature and uses Metacognitive Discrepancy Scores. Procedures and scoring criteria for the Metacognitive Discrepancy Scores were described by Ergh (2004) as follows: Following the standardized administration of task instructions, the participant is given a rating scale (see Appendix A) and asked to predict his/her performance in comparison to same-aged healthy people (pre-test predicted performance ratings). The task is then administered and following this, the participants are again asked to rate their performance using the same scale (post-test predicted performance ratings). This procedure was performed for each of the neuropsychological measures (excluding the MMSE that is only being used as a screening measure) for both the stroke and control groups. There were three primary discrepancy scores reflecting differences between: a) the predicted and postdicted ratings, b) the predicted ratings and actual performance; and, c) the postdicted ratings and actual performance. In order to compare the ratings and actual performance, participants' ratings had to first be converted to T scores. Appendix B provides the specific guidelines used to convert patient ratings to T-score equivalents. A similar procedure was used for each of the three discrepancy scores. Using the pre-test predictions, the patient predicted T-score performance (PPTP) for a specific neuropsychological task was subtracted from the patient's actual T-score performance (PATP). The discrepancy scores for each test were averaged to calculate a total Metacognitive Pretest Discrepancy Score. A similar calculation procedure was used to calculate the Metacognitive Posttest Discrepancy Score, again using the same four executive functions measures (TMT-B, COWAT, SDMT, NAB Judgment).

A similar paradigm was applied to the driving simulator performance as both discrepancy scores (Metacognitive Pretest, Metacognitive Posttest) were applied to the individual's overall T-score performance on the simulator. It is important to note that for the purposes of these analyses, the Actual Performance T scores for all simulator variables were derived from mapping the control group's performances into a normal T-distribution and converting the stroke groups' performance into T scores accordingly. Through this method, the control group's performance served as the normative sample on which the stroke survivors' performance was measured.

Procedure

Following recruitment, patients and their significant others/caregivers received and completed an informed consent form (see Appendixes C and D). Before completing the study, significant others/caregivers completed a brief cognitive screen (MMSE) to detect possible cognitive dysfunction. Significant others were excluded from further participation if they failed this screening tool (failure was defined as a score below 25 out of 30). No individuals were excluded at this point. Due to scheduling restraints, the order in which the participants completed the neuropsychological testing and driving simulator varied. However, the order of neuropsychological tests and driving simulator scenarios was kept consistent across all participants. Due to these scheduling constraints, it was not possible to counterbalance the administration of the neuropsychological and simulator measures. Before administration, but following standardized instructions for each neuropsychological task, the participants were asked to predict their performance by answering the question "How well do you think you are going to do in comparison to the average person your age?" (pre-test prediction) while provided with the accompanying scale (Appendix A). The participants then completed the task and following completion, they were asked to re-evaluate their performance according to the same scale (post-test prediction). Participants also completed the driving simulator task and received the standardized instructions. Before the first scenario, they were asked to predict their overall driving simulator performance using the same scale as the neuropsychological measures. It is important to note that all individuals were explicitly informed that their performance on the driving simulator would have no impact on their driving status. This was communicated at the time of recruitment, informed consent, and prior to starting the driving simulator.

Chapter 3: Results

Sixty-six participant pairs (33 stroke survivors, 33 controls) were involved in the present study. These participants met all inclusionary criteria. Of the 66 pairs, some participants were not able to complete all measures for various reasons. For instance, those individuals who experienced significant aphasia following their stroke were not able to complete all the neuropsychological measures (COWAT, NAB Judgement). Also, some participants experienced mild vertigo or dizziness while attempting to complete the driving simulator and discontinued the task. In these instances, discrepancy score formulas were adjusted accordingly (i.e., the average scores were calculated using 3, instead of 4 scores). For the neuropsychological measures, participants had to have completed at least 2 out of 4 tests to be included in analyses. For the simulator, analyses were focused on those individuals who completed at least 4 of the 7 scenarios, ensuring that at least 3 of the same 4 scenarios were examined. After implementing these limitations, 3 stroke survivors and 2 control participants were eliminated from further analyses.

Prior to analysis, the data were screened for violations of assumptions associated with all tests (e.g., normality, linearity, outliers, multicollinearity). This analysis revealed one control participant who was a multivariate outlier across numerous variables. As such, this case was eliminated from further analyses. Following all preliminary data screening, a total of 30 stroke survivors and 30 controls were used in all subsequent analyses.

Table 2

Oneway ANOVA comparisons of stroke and control group T scores on neuropsychological and simulator measures.

Measure	Stroke Mean (SD)	Control Mean (SD)	*F*	*Eta*^{2}
TMT-B	32.9 (14.1) (n=29)	49.3 (11.4) (n=30)	24.1***	.30
SDMT	27.2 (13.3) (n=28)	46.1 (11.8) (n=30)	32.7***	.37
COWAT	36.8 (14.6) (n=28)	49.1 (9.7) (n=30)	14.5***	.21
NAB	43.3 (12.4) (n=27)	51.9 (11.3) (n=30)	7.5**	.12
Simulator	36.8 (17.1) (n=30)	50.0 (10.0) (n=30)	16.8***	.22

Note: TMT-B=Trail Making Test-Part B; SDMT=Symbol Digit Modalities Test; COWAT=Controlled Oral Word Association Test; NAB =Neuropsychological Assessment Battery Judgment subtest
Note: *** $p < .001$; ** $p < .01$; *$p < .05$

Independent t tests were conducted to examine whether the stroke and control groups differed in terms of demographic characteristics (see Table 1), including age and education. There were no significant differences between the two group in terms of age ($t(58) = 1.97, p = .053$) or education level ($t(58) = 0.27, p = .79$). Table 2 shows the means and standard deviations of each of the neuropsychological measures for both groups.

The stroke group performed significantly worse than the control group on all neuropsychological tests with the greatest difference seen on SDMT and TMT-B. In terms of driving simulator overall performance, the stroke group performed significantly worse than controls.

Hypothesis 1: Stroke patients will display less self-awareness of deficits than healthy controls on all measures. For the purpose of this hypothesis, participants' self-awareness was examined using two different analyses. First, oneway ANOVAs were conducted on the Metacognitive Pretest Discrepancy Score (self-awareness prior to feedback) and the Metacognitive Posttest Discrepancy Score (self-awareness following feedback) to determine whether the two groups differed significantly in the accuracy of their pre- and post-test evaluations of performance. It was hypothesized that the stroke group would demonstrate significantly larger discrepancy scores than the control group. Second, correlations between their actual performance and their pre-test and post-test ratings, and pre-post test discrepancies were examined to determine whether an individual's self-evaluations were related to how well they actually performed (i.e., did those people who attained higher scores rate themselves accordingly?). Pearson correlations were performed for all neuropsychological measures, as well the overall performance on the driving simulator. It was hypothesized that the stroke group would demonstrate lower correlations between their pre- and post-test ratings and actual performance. Means and standard deviations for the actual scores, as well as the predicted and postdicted ratings (in T scores) for both groups are reported in Table 3.

Table 4 shows the oneway ANOVA comparisons between participants' Metacognitive Pretest Discrepancy Scores (Actual–Predicted) and Metacognitive Posttest Discrepancy Scores (Actual - Postdicted). It is important to note that because participants' ratings were subtracted from their actual performance, negative values indicated overestimation of performance and positive values represented underestimations. In terms of the Metacognitive Pretest Discrepancy Scores, significant differences existed between the stroke survivors and controls across all the neuropsychological measures, with the exception of NAB Judgment. The stroke survivors consistently demonstrated significantly higher overpredictions of their performance than the healthy controls. This pattern was particularly evident on both the TMT-B and SDMT tests, suggesting that stroke survivors may demonstrate disporportionate ISA in areas of processing speed and cognitive flexibility.

Table 3

Actual performance, pre-test and post-test ratings (in T scores) of stroke and control groups for neuropsychological variables and overall driving simulator performance.

	Stroke Mean (SD)			Control Mean (SD)		
	Actual	Predicted	Postdicted	Actual	Predicted	Postdicted
TMT-B	32.9 (14.1)	49.3 (6.6)	45.6 (8.2)	49.3 (11.4)	51.5 (6.6)	50.4 (6.0)
SDMT	27.2 (13.3)	50.6 (7.1)	48.4 (7.5)	46.1 (11.8)	52.0 (6.6)	50.7 (6.0)
COWAT	36.8 (14.6)	49.3 (7.1)	45.6 (8.7)	49.1 (9.7)	50.5 (4.9)	49.0 (6.4)
NAB	43.3 (12.4)	50.3 (6.7)	52.9 (5.9)	51.9 (11.3)	54.4 (6.4)	56.6 (5.8)
Mean NP	34.2 (11.7)	49.5 (5.9)	47.7 (6.3)	49.1 (8.1)	52.1 (5.1)	51.7 (4.6)
Simulator	38.0 (12.5)	52.4 (7.5)	47.8 (6.4)	50.0 (10.0)	54.1 (8.0)	50.2 (5.8)

Similar overprediction was observed on simulator performance (see Table 4). The stroke group showed significantly larger overestimations in their pre-simulator ratings versus actual performance. In contrast, the control group displayed relatively accurate predictions of their performance although they still tended to over-estimate their actual performance. Across all measures, examination of the means and standard deviations of the pre-test estimations show the stroke group to rate themselves very similarly to those individuals who had no history of stroke.

Table 4

Oneway ANOVA comparisons of Metacognitive Pre-test and Post-test Discrepancy Scores for stroke survivors and controls on neuropsychological and simulator T scores.

Variable	Stroke Mean (SD)	Controls Mean (SD)	*F*	Eta^2
Actual - Predicted				
TMT-B	-16.3 (14.2)	-2.3 (10.7)	18.6***	.25
SDMT	-23.3 (14.3)	-6.3 (12.2)	23.3***	.30
COWAT	-12.5 (14.3)	-1.4 (9.6)	12.3**	.18
NAB	-6.9 (12.5)	-2.4 (11.4)	2.0	.04
Overall NP	-15.3 (11.0)	-3.0 (7.7)	25.1***	.30
Simulator	-14.4 (14.4)	-4.1 (9.2)	10.8**	.16
Actual – Postdicted				
TMT-B	-12.6 (10.5)	-1.1 (10.6)	17.5***	.24
SDMT	-21.3 (11.6)	-5.1 (11.7)	27.6***	.33
COWAT	-7.9 (10.7)	0.1 (9.3)	9.1**	.14
NAB	-9.6 (12.5)	-4.7 (10.6)	2.6	.05
Overall NP	13.4 (9.5)	-2.6 (7.7)	23.5***	.29
Simulator	-9.8 (11.4)	-0.2 (9.2)	12.7***	.18

Note: *** $p < .001$; ** $p < .01$; * $p < .05$

Because it is clearly more difficult to predict or evaluate one's performance prior to actually completing a task (i.e., in the absence of any feedback), the Metacognitive Posttest Discrepancy Scores were computed to determine whether stroke survivors, even in the presence of immediate feedback (i.e., completing the task), would demonstrate continued ISA. This analysis revealed a consistent pattern to that seen in the pre-test evaluations; that is, the stroke group consistently overpredicted their performance by a significantly greater margin than the control group on all neuropsychological measures, with the exception of NAB Judgment. Again, the same pattern emerged in which their overpredictions were particularly large on measures of processing speed and cognitive flexibility (TMT-B, SDMT). The stroke survivors also over-predicted their performance following the simulator more than their healthy counterparts.

Both groups had a tendency to overestimate their performances across both neuropsychological and driving measures. Overall, both groups tended to rate themselves as average in comparison to same-aged peers, which was generally accurate for the control group but not for the stroke survivors. Overall, the stroke group contained significantly more individuals who overestimated both before and after their neuropsychological performance (Pre-test: $\chi^2(1,59) = 6.70, p < .01$; Post-test: $\chi^2(1,59) = 11.92, p < .001$). Of the stroke survivors, approximately two-thirds (67.9%) of them overpredicted by at least one full standard deviation (10 T-score points) their mean neuropsychological pre-test predictions and 78.3% of them demonstrated a mean neuropsychological overestimation of at least 1 standard deviation following the tests. In contrast, only one third (32.1%) of the control group overestimated their average performance by one standard deviation prior to the administration and only 21.7% of them continued to overestimate following completion.

Correlational analyses were used to examine the strength of the relationships between an individual's predictions, postdictions, and actual task performance (see Table 5). The control group's predictions exhibited moderate correlations with actual performance, with the exception of SDMT and NAB Judgment. Those healthy individuals who tended to perform better also predicted higher performance prior to testing. In contrast, the stroke survivors' pre-test evaluations were statistically unrelated to the level of actual performance across most of the individual tests and simulator scores (except FAS). This group, however, displayed a trend in which their predictions varied consistently with actual performance. Once collapsed into an average neuropsychological variable, the stroke survivors also demonstrated a positive relationship between their pre-test predictions and actual performance. In terms of overall driving performance, the healthy controls again displayed significant correlations between their predictions and actual performance, whereas the stroke group's pre-simulator ratings were not related to their level of actual performance.

Table 5

Pearson correlations (*r*) of the predicted and postdicted ratings, and the predicted-postdicted discrepancy scores with participants' actual T-score performance in both stroke and control groups.

	Trails B		SDMT		NAB Judgment		FAS		Mean NP		Simulator	
	Str.	Cont.	Str.	Cont.	Str.	Cont.	Str.	Cont.	Str.	Cont.	Str.	Cont.
Predicted T Score	.21	.40**	.14	.21	.27	.27	.29*	.37*	.41**	.39**	.03	.49*
Postdicted T Score	.67**	.39**	.50**	.26	.23	.38*	.66**	.47**	.59**	.37**	.42*	.42*
Pre-Post	-.51**	.05	-.56**	-.03	.08	-.14	-.47**	-.25	-.47**	.10	-.32*	.24

Note: Str. = Stroke survivors; Cont. = Controls
** $p < .01$; * $p < .05$

There are several patterns within the correlations between postdicted ratings and actual performance that suggested that the stroke survivors may have benefited modestly from feedback during both the neuropsychological and simulator contexts. First, postdicted ratings were strongly related to actual performance across all neuropsychological and driving measures, with the exception of NAB Judgment. Following the completion of the task, those who performed better also rated themselves higher and vice versa. Second, in most tasks, the stroke survivors demonstrated larger correlations between their postdicted ratings and actual performance than between their predicted ratings and actual performance, suggesting that their accuracy in self-rating improved with immediate feedback.

The control group continued to demonstrate significant correlations between their actual performance and self-evaluations as seen by moderate correlations with postdicted ratings across both neuropsychological and driving measures. The strength of the correlations was generally consistent from pre- and post-test ratings.

In terms of the discrepancy between pre-test and post-test self-estimates (pre-post Discrepancy score), the pattern of correlations showed an interesting trend. There were significant inverse correlations between actual performance and pre-post discrepancy scores in the stroke group. As a stroke survivor's actual performance improved, the discrepancy between predicted and postdicted ratings decreased; conversely, as a stroke survivor's performance was poorer, the discrepancy between predicted and postdicted ratings increased. Thus, the gap between prediction and postdiction tended to be more narrow for stroke survivors who did indeed perform relatively well, whereas the gap between prediction and postdiction tended to widen (show more shift) among survivors who performed most poorly. Overall, it appears that amount of shift in the survivor's awareness was strongly related to their overall performance in both neuropsychological and driving settings. Especially for survivors who performed poorly, the experience of actually performing the tasks produced more accurate self-ratings of performance as compared to prediction. This pattern was not observed in the control group as there were no significant relationships between the actual performance and pre-post discrepancy scores. However, since the control group was more accurate to begin with, they required less shift in their ratings from pre- to post-testing. Unlike the stroke group, the control group demonstrated a much greater restriction of range in their ratings. In other words, since most of them performed within the average range, they had less room to adjust their self-estimates in order to remain accurate.

Overall, the results of the first set of analyses strongly support the first hypothesis. As a group, the stroke survivors demonstrated significantly greater discrepancies between their estimated and actual performance, both before and after completion of the tasks, thus indicating clinically significant ISA. Significantly larger proportions of stroke survivors overestimated their performance by at least one full standard deviation than healthy controls both pre- and post-testing. Despite this ISA, the correlational analyses suggest that the stroke group are capable of benefiting from feedback, given substantially stronger correlations between self-estimates and actual performance at post-testing as compared to pre-testing. The purpose of Hypothesis 2 was to determine if the stroke survivors differed significantly from healthy controls in their reaction to feedback.

<u>Hypothesis 2: Stroke patients will show less variation in pre- and post-test self-evaluations (less reaction to feedback) in comparison to controls.</u> For this comparison, the Metacognitive Pre-Post Discrepancy scores were evaluated. A negative value represented a higher postdiction (i.e., participants thought they did better than they had predicted after completion) whereas a positive value meant a lower postdiction (i.e., individuals believed they did worse than originally predicted). These discrepancies were then averaged and the two groups were compared via independent t tests. It was hypothesized that the stroke group would display significantly smaller Pre-Post Discrepancy scores than the control group.

The two groups did not differ significantly in their pre-post ratings discrepancies across most measures (see Table 6). When all the neuropsychological measures were averaged, however, the stroke group displayed significantly more shift in their ratings (i.e., decreasing their post-test ratings in relation to pre-test ratings) than the controls. In general, both groups displayed very little absolute shift in their appraisals following feedback.

Table 6

Independent t tests comparing Metacognitive Pre-Post Discrepancy Scores for stroke survivors and control groups.

Variable	Stroke Mean (SD)	Control Mean (SD)	*df*	*t*	*p (one-tailed)*
Pre – Post					
TMT-B	3.7 (8.1)	1.1 (5.6)	57	1.4	.08
SDMT	2.2 (5.0)	1.2 (5.6)	57	0.7	.25
COWAT	3.4 (6.4)	1.5 (4.9)	55	1.3	.10
NAB	-2.7 (5.3)	-2.3 (3.3)	55	-0.3	.38
Overall NP	1.9 (3.3)	0.4 (3.0)	58	1.9	.03
Simulator	4.7 (7.6)	3.9 (6.3)	58	.42	.34

Because previous analyses revealed the control group to be relatively accurate in their initial prediction, there was not as much need to significantly alter their post-test ratings, hence the minimal shift. In contrast, the stroke group's pre-test predictions were quite discrepant from their actual performance which left much more opportunity for shift in ratings. Thus, the degree of initial inaccuracy may have influenced the degree of shift. To control for this potential confound, the pre-post discrepancy scores were adjusted to account for baseline predictions (i.e., discrepancy scores were divided by pre-test rating to calculate a "percentage shift" in rating variable). After accounting for the degree of "off-prediction" evident during the pre-test ratings, the stroke group continued to show significantly larger percentage shift in their post-test ratings in their average neuropsychological performance ($t(58) = 2.1, p = .02$).

Unlike the neuropsychological composite, the two groups did not differ significantly in their Metacognitive Pre-Post Discrepancy Scores during the driving simulator performance (see Table 6). Both groups appeared to benefit from feedback as post-simulator ratings were lower than pre-simulator predictions (see Table 3). Overall, these results did not support the hypothesis that stroke survivors would demonstrate less variation in their pre-post ratings. The results of this analysis suggest that stroke survivors' ability to benefit from feedback may differ depending on the nature of the task, which was examined by the study's third hypothesis and analyses.

Hypothesis 3: The stroke group will show a disproportionate unawareness of driving simulator performance (in comparison to neuropsychological tasks) than controls.

Separate mixed-model ANOVAs each compared the Metacognitive Pre-Test and Metacognitive Post-Test Discrepancy Scores of the stroke and control groups for overall driving simulator and overall neuropsychological performance. The between groups variable was group membership (Stroke versus Controls) whereas the within groups variable was domain assessed (neuropsychological composite or driving simulator). As per the hypothesis, it was expected that a main effect would be found for group membership and domain, as well as a significant interaction between these variables.

In terms of Metacognitive Pre-test Discrepancy Scores, there was a significant main effect for group ($F(1,58) = 25.4, p < .001, \eta^2 = .31$) as the stroke group displayed significantly larger overpredictions than the controls, a finding consistent with previous analyses. In contrast, there was no main effect for domain ($F(1,58) = .01$, $p = .94$) as there was no significant difference between the magnitude of overprediction of the neuropsychological and simulator performances. As can be seen in Figure 1, the interaction between group and domain was also not significant ($F(1,58) = .35, p = .56$) as the stroke group showed less accurate ratings regardless of domain.

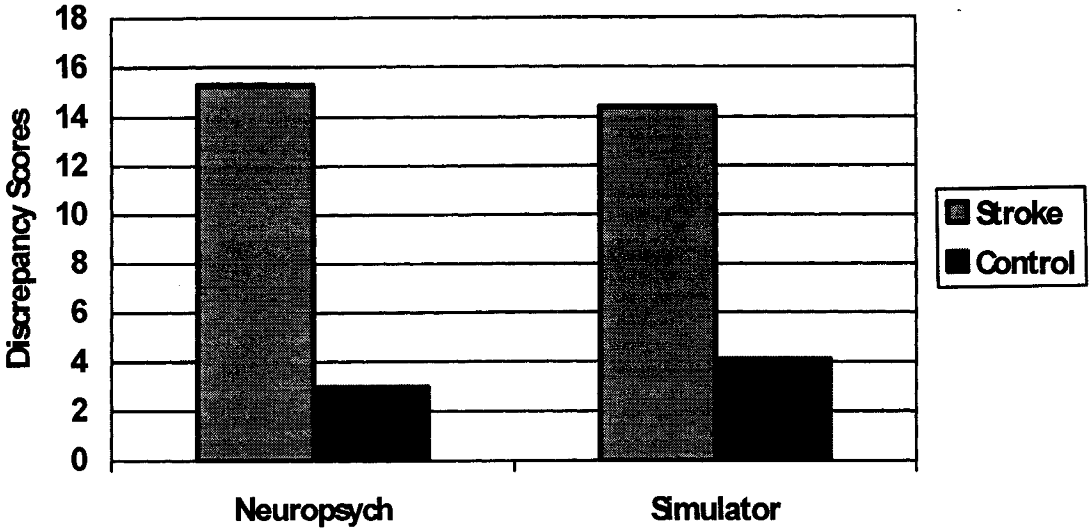

Figure 1: The relationship between Metacognitive Pre-test Discrepancy Scores, Group Membership, and Domain.

Note: The above representations of the Metacognitive Pre-test Discrepancy Scores are in positive values to display the pattern of over-prediction from actual performance (values closer to 0 represent more accurate estimations)

In terms of Metacognitive Post-test Discrepancy Scores, a similar pattern emerged. Again, a significant group main effect was seen ($F(1,58) = 24.88, p < .001, \eta^2 = .30$) as well as a significant domain main effect ($F(1,58) = 4.87, p < .05, \eta^2 = .08$) as the postdiction discrepancy with actual performance was greater in the stroke group and significantly higher for the neuropsychological measures. The group X domain interaction was not significant ($F(1,58) = .21, p = .65$) suggesting that the two groups did not differ significantly in their pattern of postdiction ratings across domains.

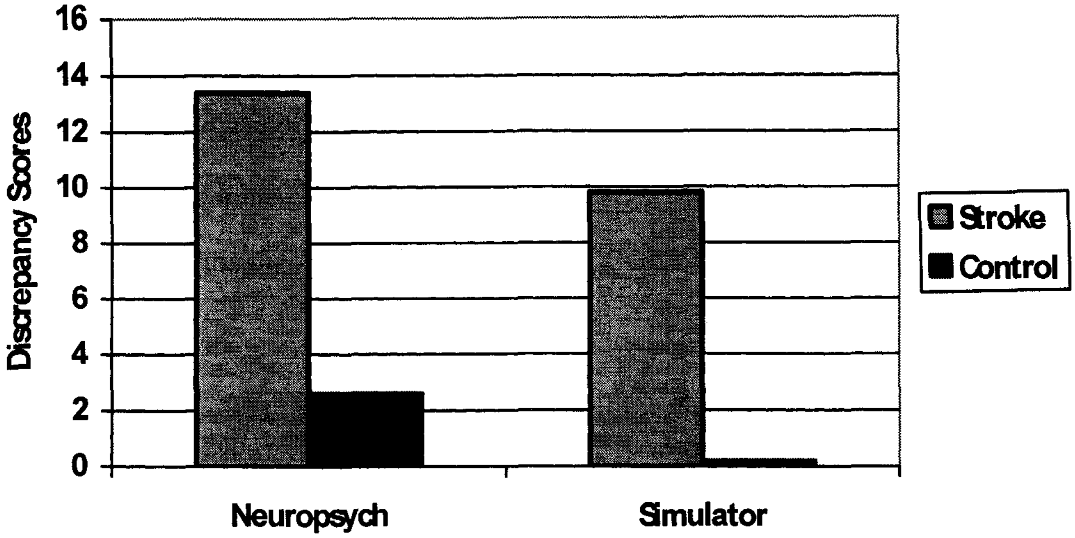

Figure 2: The relationship between Metacognitive Post-test Discrepancy Scores, Group Membership, and Domain.

As the final part of the analyses, the Metacognitive Pre-test and Post-test Discrepancy Score were collapsed into an omnibus mixed model ANOVA. For this analysis, the between groups variables was group membership while both domain (neuropsychological versus simulator) and time (pre- versus post-test) were entered as within subjects variables. As with previous results, there was a large main effect for group (F(1,58) = 26.54, $p < .001$, $\eta^2 = .31$) as the stroke survivors demonstrated higher over-estimations before and after the tests. There was also a large main effect for time (F(1,58) = 28.88, $p < .001$, $\eta^2 = .33$) as both groups demonstrated significantly larger over-estimations of their performance prior to testing in comparison to post-test predictions. In other words, both groups appeared to benefit from the immediate feedback inherent in completing the tasks and as such their predictions became more accurate. In particular, both groups showed more accurate postdictions of simulator performance in comparison to neuropsychological measures as evidenced by a significant domain X time interaction ($F(1,58) = 10.34$, $p < .01$, $\eta^2 = .16$). Contrary to the hypothesis, however, the stroke group's shift in awareness from before to after testing did not differ across domains and differently than the control group as the test X time X group interaction did not reach significance (*F*(1,58) = .145, *p* = .70).

Overall, the results of the third analyses did not support the hypothesis. Although the stroke group displayed significantly from the controls in the accuracy of their ratings, this pattern did not differ depending on the domain. There was, however, a domain effect observed as both groups combined showed more accurate ratings of their driving simulator performance following feedback.

Chapter 4: Discussion

The purpose of this study was to examine the nature of self-awareness deficits and how they manifest in driving-related performance following stroke. To investigate the relationship between self-awareness and driving simulator abilities, the study had stroke survivors and healthy controls evaluate their performance on various driving simulator and neuropsychological tasks. By having participants rate familiar driving skills and novel neuropsychological performance, this study investigated whether self-awareness changed as a function of the context involved. Consistent with previous research, it was hypothesized that stroke survivors would demonstrate ISA, defined as significantly larger discrepancies between their actual and estimated performance (i.e., larger estimated than actual scores) than healthy controls. Second, it was hypothesized that stroke survivors would benefit less from immediate feedback than healthy controls as could be observed by significantly less shift between pre- and post-test self-evaluations. Finally, it was hypothesized that the nature of ISA within the stroke group would differ as a function of the context. Given universal self-enhancement biases regarding driving ability, as well the emotional valence placed on driving ability, it was hypothesized that the stroke group would show poorer self-awareness on driving simulator performance in comparison to neuropsychological measures.

The results of this study strongly supported the first hypothesis as the stroke survivors significantly overestimated their actual performance on almost all neuropsychological and driving simulator variables. This overestimation was present both before and after completion of each task and the degree of overestimation was significantly larger than healthy controls. In general, both groups rated themselves as average in comparison to their same-aged peers, an appraisal that was accurate for the healthy controls but not for the stroke survivors, who generally performed at least one to two standard deviations below the norm. Clinically, these scores correspond to the mildly to moderately impaired range in comparison to same-aged peers, the same group to which they rated themselves. Even after completing the task, almost 4 of every 5 stroke survivors overestimated their performance by at least one full standard deviation, whereas only approximately 1 of 5 healthy controls did. The stroke survivors' ISA was noticeably greater during tasks involving visuomotor processing speed (e.g., TMT-B, SDMT).

Contrary to the second hypothesis, several analyses revealed that the stroke survivors were able to benefit from feedback as indicated by significant shift from pre- to post-test self-ratings of performance. First, the stroke group's pre-test ratings were not related to their actual performance whereas post-test ratings were significantly correlated with actual performance. Second, significant correlations between Pre-Post Discrepancy scores and actual performance suggest that the stroke survivors that performed better were able to readjust their self-evaluations more accurately. In other words, the gap between actual and estimated performance decreased as individuals performed better. Finally, although there was no significant difference in the amount of shift on each individual neuropsychological test, the Metacognitive Pre-Post Discrepancy Score for the neuropsychological composite was significantly larger for the stroke group, indicating that the stroke group, to some degree, recalibrated (i.e., decreased) their post-test ratings in comparison to pre-test ratings. Whereas the control group was accurate from the beginning (and thus requiring little shift following the task), the stroke group was quite inaccurate prior to the testing, thus allowing much room for improvement in accuracy. Even when controlling for the degree of initial inaccuracy, this pattern remained indicating that the stroke group still showed greater response to feedback. It is important to note, however, that his improvement was one of relative proportions, as the stroke group remained significantly inaccurate even following feedback.

Unlike the neuropsychological performance, the stroke survivors did not differ from the control groups in their ratings shift following feedback from the driving simulator. In fact, both groups showed a larger shift in their ratings during the simulator task in comparison to the neuropsychological measures. Although this pattern suggests that self-awareness differs across contexts, it is not a phenomena exclusive to stroke. Previous researchers have postulated that affective and motivational factors are just as, if not more, important than cognitive ones in determining awareness (Flashman & McAllister, 2002; Marcel, 2004). Therefore, it would be expected that when faced with a task so relevant to an individual's independence such as driving, one would display an emotional defence mechanism precluding one from accurately evaluating one's abilities. As such, it was hypothesized that stroke survivors would display less self-awareness of driving deficits rather than less emotionally-laden neuropsychological tasks. Overall, the results of the analyses did not support this hypothesis. Although the stroke survivors exhibited significantly larger overestimations across all domains, there was no difference in the magnitude of this overestimation between neuropsychological and driving variables prior to task completion. On both neuropsychological and driving variables, the stroke survivors and their healthy counterparts exhibited more accurate ratings following task completion, thus indicating some ability to benefit from feedback. Contrary to expectations, this was particularly true of the driving simulator tasks as there was a significant difference between post-simulator and post-neuropsychological self-evaluations. In other words, both groups were able to benefit from the immediate and concrete feedback inherent to the driving simulator more so than they could from the novel neuropsychological tests. This pattern again suggested that self-awareness may differ as a result of context or task involved, but this may represent a universal phenomenon rather than one specific to neurological populations such as stroke.

ISA and Driving Ability Following Stroke

The results of the current study both replicate and expand upon previous research investigating self-awareness and driving-related performance following stroke. As expected, the stroke survivors' performance was significantly lower than healthy controls across all executive functioning tasks, with most scores in the mildly or moderately impaired range clinically. This is consistent with previous research that has showed stroke survivors performing worse on a variety of driving components including reaction time, visual scanning, information processing speed, distractibility, poor judgement, and attention deficits (Ball & Owsley, 1992; Engum et al., 1988; Sundet et al., 1995). The stroke group also performed well below the normative sample in terms of overall driving simulator performance. This is not surprising given that stroke survivors did poorly on individual executive tasks and good driving simulator performance requires a higher-order integration and application of these skills in a coordinated and purposeful action, that in itself which could be considered a critical executive function.

Despite these performance deficits across all domains, the stroke survivors displayed ISA as they consistently rated themselves as average in comparison to same aged peers. In fact, their estimations were essentially comparable to a group of individuals who have never suffered a stroke at all. This level of ISA is consistent with previous research regardless of how self-awareness has been measured (e.g., self versus significant other, self versus therapist, actual versus predicted performance). The findings from this study support the results found by Marcel and colleagues (2004) who used a similar actual versus predicted performance paradigm to examine the self-awareness of stroke patients on a verbal fluency and mental flexibility task. Overall, the patients that demonstrated more severe neuropsychological impairments were also more likely to show more ISA (i.e., higher overestimations). Most patients were more accurate in their post-test ratings in comparison to pre-test ratings. From this pattern, the researchers concluded that accurate awareness of deficit required some calibration based on direct personal experience with the deficit and a special type of mental flexibility that allowed for adjustment of behaviour based on experience. The results of this study replicate these findings as the correlational analyses revealed that those stroke survivors who achieved higher actual performance across most measures also showed more accurate postdictions and the most potential to benefit from feedback given lower pre-post discrepancies. Those who performed worse also showed higher levels of ISA. Consistent with Marcel's theory of the importance of mental flexibility in predicting self-awareness, the stroke group, who showed greater ISA, also showed significantly lower performance on neuropsychological measures of mental flexibility (TMT-B) during the present study.

The results of this study, as well as Marcel's conclusions, are consistent with previous metacognitive and cognitive psychological theory. Although both groups demonstrated general self-enhancement bias, the ISA exhibited by the stroke survivors in the current study cannot be explained by this alone as the degree of overestimation was significantly larger than the normal controls. It is probable that individuals who have suffered neurological injury lack several of the cognitive processes needed to accurately rate their performance. Of these, mental flexibility and adjustment skills may be of particular interest. According to the anchoring-and-adjustment heuristic proffered by Tversky and Kahneman (1974), one way to make judgements under uncertainty is to anchor on previous information that comes to mind and adjust until a plausible estimate is reached; therefore, either inaccurate initial anchors or insufficient adjustment commonly invoke judgemental bias. Within this framework, it has been proposed that initial information tends to exert undue influence on subsequent adjustment processes, leaving final estimates too close to the original anchor (Epley & Gilovich, 2006). Therefore, it is possible, that following a neurological event such as stroke, an individual uses their previous driving experience as the anchor on which they base their post-stroke ratings. In other words, if an individual considered himself or herself to be either an average or above average driver prior to their stroke, this preconceived anchor would bias one's ability to adjust one's ratings according to new information (i.e., stroke sequelae) and as a result the individual would continue to himself or herself as average or above.

Although the anchoring-and-adjustment heuristic appears to be a universal phenomenon, it is very probable that neurological injuries that hinder one's cognitive flexibility, such as stroke, would demonstrate an exaggerated pattern. Similar to inaccurate initial anchors, insufficient adjustment may also help explain the presentation of ISA observed during the present study. Consistent with the theories implicating decreased mental flexibility in ISA, it is probable that stroke survivors have more difficulty with the complicated and effortful assessment required to adjust from self-ratings. Recent research has shown that people adjust insufficiently from an initial anchor value because they stop adjusting once their adjustments fall within an implicit range of plausible values (Epley & Gilovich, 2006). This would explain why the stroke group, despite poor performance, rated themselves within the average range of abilities in comparison to same-aged peers, as average is where most individuals fall across most domains. Finally, it is possible that stroke survivors, in general, lack the ability to make accurate estimates about ambiguous information regardless of whether the information pertains to themselves or others. This is consistent with previous research that suggests that stroke survivors perform significantly worse on measures of cognitive estimation (Scott et al., 2007).

Previous studies have revealed contradictory results pertaining to the nature of self-awareness deficits across different domains or contexts. Some researchers have reported that following stroke, some individuals exhibit the largest overestimations during motor-based tasks, while rating themselves as more impaired on cognitive and emotional variables (Gauggel et al., 2000). In contrast, Prigatano and colleagues (1990) reported greater ISA in traumatic brain injury survivors of social interaction skills, emotional control, and cognitive tasks in comparison to physical activities and basic self-care in which individuals were more accurate. Fischer et al. (2004) reported that individuals who had suffered a stroke only overestimated their performance on memory testing whereas simple motor tasks (i.e., finger tapping) were rated accurately. These discrepancies could be explained by the fact that physical limitations and basic self care disabilities are readily recognizable deficits that allow for direct observation (e.g., hemiplegia, not being able to dress oneself) whereas more cognitively based deficits, such as memory and processing speed are more subtle. Of the cognitive-based deficits, executive functioning tasks, in particular, have been reported to be the most strongly related to ISA (Burgess et al., 1998) and as such, were chosen to be used in the current study. By using the tests most related self-awareness, it would allow for a better comparison of whether self-awareness does fluctuate depending on the nature of the task involved.

The current study supports the notion that ISA may be prominent during abstract and cognitive-based tasks as stroke survivors showed ISA on almost all the executive functioning tasks, even after feedback. The areas that the stroke survivors demonstrated the most ISA were on tasks that required visual scanning, cognitive flexibility, and processing speed (TMT-B and SDMT) and it remained quite resilient even after feedback. The lack of awareness within these domains is particularly problematic given that these tasks are consistently found to be some of the most predictive of on-road performance and driving skills (Hopewell, 2002; Mazer et al., 1998; Schanke & Sundet, 2000; Sundet et al., 1995).

The results of the current study provide insight into the manifestations of driving awareness following stroke as much of the previous research has investigated the relationship between driving and stroke, or self-awareness and stroke, but has not systematically investigated all three factors. Whereas the ISA associated with neuropsychological deficits may result from the fact that they are subtle and not easily detected by an individual, driving ability provides a more concrete indicator of abilities. Despite this, the stroke survivors still showed very inaccurate estimations of their abilities in this context as well. Previous studies have shown individuals with neurological impairments, such as TBI, to perform significantly worse on driving simulators than healthy controls (Lew et al., 2005). Whereas some researchers have suggested that stroke survivors are capable of making accurate judgements about driving ability (Golper et al., 1980), others have reported the opposite (Hartje et al., 1991). Fisk and colleagues reported that 30% of stroke survivors resumed driving following stroke, although less than 10% sought out any formal evaluation of driving skills, suggesting the possibility of poor insight into driving –related deficits. The results of the present study help clarify these controversial findings by showing that most stroke survivors have very poor awareness of driving deficits following their injuries. Since the stroke group consisted of both drivers and non-drivers (approximately 2:1, respectively), it appears that the ISA exists regardless of actual driving exposure, which is particularly disconcerting. However, this is consistent with previous reports (Coleman et al., 2002) that have shown no differences in perception of driving abilities between those individuals who have and have not resumed driving following neurological injury. The level of ISA for driving ability displayed by the present stroke group is also consistent with findings suggesting that awareness of one's driving limitations to be unrelated to objective driving records and direct evidence accidents (Marottoli & Richardson, 1998). Unlike this research, the current study did reveal that stroke survivors, similar to the general population, are capable of benefiting from the type of feedback inherent to driving simulator exposure, a phenomenon not previously detected by earlier self-awareness measures. The temporal stability of such benefit, however, has yet to be determined.

Metacognitive Discrepancy Scores and ISA

Clearly, the results of the current study show the use of the Metacognitive Discrepancy scores as valid measures of self-awareness. While the current findings are consistent with previous research implementing this technique (Ergh, 2004; Marcel et al., 2004), it is important to note that they also reveal similar conclusions about the manifestations of ISA using other methodologies, suggesting a promising degree of concurrent validity. One of the most often used indices of ISA has been examining the discrepancy between a patient's self-ratings and the ratings of that patient's significant other, caregiver, or health professional/therapist. The ISA demonstrated during the current study is commensurate with previous studies that have found stroke survivors significantly and continually over-rate their performance in comparison to their therapist's rating of the same domain (Hartman-Maeir et al., 2003). As it pertains to driving, previous studies (Coleman et al., 2002) have shown that patients' perceptions of their abilities did not differ between groups of individuals who had and had not returned to driving. In contrast, significant others' ratings of abilities were significantly different between driver and non-drivers and only the significant other's rating of the patient's fitness to drive made any significant contribution to the prediction of driving status. Similarly, in a recent study by Scott and colleagues (2007), stroke survivors showed disproportionate overestimations of driving ability in comparison to healthy counterparts when asked about rating their driving performance. Interestingly, stroke survivors exhibited more accurate self-appraisals when different frame of references were used. In other words, when asked to compare themselves to their significant other, stroke survivors rated themselves lower than if comparing themselves to the general population. This pattern suggests that a concrete and tangible frame of reference may play a role in eliciting self-awareness. This is consistent with the present findings showing that both stroke survivors and healthy controls showed more accurate self-ratings following driving simulator performance. Overall, the results of the current study expand upon previous findings by showing that overestimations of driving ability in stroke survivors occur, not only in subjective comparisons, but also in more objective actual versus prediction paradigms.

Clinical Implications

In terms of clinical and practical implications, this study contributes to the current knowledge surrounding rehabilitation of deficits following stroke and the use of driving simulators as an effective rehabilitation tool. The current study has expanded on the present literature by providing a sensitive and valid indicator of self-awareness of deficit. Past research has utilized self-reports or significant other opinions as a basis of evaluation. Unlike these previous attempts that rely solely on subjective reports, the use of the Metacognitive Discrepancy scores allows for an objective comparison between an individual's actual and estimated performance. The use of significant other reports has been proven to be a very effective tool in the accurate evaluation of cognitive and behavioural deficits (Coleman et al., 2002), particularly when it comes to activities of daily living, such as driving. This measurement approach has its shortcomings, however, with perhaps the most important being the difficulty in being fully objective when one's decision may have significant consequences for their life as well. For instance, for an elderly couple in which the stroke survivor was the only one of the pair who had a valid driver's license, asking the significant other to objectively evaluate their ability to drive would carry with it significant consequences to the couple's independence. As such, it would not be surprising if the significant other provided a less critical account of driving ability, even when faced with evidence to the contrary. In addition, asking the significant other to be the gatekeeper to their partner's independence could easily lead to marital conflict and undue stress, both of which would be detrimental to the recovery process and psychosocial functioning. The use of actual versus predicted performance paradigms takes the responsibility away from the significant other while still providing a reliable index of one's abilities. In fact, this approach is ideal in a neuropsychological and rehabilitation setting because it allows for an objective evaluation of actual neuropsychological functioning as well as an evaluation of insight into one's deficits, both of which are significantly predictive of rehabilitation outcome and prognosis.

The introduction of a Pre-Post Metacognitive Discrepancy score in the current study also has several clinical advantages. It is possible that the type of ISA differs depending on whether an individual is asked to predict performance either before or after testing. Pre-test self-evaluations can give the clinician a broad sense of global awareness of deficit. For instance, most neuropsychological test instructions provide the individual with an idea of what they are going to be asked to do and also the skills involved (i.e., on timed tasks, individuals are often instructed to work as fast as they can because the examiner is timing their performance). As such, if an individual who has suffered a brain injury has insight into their slower processing, it is expected that they will predict lower performance. If the individual continues to predict average or above average skills, it may indicate the potential presence of ISA.

However, isolated reliance on pre-test discrepancy scores is problematic as many individuals, regardless of neurocognitive functioning, find it difficult to predict performance on a task with which they have no previous experience to anchor their expectations. The use of post-test discrepancy scores will help reduce this confound as the person will experience the task and use this experience as a concrete basis of feedback as to how they do and if they notice any struggles. Again, however, this alone will not allow for a comprehensive representation of one's self-awareness. If the client is asked to evaluate their performance both before and after the task, a Metacognitive Pre-Post Discrepancy score allows a clinician to examine how, if at all, the client can respond to feedback and demonstrate the mental flexibility and openness needed to accurately appreciate one's true abilities. ISA is one of the biggest detriments to successful rehabilitation as it is often difficult to treat symptoms that are not perceived to exist. Similarly, if a client is not capable, for whatever reason, of benefiting from feedback or direct evidence of deficits, that will greatly hinder remediation techniques. Therefore, the introduction of a Metacognitive Pre-Post Discrepancy score can offer very important quantitative and qualitative information about an individual's suitability for rehabilitation efforts, and optimally, may act as an indicator of future rehabilitation success. It can also be used serially which could be used as a marker of improved self-awareness and rehabilitation efficacy. However, it is important to note that although increased self-awareness of deficits carries long term benefits to an individual's integration back into their life, it can have short term consequences to one's emotional and psychological functioning. Whereas an individual previously oblivious to his or her own deficits does not experience much distress about functioning, bringing awareness to such deficits can have a negative impact on the client's self-esteem, coping, and general mood. It is imperative that when clinicians are attempting to rehabilitate ISA, a multifaceted approach is used, with the inclusion of supportive individual and/or family psychotherapy or counselling.

Although the use of Metacognitive Discrepancy scores allow for a standardized assessment and identification of ISA, they, in themselves, do not act as a rehabilitation intervention tool. In contrast, the driving simulator is capable of doing such work and the results of the current study suggest that it has the potential to do so effectively. With the advent of more sophisticated virtual technology, current driving simulators provide a vastly more realistic and ecologically valid index of abilities over their predecessors (e.g., simple brake and gas pedal reaction time lab tests). With this improved technology, it is possible that higher-order driving deficits not previously detected by simplistic operational research measures would become more obvious with such driving simulator assessments. These advantages over earlier technologies may help provide stroke survivors, along with other neurologically impaired individuals, with concrete feedback and evidence about their abilities to cope with the demands of driving. At the same time, they remain a safer option than on-road examinations when neuropsychological measures suggest that cognitive functioning may be compromised.

Despite the promising results of the driving simulator use in rehabilitation and retraining of driving skills, it is possible that individuals will still demonstrate a great deal of unawareness of deficits, or denial of difficulties when it comes to their driving skills. Although the present study demonstrated stroke survivors' ability to benefit from the feedback inherent to the simulator, the temporal stability of this benefit and adjustment has yet to be determined. It is possible, that over longer periods of time, once removed from the immediate feedback, stroke survivors would continue to show very resilient ISA and very little residual shift in their self-appraisals. Consistent with this hypothesis, Marottoli and Richardson (1998) found older drivers' confidence and self-awareness of driving skill were unrelated to objective evidence of driving ability such as history of adverse driving events (e.g., accidents). Again, this is consistent with the seemingly universal phenomenon of self-enhancement bias (Delhomme, 1991), a pattern also observed in the current study as the majority of individuals, regardless of injury history, rated themselves at least average, if not above average on driving simulator performance. It is also consistent with the aforementioned anchoring-and-adjustment heuristic (Tversky & Kahneman, 1974). However, as will be discussed below, the nature and resiliency of self-awareness of driving deficits may differ depending on whether the person is participating in an actual on-road test or on a less realistic driving simulator.

Limitations to the Present Study

This study was limited by several methodological issues. Although the study benefited from a relatively racially and demographically diverse sample, a larger clinical sample size is needed to replicate and generalize the current findings. The heterogeneous stroke group may have also limited the specificity of the findings as the study did not contain any consistent index of stroke severity. The small sample size did not allow for a separation and direct comparison of left- versus right-sided stroke to determine whether a consistent lateralization pattern emerged. Given the unequal representation of patients with left- versus right-sided strokes in this study, it is possible that the sample resulted from a referral bias, with left-sided stroke survivors (with significant language issues) presenting in a rehabilitation setting more often than right-sided stroke survivors (with less obvious deficits). Following stroke, there is a natural recovery slope in terms of cognitive and physical functioning. As such, the nature of ISA may differ over the course of recovery. The current study contained a very large chronicity range that, although lends support for the general robustness of the current findings, does not make it possible to delineate how time since injury may affect self-awareness of driving ability. However, it is worth noting that previous research has suggested that individuals who have suffered a stroke remain inaccurate in their assessment of the impact the stroke has had on their life long after the acute phase of recovery and that time since injury is not a significant predictor of self-awareness (Hibbard et al., 1992). Similarly, a direct comparison of stroke survivors who had and had not resumed driving was not completed. However, recent research has shown that regardless of actual driving status, stroke survivors continue to rate themselves as average or above average in comparison to other drivers (Scott et al., 2007). Finally, the current study did not include an evaluation of how emotional and psychological sequelae play a role in ISA. Mood issues like depression, are generally accepted as influencing an individual's perception of themselves and their world.

The very recent use of more sophisticated driving simulator mechanisms has many advantages for future research and the ecological validity of research findings.

However, because of the novelty of the particular driving simulator used in this study, large standardizations have not been conducted. This forced the use of a relatively small number of normal healthy controls to serve as our normative population on which T scores were based. Although driving simulators are a significant advance in driving research, even the most sophisticated virtual driving simulators cannot match the inherent demands of on-road evaluations. Although the driving simulator used in this study was used to simulate a familiar and in most instances a fairly automatized task, involvement in this simulation task was novel to most, if not all, of the participants. It is still possible that self-awareness differs depending on the familiarity of, or the importance one places on, a task, a hypothesis best tested using actual on-road driving situations. Stroke survivors may be more likely to recognize shortcomings or changes in performance when faced with a task that they have done for a long time and have a good baseline for comparison (i.e., actual on-road driving) since they cannot attribute difficulties to factors associated with the simulator themselves.

Directions for Future Research

This study serves as a foundation for future research examining the nature of self-awareness, driving after stroke, and simulator use. Previous research has been contradictory with regards to the hemispheric asymmetry of self-awareness deficits with some studies favouring a lateralization effect (Anderson & Tranel, 1989; Hartmann-Maeir et al., 2002; Marcel et al., 2004) whereas others do not (Hartmann-Maeir et al, 2003; Hibbard, Gordon, Stein, Grober, & Sliwinski, 1992). It is possible that these disparate findings result from divergent definitions and measurement of self-awareness, as well as the differing contexts or abilities that have been evaluated. Using the current methodology to compare left- versus right-sided strokes may help to determine if, and to what degree, hemispheric asymmetries exist. Similarly, further comparison of groups by other stroke (i.e., time post injury, severity, and presence of comorbid mood issues) and demographic characteristics (i.e., age, gender, and education level) would enlighten further the nature of self-awareness deficits and how they affect driving resumption. Previous research has been inconclusive as to how variables such as age and gender influence driving self-evaluations among the normal population (Finn & Bragg, 1986; Marcel et al., 2004). Similarly, there is a strong possibility that demographic variables, such as age and gender, may affect the match between user and technology. In other words, younger males may already be more comfortable and adept at video games and other similar technologies which would affect their performance on driving simulators.

It appears that self-awareness partly depends on the context or skill involved regardless of neurocognitive functioning. Whereas this study focused on driving simulator and neuropsychological performance, future research can begin to examine other contexts or abilities that may be differentially affected by ISA. Following stroke, many individuals are faced with the challenge of reintegrating into work, home, and community. Insight into how one is handling the demands of their job, social settings, and relationships, is crucial to successful return to premorbid functioning. Research examining survivors' self-awareness in these areas would be very clinically relevant and would greatly aid rehabilitation efforts. By the same token, the current self-awareness paradigm could be applied to other clinical and neurological populations like traumatic brain injury, Alzheimer's disease, and depression.

Although the current Metacognitive Discrepancy scores demonstrated promising results, future research would be useful in further determining the most effective presentation of this paradigm. For instance, the current study asked individuals to rate themselves in comparison to same-aged peers. Although this allows for the most direct comparison to actual performance, cognitive psychology theory suggests that it may serve to bias individual's responses toward rating themselves as average. If individuals were asked to rate themselves in comparison to a more concrete frame of reference, such as their significant other, this may elicit more accurate ratings, as suggested by previous research (Scott et al., 2007). Also, participants were asked to make very general estimations based on overall performance. This requires an accurate estimation and integration of various aspects of any given task, a complex process perhaps too demanding for stroke survivors. Instead, if stroke survivors were asked to rate themselves on several discrete variables, they may demonstrate improved self-awareness. For example, instead of asking them to rate their overall driving performance, a clinician may ask the individual to rate how fast they were driving or how well they obeyed traffic signs. Finally, stroke survivors may show improved self-awareness of deficits if you ask them to rate themselves to how they believed they would have performed prior to their injury. It is possible some of the stroke survivors in this study considered themselves superior drivers prior to their injury and by rating themselves as average, are admitting some decline in performance. By asking them to use themselves as a direct frame of reference, clinicians may elicit a more accurate picture of ISA. Despite the over-predictions, it would be beneficial for future research to delineate how much stroke survivors' over-estimations are due to context-specific ISA or more general cognitive estimation deficits that hinder their ability to accurately evaluate ambiguous information.

This study was conducted within the context of a larger longitudinal investigation of driving resumption following stroke, including standardized on-road evaluations. The inclusion of on-road assessments will lead to various avenues for future research. For instance, similar self-awareness investigations can be conducted with on-road performance as this will serve as a more familiar context than the driving simulator. Knowing the abilities of ISA and driving simulator performance to successfully predict on-road performance would be important in determining rehabilitation approaches. Previous research has been unclear as to the utility of driving simulators to predict on-road performance (Keller et al., 2003; Lew et al., 2005; Monga, 1997; Nouri & Tinson, 1988; Owsley, 1997) but have been greatly limited by the primitive nature of the driving simulators themselves (e.g., consisting of simple green light acceleration and red light braking reaction time). If the newer and more sophisticated simulators prove to be significantly predictive of on-road success and safety, then these instruments and methods may begin to be used as sensitive and cost-effective screens for fitness to drive.

Finally, this study has contributed to a new line of research looking at the utility of driving simulators as a rehabilitation and assessment tool. It appears from this study that the simulator can elicit some improvement in the accuracy of self-ratings as seen by stronger relationships between postdicted ratings and actual performance than between predicted ratings and actual performance. Future research could further investigate whether driving simulators may be used as a method of improving self-awareness of deficit and serving as a retraining tool for basic driving skills as they provide immediate feedback to the individual in a safe yet ecologically valid setting. To do so, repeated administrations of simulator training sessions and accompanying pre and post self-evaluations would allow for an examination of learning slopes and self-evaluations with increased exposure to driving tasks prior to going on the road. This line of research would also allow the examination of the temporal stability of improved self-awareness as a result of simulator use. In other words, do the acute changes seen in this study translate into longer term improvements in self-awareness?

Conclusions

In conclusion, this study replicates the findings from previous research stating that stroke survivors, regardless of context, consistently demonstrate ISA. Clinically, this presentation clearly requires a health practitioner to avoid basing prognostic or rehabilitation decisions on the client's report alone. Instead, the use of Metacognitive Discrepancy scores would provide valid measures of self-awareness and ability to benefit from feedback in neurologically impaired individuals. Finally, the results of the current study suggest that driving simulators allow for a safe and effective way to assess driving skills in individuals wishing to resume driving. Perhaps even more importantly, they can act as a critical intervention tool for improving driving skills themselves, as well as eliciting improved self-awareness of deficit. Self-awareness remains a critical moderating variable between neurocognitive impairment and functional outcome in the community.

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Appendix A

METACOGNITIVE RATING SCALE

INTRODUCTION OF METACOGNITIVE RATING SCALE:

We will be using this rating scale (HAND PATIENT THE RATING SCALE) **for the next few tasks. I want to first make sure you know how to use it. I will ask you to rate how well you think you will do on several tasks compared to other healthy people your age. This is a scale is similar to the grading scale used for most classrooms, where below 50 indicates extreme difficulty performing the task and above 100 indicates extreme ease performing the task. For example, if you think you would perform like most healthy people, i.e., you will give the equivalent of a "C" performance then you would give me a number between 70 and 80. The lower the numbers correspond with poorer performance and the higher numbers correspond with better performance. So if you think you might have <u>some</u> difficulty with the task, i.e., you think you would do worse than other healthy people your age, maybe a "D" performance, then you would give me a number between 60 and 70. If you think that you would do really well on the task compared to healthy people your age, i.e., you would do much better than people your age and maybe score an "A", then you would give me a number between 90 and 100.**

So if you thought you would perform like most other healthy people your age what number would you give me? __ (NUMBER SHOULD BE BETWEEN 70 - 80)
What about if you thought you would have a lot of difficulty with the task and do much worse then others your age, what number would you give me? __ (NUMBER SHOULD BE BETWEEN 50 - 60)
What about if you thought you would do extremely well on the task, i.e., do extremely better than almost everyone your age, what number would you give me? __ (NUMBER SHOULD BE BEWTWEEN 100 - 110)

Interviewer note: Make sure the respondent was able to use the scale before proceeding.

40 50 60 70 80 90 100 110

F-	F	D	C	B	A	A+
Extremely Worse	Much Worse	Worse	Same	Better	Much Better	Extremely Better

<u>PRE-TASK RATING</u>
FOLLOWING THE STANDARDIZED ADMINISTRATION OF TASK INSTRUCTIONS, THE PARTICIPANT RATES HOW WELL SHE BELIEVES SHE WILL PERFORM COMPARED TO OTHERS HER AGE.

Use the rating scale to indicate how well do you think you will perform on this task compared to healthy people your age? Did you think you would score in the lower range of that category, e.g., like a (*USE LETTER GRADE*) minus, the upper range, e.g., like a (USE LETTER GRADE) plus, or right in the middle, e.g., like a *(USE LETTER GRADE)*?

THE TASK IS THEN ADMINISTERED.

<u>POST-TASK RATING</u>
FOLLOWING THE TASK, PARTICIPANTS RATE HOW WELL THEY BELIEVED THEY PERFORMED.

Use the rating scale to indicate how well you think you performed on the task compared to healthy people your age? Did you think you would score in the lower range of that category, e.g., like *a (USE LETTER GRADE)* **minus, the upper range, e.g., like a** *(USE LETTER GRADE)* **plus, or right in the middle, e.g., like a** *(USE LETTER GRADE)?*

Appendix B

Conversion of Patient Ratings to T-Score Equivalents

Patient Rating: Extremely Worse (40 through 49) – Moderately to Severely Impaired
IF RATING < 40 T-SCORE EQUIV = 29.5.
IF RATING = 40 T-SCORE EQUIV = 30.
IF RATING = 41 T-SCORE EQUIV = 30.5.
IF RATING = 42 T-SCORE EQUIV = 31.
IF RATING = 43 T-SCORE EQUIV = 31.5.
IF RATING = 44 T-SCORE EQUIV = 32.
IF RATING = 45 T-SCORE EQUIV = 32.5.
IF RATING = 46 T-SCORE EQUIV = 33.
IF RATING = 47 T-SCORE EQUIV = 33.5.
IF RATING = 48 T-SCORE EQUIV = 34.
IF RATING = 49 T-SCORE EQUIV = 34.5

Patient Rating: Much Worse (50 through 59) – Mildly Impaired
IF RATING = 50 T-SCORE EQUIV = 35.
IF RATING = 51 T-SCORE EQUIV = 35.5.
IF RATING = 52 T-SCORE EQUIV = 36.
IF RATING = 53 T-SCORE EQUIV = 36.5.
IF RATING = 54 T-SCORE EQUIV = 37.
IF RATING = 55 T-SCORE EQUIV = 37.5.
IF RATING = 56 T-SCORE EQUIV = 38.
IF RATING = 57 T-SCORE EQUIV = 38.5.
IF RATING = 58 T-SCORE EQUIV = 39.
IF RATING = 59 T-SCORE EQUIV = 39.5

Patient Rating: Worse (60 through 69) – Low Average
IF RATING = 60 T-SCORE EQUIV = 40.
IF RATING = 61 T-SCORE EQUIV = 40.5.
IF RATING = 62 T-SCORE EQUIV = 41.
IF RATING = 63 T-SCORE EQUIV = 41.5.
IF RATING = 64 T-SCORE EQUIV = 42.
IF RATING = 65 T-SCORE EQUIV = 42.5.
IF RATING = 66 T-SCORE EQUIV = 43.
IF RATING = 67 T-SCORE EQUIV = 43.5.
IF RATING = 68 T-SCORE EQUIV = 44.
IF RATING = 69 T-SCORE EQUIV = 44.5

Patient Rating: Same (70 through 79) - Average
IF RATING = 70 T-SCORE EQUIV = 45.
IF RATING = 71 T-SCORE EQUIV = 46.
IF RATING = 72 T-SCORE EQUIV = 47.
IF RATING = 73 T-SCORE EQUIV = 48.
IF RATING = 74 T-SCORE EQUIV = 49.

IF RATING = 75 T-SCORE EQUIV = 50.
IF RATING = 76 T-SCORE EQUIV = 51.
IF RATING = 77 T-SCORE EQUIV = 52.
IF RATING = 78 T-SCORE EQUIV = 53.
IF RATING = 79 T-SCORE EQUIV = 54.

Patient Rating: Better (80 through 89) – Above Average
IF RATING = 80 T-SCORE EQUIV = 55.
IF RATING = 81 T-SCORE EQUIV = 55.5.
IF RATING = 82 T-SCORE EQUIV = 56.
IF RATING = 83 T-SCORE EQUIV = 56.5.
IF RATING = 84 T-SCORE EQUIV = 57.
IF RATING = 85 T-SCORE EQUIV = 57.5.
IF RATING = 86 T-SCORE EQUIV = 58.
IF RATING = 87 T-SCORE EQUIV = 58.5.
IF RATING = 88 T-SCORE EQUIV = 59.
IF RATING = 89 T-SCORE EQUIV = 59.5

Patient Rating: Much Better (90 through 99) - Superior
IF RATING = 90 T-SCORE EQUIV = 60.
IF RATING = 91 T-SCORE EQUIV = 60.5.
IF RATING = 92 T-SCORE EQUIV = 61.
IF RATING = 93 T-SCORE EQUIV = 61.5.
IF RATING = 94 T-SCORE EQUIV = 62.
IF RATING = 95 T-SCORE EQUIV = 62.5.
IF RATING = 96 T-SCORE EQUIV = 63.
IF RATING = 97 T-SCORE EQUIV = 63.5.
IF RATING = 98 T-SCORE EQUIV = 64.
IF RATING = 99 T-SCORE EQUIV = 64.5.

Patient Rating: Extremely Better (100 through 110) – Very Superior
IF RATING = 100 T-SCORE EQUIV = 65.
IF RATING = 101 T-SCORE EQUIV = 65.5.
IF RATING = 102 T-SCORE EQUIV = 66.
IF RATING = 103 T-SCORE EQUIV = 66.5.
IF RATING = 104 T-SCORE EQUIV = 67.
IF RATING = 105 T-SCORE EQUIV = 67.5.
IF RATING = 106 T-SCORE EQUIV = 68.
IF RATING = 107 T-SCORE EQUIV = 68.5.
IF RATING = 108 T-SCORE EQUIV = 69.0.
IF RATING = 109 T-SCORE EQUIV = 69.5.
IF RATING = 110 T-SCORE EQUIV = 70.
IF RATING > 110 T-SCORE EQUIV = 70.5.

Appendix C

INFORMED CONSENT FORM

Principal Investigator: Lisa J. Rapport, Ph.D.

Introduction and Purpose:
Research is being conducted at Wayne State University to examine recovery of independent functioning after stroke. The purpose of this study is to collect information about the best predictors of recovery of function and assessment of driving status after stroke. I am being asked to take part in this research study because I am an adult aged 18 years or older and I had a stroke.

Procedure:
If I take part in this study, I will be asked to answer questions about my recovery since my stroke. I will be asked to complete questionnaires. If I seek to resume driving, I may also be asked to complete a computerized driving evaluation at the School of Allied Health and Pharmacy. As an additional component of this study, I realize that my medical and driving records may be obtained and only will be used for the purposes of this study. I understand that a significant other such as a family member also may be contacted to participate in the study and provide information about my recovery.

Risks:
There are no expected risks from participating in this study. Some people may experience temporary frustration from some of the testing that will be done. In the unlikely event of any injury resulting from this research, no reimbursement, compensation, or free medical treatment is offered by the Detroit Medical Center or Wayne State University.

Benefits:
There will be no direct benefit for me for taking part in this study. Analysis of the information will increase awareness of the best ways to assess driving ability and may help more people who have sustained strokes resume the activities they did before the stroke, including safe driving.

Cost of Participation:
There will be no additional cost to me or my insurance carrier for participation in this study.

Compensation:
I will be paid $25 when I complete the questionnaires. If I participate in the driving simulator evaluation, I will be paid an additional $25.

Voluntary Participation/Withdrawal:
My participation is entirely voluntary. I can refuse participation at any time. Refusal to participate will not affect the treatment I receive now or in the future. I can decide to withdraw from the study at any time. My decision will not change the present or future health care or other services that I receive.

Confidentiality:
All information that is collected for this study will be kept entirely confidential. I will be identified in the research records by a code number. Information that identifies me personally will not be released without my written permission. Any presentation or publication based on the results from this study will not identify me by name or otherwise.

Questions: If I have any questions regarding this study or my participation in it, now or in the future, I can contact Dr. Lisa Rapport at (313) 577-2800 or Dr. Renee Coleman at (313) 745-9763. If I have any questions regarding my rights as a research subject, I can contact the Chairman of the Behavioral Investigation Committee at (313) 577-1628.

Consent to Participate in Research Study: I have read or had read to me all of the above information about this research study, including the research procedure, possible risks, and the costs and benefits to me. The content and meaning of this information was explained. All of my questions have been answered to my satisfaction. I hereby consent and voluntarily offer to follow the study requirements and take part in this study. I will receive a signed copy of this consent form.

Signature of Study Subject	Date
Printed Name of Study Subject/Patient	Date
Signature of Legally Authorized Representative	Date
Relationship to Subject	
Signature of Witness	Date
Signature of Investigator/Designee Obtaining Informed Consent	Date

Appendix D

INFORMED CONSENT FORM FOR CAREGIVER/SIGNIFICANT OTHER

Principal Investigator: Lisa J. Rapport, Ph.D.

Introduction and Purpose:
Research is being conducted at Wayne State University to examine recovery of independent functioning after stroke. The purpose of this study is to collect information about the best predictors of recovery of function and assessment of driving status after stroke. I am being asked to take part in this research study because I am an adult aged 18 years or older and my significant other had a stroke.

Procedure:
If I take part in this study, I will be asked to answer questions about my significant other's recovery since his or her stroke. I will be asked to complete questionnaires about myself and my significant other. I may also be asked to complete some paper and pencil tasks and a computerized driving evaluation at the School of Allied Health and Pharmacy. I am aware that the researchers may be interviewing my significant other.

Risks:
There are no expected risks from participating in this study.

Benefits:
There will be no direct benefit for me for taking part in this study. However, the information may help more people who have sustained strokes resume the activities they did before the stroke, including safe driving.

Cost of Participation:
There will be no additional cost to me or my insurance carrier for participation in this study.

Compensation:
I will be paid $25 when I complete the questionnaires. If I participate in the driving simulator evaluation, I will be paid an additional $25. In the unlikely event of any injury resulting from this research, no reimbursement, compensation, or free medical treatment is offered by the Detroit Medical Center or Wayne State University.

Voluntary Participation/Withdrawal:
Taking part in this study is voluntary. I may choose not to take part in this study, or if I decide to take part, I can later change my mind and withdraw from the study. My decision will not change the present or future health care or other services that I receive.

Confidentiality:
All information that is collected for this study will be kept entirely confidential. I will be identified in the research records by a code number. Information that identifies me personally will not be released without my written permission. Any presentation or publication based on the results from this study will not identify me by name or otherwise.

Questions: If I have any questions regarding this study or my participation in it, now or in the future, I can contact Dr. Lisa Rapport at (313) 577-2800 or Dr. Renee Coleman at (313) 745-9763. If I have any questions regarding my rights as a research subject, I can contact the Chair of the Behavioral Investigation Committee at (313) 577-1628.

Consent to Participate in Research Study: I have read or had read to me all of the above information about this research study, including the research procedure, possible risks, and the costs and benefits to me. The content and meaning of this information was explained. All of my questions have been answered to my satisfaction. I hereby consent and voluntarily offer to follow the study requirements and take part in this study. I will receive a signed copy of this consent form.

____ ____________________
Signature of Study Subject Date

____ ____________________
Printed Name of Study Subject/Patient Date

____ ____________________
Signature of Legally Authorized Representative Date

____
Relationship to Subject

____ ____________________
Signature of Witness Date

____________________________ ______________ ____________________
Signature of Investigator/Designee Obtaining Informed Consent Date

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