

Understanding the challenges of the older driver: Attention, road complexity and assessment

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## ABSTRACT

Older adults are at an increased risk for motor-vehicle collisions (MVCs) once distance driven is considered, a finding that is partly attributed to a decline in attention related processes associated with age. MVCs typically occur in highly specific areas, suggesting a role of the complexity of the driving environment contributing to the occurrence of MVCs. The goal of this thesis was to explore the attentional demands of simulated driving events of varying complexity among young, mature and older drivers. In the present studies, attentional demand associated with driving was assessed through the peripheral detection task (PDT), a method in which a stimulus unrelated to the driving task is presented and drivers manually respond immediately upon its detection; latency to respond is recorded. The complexity of the driving environment was operationalized in terms of vehicle handling and of information processing elements. In the first study, inexperienced drivers completed a series simulated driving scenarios that varied according to their information processing and vehicle handling demands. The results showed a reduction in PDT performance at intersections where information processing is increased as well as when handling maneuvers behind a lead vehicle were required. Building on these findings, the second study employed the identical protocol as the first but examined differences in attentional demand between mid-aged and older drivers. The results indicated that when information processing demands were increased through the addition of traffic, and buildings, all participants exhibited greater workload regardless of age. The third study presented young, mid-aged, and older drivers with a simulated driving assessment course and administered several cognitive tasks. The results of the third study supported the hypothesis in that complex driving situations elicited greater attentional demand among drivers of all ages. Older adults showed greater attentional demand in comparison to young and mid-aged adults even after controlling for baseline response

time. Older drivers also scored poorer on a global measure of driving safety. The results of this thesis highlight the roles of intrinsic and extrinsic factors involved in safe driving and are discussed in terms of appropriate interventions to improve road safety.

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### Formatting:

This dissertation is presented in article format. The first and third articles have been published in peer-reviewed scientific journals and are formatted and organized according to the specifications of the journals in which they are published. As the primary author of the studies, Arne Stinchcombe is listed as the first author on the publications. The remaining sections of the thesis are formatted according to the guidelines of the American Psychological Association.

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## CHAPTER 1

### GENERAL INTRODUCTION

#### *Context*

Transportation represents a basic human need for all individuals and, as a means to satisfy this need, driving a motor vehicle has become ubiquitous in many parts of the world. Driving is associated with autonomy and independence, and contributes to a sense of well-being, an ability to preserve social contacts, and to overall quality of life (Ragland et al., 2004). As in most developed countries, Canadians are heavily reliant on the automobile particularly due to the distances that must be traveled between residential areas such as suburbs and urban centers, as well as within them. In 2003, cars and light trucks accounted for the greatest number of kilometers traveled (over 450 million kilometers), followed by air travel (90 million kilometers traveled) (Statistics Canada, 2006). Vehicle ownership in Canada increased significantly following WWII, due to lower fuel and vehicle prices as well as social forces such as higher-household incomes, smaller-sized households, and more women entering the workforce (Environment Canada, 1996). In 1951, for example, vehicle ownership records indicate that there were approximately five individuals for every vehicle registered in Canada whereas by the mid-1980's there were less than two individuals per registered vehicle (Statistics Canada, 2006).

Continued reliance on the automobile is often attributed to the expansion of suburban areas as well as employment growth within the suburbs (Statistics Canada, 2006). With such changes have come adjustments to the typical commuting pattern; rather than simply commuting towards a common city-centre using a route supported by conventional public transportation, commuters are increasingly commuting from suburb to suburb or even from city-centre to

suburb. Accordingly, Canadians spent an average of 63 minutes per day transporting themselves to and from work in 2005, compared to 54 minutes in 1992 (Turcotte, 2005).

Obviously there are a number of benefits associated with driving such as access to employment from one's residence, access to necessary services like medical care and groceries, social contact and, importantly, a sense of autonomy and independence. With these benefits, however, driving does come at a cost in the form of property damage, injuries, and fatalities resulting from motor vehicle collisions (MVCs). A Transport Canada (2001) report revealed a number of trends in motor vehicle collisions (MVCs) between 1988 and 1997. Most significantly the report found that during the period there was an overall decrease in MVCs. Despite this welcomed trend, in 1997 there were still over 600,000 MVCs reported of which 75.3% resulted in only property damage, 24.3% resulted in injury, and .04% resulted in fatality.

In addition to the tragedy of the actual fatalities and injuries associated with MVCs there is also a significant financial and social cost involved. Nationally it is estimated that \$25 billion dollars in direct financial costs are associated with crashes and casualties (Vodden, Smith, Eaton, & Mayhew, 2007). Moreover, in Ontario it is estimated that in 2004 MVCs generated \$18 billion in social costs. In this case, social cost refers to a range of costs incurred due to collisions and broadly includes healthcare, diminished labor force, assistance services (e.g., police, fire), property damage, etc. The largest single contributor to those costs was the direct cost of fatalities accounting for \$11 billion, followed by injuries accounting for \$4 billion, and finally property damage accounting for \$2 billion. On average, across all collision severities, the average social cost of a collision in Ontario in 2004 was \$77 thousand (Vodden et al., 2007).

Globally, the impact of MVCs is even more striking. Currently, an estimated 1.2 million road users are killed in traffic collisions each year throughout the world; this value is expected to

increase by 60% by the year 2020 should current trends continue (Transport Canada, 2004). In Canada however, the frequency with which MVCs occur has been decreasing. Compared to years previous, current fatalities and serious injuries resulting from traffic collisions are at historical lows even when considering the steady increases in the number of vehicles on the roads. Nevertheless, Ontario's Chief Medical Officer of Health reported in 2003 that unintentional injury is the fourth leading cause of death and hospitalization in Ontario (D'Cuhna, 2003). Due to the potential personal, societal, and financial consequences, the use of automobiles represents a major public safety concern both in Canada and around the globe.

### *Influence of age*

In order to guide research and shape policy relating to driving it helps to identify factors that influence the likelihood of a MVC. Research often cites driver characteristics such as male gender, decreased cognitive status, and inexperience as significantly predicting MVC (Begg & Langley, 2001; Vaez & Laflamme, 2005; Valcour, Masaki, & Blanchette, 2002). One of the most researched driver characteristics relates to driver age.

In particular, young adults are acknowledged as the cohort most frequently implicated in at-fault MVCs (Williams, 2003). For example, Doherty, Andrey, and MacGregor (1998) examined police reported crashes in Ontario in 1988. MVC involvement rates for drivers 16-19 years were found to be significantly higher than those of 20 years and above. In a National study conducted by Roberts, Vingilis, Wilk and Seeley (2008), self-report MVC injuries from the National Population Health Survey (NPHS) as well as official police records from Transport Canada's Traffic Accident Information Database (TRAID) were examined. With respect to age, their results indicated that both self-report and police records were similar in pointing to

adolescents being at greatest risk of injury resulting from a MVC, a trend that decreases as they progress into adulthood.

In general, this over-representations in MVCs has been attributed to the tendency of young drivers to engage in risky driving behaviours (Clarke, Ward, & Truman, 2005; Ulleberg, 2001). In an age-comparison study, Hatfield and Fernandes (2009) examined risk taking behaviours of 200 participants. Compared to mid-aged drivers, young drivers demonstrated lower risk-aversion, higher tendency for actually taking risks, as well as stronger motivation to engage in risky driving related to excitement, sensation-seeking, and social influence. These findings are corroborated by the types of MVCs in which younger adults are implicated since their MVCs typically involve a single vehicle, tend to involve one or more driving errors, have speed as a factor, and often involve alcohol (Kweon & Kockelman, 2003; McGwin & Brown, 1999).

The age group most frequently implicated in MVCs is young adults whereas the age-cohort least frequently cited is older adults (greater than 65 years). Important to consider, however, is that, compared to young adults, fewer older adults are licensed to drive and those who are drive fewer kilometers. When considering mileage-based crash rates, older adults are indeed implicated in more MVCs than younger adults (Lyman, Ferguson & Williams, 2002; Stamatiadis, 1996; Stamatiadis & Deacon, 1997). Moreover, due to their greater frailty and reduced resistance to injury, older drivers are more likely to experience casualties (i.e., injury or death) (Augenstein, 2001). Older drivers are more often involved in MVCs that occur in good weather, during daylight hours, at intersections, and when making turns (Langford & Koppela, 2006; McGwin & Brown, 1999). Moreover, older drivers are usually involved in multi-vehicle crashes, especially at intersections, characterized by errors related to failure to yield right of way,

difficulties merging into traffic, changing lanes, leaving a parking position, and reversing (Hakamies-Blomqvist, 1993). Many authors contend that the mileage-based overrepresentation of older adults in MVCs is due to functional decline associated with normal aging (e.g., Raitanen, Törmäkangas, Mollenkopf, & Marcellini, 2003; Ross et al., 2009).

Interestingly, older drivers, unlike younger drivers, tend to show awareness of their difficulties and engage in compensatory behaviors to avoid travel under conditions perceived as threatening or which may cause discomfort (Brouwer & Ponds, 1994; De Raedt & Ponjaert-Kristoffersen, 2000). Examples of compensatory behaviours that have been documented in the literature include reducing speed, avoidance of highways, avoidance of unnecessary turns, and driving at non-peak hours (e.g., Rimmö & Hakamies-Blomqvist, 2002; Simoes, 2002).

An added component of the involvement of older adults in MVCs is that not all older adults are at equal risk. More precisely, recent research by Langford, Methorst, and Hakamies-Blomqvist (2006) sought to investigate the association between annual distance driven, age, and crash involvement. Over 45 thousand drivers were surveyed in the Netherlands regarding their driving habits. The results indicated that only older drivers who travel less than 3000 km per year had elevated crash risks. Their findings confirmed earlier research that indicated a “low mileage bias” among older drivers (Hakamies-Blomqvist, Raitanen, & O’Neill, 2002).

Despite the fact that older adults have been shown to counterbalance their age-related decline by engaging in compensatory strategies and that only a subset of this cohort are at the highest risk of MVC, older drivers’ behaviour continues to remain a serious public safety concern. More specifically, Canada’s senior population is growing. Currently, older adults constitute the fastest growing segment of the Canadian population. In 2001, it was estimated that there were 3.92 million Canadians over the age of 65 years, which is two-thirds more than in

1981 (Canadian Institutes for Health Research, 2006). In comparison, during the same time period, the rest of the population experienced an overall growth of only 25%. As the ‘baby boomers’ (i.e., born between 1946 and 1965) age, the Canadian senior population is expected to reach 6.7 million by 2021, and a staggering 9.2 million by 2041. In fact, the fastest growth in the senior population is occurring among the oldest Canadians. By 2041, individuals over the age of 85 years are expected to make up 4% of the overall Canadian population. This population trend is due to several factors, including reduced fertility rates, aging ‘baby boomers’, as well as increased longevity. In 1997, life expectancy at birth for Canadians reached 75.8 years for men and 81.4 years for women. Life expectancy is expected to continue to increase, reaching 81 years for men and 86 years for women in 2041 (Health Canada, 2002). Moreover, ‘baby boomers’ drive more than previous generations and due to differences in lifestyle are more likely to keep driving (Spain, 1997). As such, researchers predict that by 2025 more than 40% of all fatal crashes may be associated with age-related frailties (Staplin, Lococo, Gish, & Decina, 2003).

### *Crash site profile*

Established predictors of age-related crashes have generally been presented and described in the previous text; however, to understand the nature of the specific challenges facing older adult drivers, a more in-depth discussion is necessary. When describing MVCs, they are often broadly characterized in terms of how many vehicles are involved (i.e., single vs. multiple MVC) and the roadway configuration at which the MVC occurs. In North America, two studies represent the most recent large-scale crash analysis for all drivers: one, a report by Transport Canada (2001) and the other by the U.S. Department of Transportation. In the former, all MVCs registered in the National database TRAIID database were analyzed for the 10-year period from

1988 through 1997. This report examined MVCs in terms of environmental elements such as weather, road attributions, and crash characteristics. The U.S. report examined all police-reported crashes that occurred in 2002 and analyzed them in terms of their crash type, physical setting, and their pre-crash scenarios. In total, over six million MVCs resulting in more than 41,000 fatalities and over three million injured individuals were analyzed (Najm, Sen, Smith & Campbell, 2003).

Single-vehicle MVCs are those in which only one vehicle is implicated. These types of collisions make up approximately 25% of the total crashes (Najm, Sen, Smith & Campbell, 2003). Single-vehicle MVCs include striking an inanimate object, pedestrian, cyclist, or animal. In Canada, most single-vehicle collisions occurred on Saturdays, in the summer months, on rural roads, between midnight and 3am. The most common type of single-vehicle collision occurred when a vehicle strayed from the roadway; within this type of MVC the most common crash configurations were going straight and departing off the roadway (24%), going straight and losing control (20%), and, turning and losing control (15%).

The remainder of MVCs involves two or more vehicles. Within this category of crashes, rear-end type collisions (i.e., the front of a following vehicle strikes the rear of a lead vehicle, both traveling in the same direction) and crossing path collisions (i.e., one moving vehicle cuts across the path of another, initially approaching from either lateral or opposite directions, in such a way that they collide at or near a junction) account for the greatest number of total MVCs at 29% and 26%, respectively. The majority of multiple-vehicle collisions occurred in urban areas, on weekdays, between 3pm and 6pm.

Globally, there are several environmental predictors that can be used to estimate the likelihood of a MVC. Of them, the most significant individual predictors of MVCs in highway

conditions include greater distance of travel, undivided highways, and multiple lanes (Agent & Deen, 1975). Moreover, the greatest single factor affecting crash occurrence is traffic volume (Wang & Abdel-Aty, 2008; Zhou & Sisiopiku, 1997).

It is clear that inexperience (as indicated by losing control of the vehicle), and risky driving behaviours (as indicated by late-night/early morning crashes and weekend driving) are major contributors to the likelihood of single-vehicle MVCs. As well, with respect to age, single-vehicle motor crashes are highly associated with young drivers (Stamatiadis & Deacon, 1997). More precisely, research on 16-year old drivers found that a higher proportion of crashes of teenagers are single-vehicle events and involve driver culpability, speeding, and high vehicle occupancy (Ulmer, Williams, & Preusser, 1997). Separate research points to factors such as driving too fast for the current driving conditions, changing lanes improperly, losing control of the vehicle, driving while under the influence of alcohol or drugs, and not using a seatbelt all predicting crashes among young cohorts (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998).

In relation to multiple-vehicle MVCs, it is not surprising that the characteristics of these situations reveal that these collisions frequently occur in highly congested urban areas; MVCs that occur in road environments with more road users are more likely to implicate more than one vehicle. Regarding age-differences, older adults, unlike young drivers, are often implicated in MVCs with more than one vehicle. One age-comparison study found that crashes in which older adults were at-fault typically involved intersections, failure to yield the right of way, unseen objects, and failure to heed stop signals (McGwin & Brown, 1999). Moreover, a study conducted by Zhang, Fraser, Lindsay, Clarke and Mao (1998) concluded that crash-risk among older drivers was primarily due to medical conditions, failure to yield the right-of way, and collision at an intersection. Unlike young drivers whose crash risk is due to inexperience and

risk-taking behaviours that seem to decrease as they age, older drivers' challenges are more likely to involve a perceptual insufficiency in which critical stimuli in the driving environment are not taken into account, resulting in a MVC (Caird, Edwards, Creaser, & Horrey, 2005; Skyving, Berg, & Laflamme, 2009).

The discussion so far has been rather broad and largely has taken an epidemiological approach to understanding the challenges facing drivers and, more specifically, older adults in relation to MVCs. Using large databases and population statistics, the aforementioned studies revealed the implications of driving for public safety, the risk posed by older drivers, and the potential serious impact of an aging population on MVCs. This body of literature has identified some characteristics of the older driver such as that they experience functional decline (e.g., reduced processing speed, reduced eye sight) for which some drivers are able to compensate, and that they are implicated in MVCs in highly congested areas. Based on the abovementioned literature, the difficulties experienced by older drivers occur because of perceptual errors resulting from functional decline associated with normal aging and impaired health (Dobbs, Carr, & Morris, 2002). To better understand these errors a discussion of the specific deficits of older drivers at the individual psychological level is necessary. Prior to providing evidence as to the importance of cognitive function and driving among the elderly, it is useful to operationalize the driving task by means of a theoretical framework. As such, a brief review of accepted theoretical models of driving behaviour is appropriate.

### *Framework*

Driving is a complex and dynamic task which involves a myriad of psychomotor, perceptual and cognitive processes. In order to comprehend and discuss driving behaviour among older adults, an operationalization of the task seems appropriate. More specifically,

numerous authors have proposed models of driver behaviour to assist in conceptualizing the complex and dynamic nature of driving itself (e.g., Anstey, Wood, Lord, & Walker, 2005; Galski, Bruno, & Ehle, 1992; Grandenigo, 2002). One recent model by Fuller (2005), known as the task capability interface model, represents a comprehensive framework that combines the capabilities of the road user and the demands of the road environment. In this model, Fuller (2005) presents the interaction between driver characteristics (e.g., experience, age, competence, etc), task demands (e.g., road conditions, perceptual complexity, other road users), and overall safety.

A more general approach is that of human factors where the focus is the boundaries of human information acquisition and processing (Sanders & McCormick, 1987; Wickens & Hollands, 2000). These models focus on the design of motor vehicles and roadway based on the capacity of the driver. In the human factors view, MVCs occur due to the inability of the vehicle and roadway to meet the needs of the driver.

Cognitive psychological models of driver behaviour place emphasis on the interplay between driving-related decisions, handling the vehicle, as well as perceiving and responding to stimuli (Rasmussen, 1986). Therefore, these models are particularly suited to examining higher order functions. One widely accepted model that falls within this domain is that of Michon (Michon, 1985; van Zomeren, Brouwer, & Minderhoud, 1987). Michon's hierarchical model of driver behaviour includes three interdependent levels of driving skills and which are identified as strategic, tactical, and operational. Since its conceptualization, Michon's model has been applied widely in research and has also been appreciated for its clinical relevance (Unsworth, Lovell, Terrington, & Thomas, 2005).

Of the three interdependent levels of driving skill and control in Michon's hierarchical model of driver behaviour the highest level is strategical and involves general planning of a driving trip including identifying trip goals, the route to take, the cost of the trip, and consideration of factors such as weather conditions. Next, the tactical level examines the way in which the traffic situation is mastered. For example, the tactical level includes behaviours and skills required to negotiate a curve, to overtake another vehicle, adapt the speed of the vehicle, etc. Finally, the lowest level of Michon's hierarchy is the operational level which involves the sensory-motor, behavioural, and cognitive skills involved while driving. Specifically, the operational level includes the skills required to steer the vehicle, operate the gas and brakes, as well as attend, process and respond to relevant stimuli.

Each of the levels is considered hierarchic in that decisions that are made on the strategical level affect performance at the tactical level which, in turn, affects performance at the operational level. Despite this, each level of Michon's hierarchy does differ in terms of its temporal characteristics. Specifically, among all levels of the model, planning activities that are conducted at the strategical level may take the longest time to complete (i.e., a few minutes or longer) and can usually be made without any time pressure. Next, activities at the tactical level last only a few seconds and involve slight time pressure. Finally, activities at the operational level can last less than a second and exert continual time pressure. In the hierachical model, time pressure may be mediated by higher levels. For example, the temporal demand of the operational level can be reduced by leaving more distance between the driver and a lead vehicle in front which represents a compensation technique at the tactical level.

Michon's 3-level hierarchical model of driver behaviour is useful in terms of operationalizing the driving task. It may also be utilized when understanding the challenges of

older adults. At the strategical level, older adults have been shown to drive fewer kilometers, avoid driving in darkness, during unfavorable weather conditions, and during rush-hour (Ball et al., 1998; Hakamies-Blomqvist, 1994). Moreover, older drivers have been found to plan their routes in greater detail in comparison to mid-aged drivers (McGwin & Brown, 1999).

At the tactical level, older drivers have been shown to compensate by reducing their speeds and allowing more distance between themselves and other drivers (De Raedt & Ponjaert-Kristoffersen, 2000). Deficits at the tactical level have also been documented among older drivers. Specifically, as previously discussed, it is widely acknowledged that older adults have difficulties negotiating intersections, particularly those involving left-turns (Keskinen, Ota, & Katila, 1998). Moreover, difficulties with general maneuvering as well as entering highways have been reported among this cohort (Staplin & Lyles, 1992).

The final component of Michon's hierarchical model of driving behaviour is operational, referring to sensory-motor, behavioural, and cognitive processes that occur in less than one second. In a comprehensive literature review recording predictors of driving performance among older adults, Anstey, Wood, Lord and Walker (2005) outlined a number of operational factors associated with driving behaviour. Regarding sensory factors, visual acuity is the most commonly measured ability correlated with driving performance. For example, Marottoli and colleagues (1998) administered a comprehensive older driver assessment battery to determine the predictive association of independent tests with self-reported driving safety. Among other predictors, their results indicated that individuals with poor visual acuity (as assessed by the Rosenbaum test) were at a significant increased risk of having been involved in a MVC. Despite this, the evidence regarding the predictive value of visual acuity is inconsistent. For instance, one large epidemiological study found drivers with lower visual acuity to have an increased risk

of self-reported crashes (Ivers, Mitchell, & Cumming, 1999) whereas a similar, more recent study did not (Margolis, Kerani, McGover, Songer, & Cauley, 2002). Consequently, Anstey, Wood, Lord and Walker (2005) as well as other authors conclude that sensory factors alone are not sufficient to predict driving safety among older drivers as they do not draw upon the visual and cognitive complexity of the driving task (Owsley et al., 1998; Wood, 1999).

Among cognitive factors associated with driving outcomes, speed processing, memory, mental status, and attention are all significant predictors (Anstey et al., 2005). Speed of processing is often assessed through simple and choice reaction time in which participants manually respond to a stimulus as fast as they possibly can. Small associations between simple-reaction time and self-reported crash history have been reported (Marottoli et al., 1998) while moderate correlations exist between choice-reaction time and driving outcomes (McKnight & McKnight, 1999). With regard to memory, poor recall and recognition scores are moderately correlated with driving outcomes ( $R \approx .30-.50$ ) (Odenheimer et al., 1994). Also, a visual process entitled peripheral motion contrast sensitivity threshold (RMCT), has recently been shown to be related to self-reported driving habits among older adults (Henderson, Gagnon, Bélanger, Tabone, & Collin, 2007; Henderson, Gagnon, Collin, Tabone, & Stinchcombe, 2009). In a study in which several visual and cognitive measures were compared with on-road test performance, detection of motion was one of the three best measures for discriminating safe from unsafe drivers (Wood, Anstey, Kerr, Lord, & Lacherez, 2008).

A further operational element that pertains to the driving difficulties of older adults is attention; attentional deficits among older drivers have been widely researched and there is considerable consensus among academics that attention plays a significant role in predicting the driving difficulties of older adults (see Trick, Enns, & Vavrik, 2004). For this reason a

comprehensive review of the literature relating to attention and older drivers was necessary and is presented in the following section.

Prior to a discussion of the role of attention in driving, however, it seems appropriate to amalgamate the findings related to older adults at each level of Michon's hierarchical model. Indeed, if older adults' driving behaviour is described as strategical, tactical, and operational, it seems that based on the literature, most of their difficulties arise from operational limitations for which strategical and tactical compensatory mechanisms may be performed. In this light, strategical and tactical compensation should reduce the risk of MVC associated with such operational limitations. To this end, a study by De Raedt and Ponjaert-Kristoffersen (2000) sought to determine whether strategic and tactical compensation would successfully improve the safety of older drivers. The authors had older participants complete an on-road test and classified them as safe, average or unsafe. In terms of strategic compensation, participants completed a questionnaire that assessed which situations they avoided while driving. Regarding tactical compensation, observations during the road test were made regarding choice of speed, distance from the car in front, anticipating other road users, and anticipating changing roadway situations. Finally, self-reports of at-fault accidents within the last 12 months were requested of each participant. Their results indicated that in fact older adults labeled as unsafe drivers who engaged in strategical and tactical compensatory mechanisms were able to avoid crash.

De Raedt and Ponjaert-Kristoffersen's (2000) study demonstrates the interaction between the three levels of Michon's model. More precisely, their findings revealed that despite operational deficits, older drivers could engage in strategical and tactical compensation and thereby improve their on-road safety. This study points to the success of the model classifying

driving elements and helping to understand the various behaviors of drivers and the interaction between them.

Driving is a multifactorial task drawing upon a myriad of cognitive and behavioural processes (Fuller, 2005). By compartmentalizing individual elements, Michon's model allows for the simplification of driving behaviours. This discussion of Michon's model has focused on the challenges of the older driver, yet the model applies to drivers of all cohorts as it focuses on the skill and behaviours of the driver rather than the age-cohort to which they belong (Michon, 1985). Thus, the model is particularly useful when interpreting differences between older, mid-aged and younger drivers (Unsworth et al., 2005).

#### *Operational limitations: the role of attention*

Michon's hierarchical model of driver behaviour is an appropriate model through which to operationalize the driving task (Unsworth et al., 2005; van Zomeren et al., 1987). One operational factor that has been identified as fundamental to driving is attention (Shinar, 1978) and, as such, its role has been heavily researched. For example, in a large study that investigated 1357 fatal multi-vehicle MVCs where alcohol was not involved, Summala and Mikkola (1994) found that the only causal factor that increased with age was failures of attention. Given the importance of this construct to driving, the next section of this text will be devoted to discussing the relevant research related to attention and driving as well as the attentional deficits associated with MVCs among older drivers. This discussion will cite research where attentional problems result directly in crash, and research focusing on the validity of external measures of attention (i.e., pencil paper or computer-based) as well as measures of attention within the driving task in predicting driving outcomes.

Generally, attention can be described as the cognitive process of selectively concentrating on one aspect of the environment while ignoring other aspects (Strayer & Drews, 2007). There is no question that attention is involved in driving as drivers are required to perceive and make decisions regarding a myriad of stimuli that are constantly changing as the driver moves through traffic. However, in order to better understand the complexity of this process, a more precise discussion is necessary.

As such, it is important to acknowledge cognitive theories of attention. Early theories saw attention as selecting incoming sensory information for conscious processing while filtering out remaining sensory information from conscious processing. This approach is known as a selection filter theory and was initially introduced by Broadbent (1958) who held that the attentional mechanism operates much like an on-off switch through which attention serves to direct processing to one sensory input channel which is then analyzed for meaning and available for consciousness. Additionally, the theory holds that input that is not attended or selected should have no impact on behaviour as it is not processed beyond the sensory level and is thus unavailable for consciousness.

Triesman (1960) took issue with the notion that unattended information would have no impact on behaviour and set out to test whether this was the case. In a series of classic experiments, Triesman had participants perform a dichotic listening task in which two entirely separate compound sentences were presented simultaneously through the left and right channels on a set of headphones. Halfway through each sentence, the channels would switch so that the sentence that was being presented on the left could now be heard on the right and vice versa; participants were instructed to only shadow one ear while ignoring the other. Results indicated that participants experienced difficulty when the meaning of the shadowed sentences switched to

the nonshadowed ear. This finding suggests that meaning for unattended information does, in fact, have an effect on behaviour. Treisman (1964) proposed treating the mechanism by which attention is allocated as an attenuator rather than simply an on-off switch. Specifically, her model suggests that attention may be adjusted to allow for more or less information to be processed for conscious processing. In this sense, attention is a matter of degree rather than simply an all or nothing approach.

The theories proposed by Broadbent (1958) and Treisman (1964) focus mostly on the attentional process through which some information is received and other information is ignored. Their theories are often referred to as *early selection theories* because in both cases stimuli that are not “selected” never reach conscious processing. Other authors have placed emphasis on the response element of the attentional mechanism. More precisely, the *late-selection theories* hold that all messages are routinely processed for at least some aspects of meaning and that the selection of which message to respond to thus happens later in processing (Norman, 1968). Essentially, all information is processed to some degree and the mechanisms of attention (e.g., a response selector) activate the appropriate responses based on their relevance to the individual (Deutsch & Deutsch, 1963).

More recently, Posner and Petersen (1990) have developed a separate theory of attention. Essentially, these authors contend that attention may be subdivided into three attentional systems: alerting, orienting and executive attention. Together these three systems are entitled the Attentional Network theory. The alerting system involves achieving and maintaining alertness, or readiness to respond to incoming signals. Essentially, the abrupt appearance of visual stimulus away from the gaze is detected first in an individuals’ peripheral vision (Beane & Marrocco, 2004). Next, orienting concerns the shifting of attention from one location to another

in order to select information from sensory input. Normally this is accomplished by shifting one's gaze and head to focus on a location of interest. Finally, executive attention comes into play when processing and responding requires any kind of control. For example, control would be necessary when response conflict occurs because a well learned task (e.g., reading) has to be overridden in favor of a less practiced task (e.g., naming the colour of a colour word) as is the case with the ubiquitous Stroop test. The attention systems in the Attentional Network theory may be applied to driving. First, the alerting system continually monitors the on-road environment through the periphery for novel or potentially threatening stimuli. Next, the orienting function draws foveal gaze (by means of eye movements and head movements) to a specific location or stimulus of interest. Finally, should response conflicts occur, such as coming to a streetlight indicating a malfunction by blinking red, the executive system guides appropriate responses outside the individual's repertoire of over-learned behaviours.

What is interesting in reference to Posner's Attentional Network theory is that it has garnered significant support from cognitive, neuroimaging, event-related potential, and genetic studies (Fan, Wu, Fossella, & Posner, 2001; Neuhaus et al., 2007; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Together, these studies have established that the attention systems are associated with separate neural structures and neurotransmitter systems. More specifically, the alerting system has been associated with the locus coeruleus, right frontal cortex, and the parietal cortex as well as with the neurotransmitter norepinephrine; the orienting system with the superior parietal lobe, temporal-parietal junction, frontal eye fields, and superior colliculus as well as with the neurotransmitter acetylcholine; and, finally, the executive system with the anterior cingulate cortex, lateral ventral cortex, prefrontal cortex, and the basal ganglia as well as with the neurotransmitter dopamine.

The abovementioned models of attention are theoretically useful and may be applied to the driving task. In view of the driving literature and attention literature, Trick and colleagues (2004) suggest confusion between these bodies of literature and, to rectify this, these authors proposed an integration of two theories to form dimensions which summarize the attentional demands of driving. The first dimension originates from the work of Schneider and Shiffrin (1977) and distinguishes between whether the selection of information is automatic or controlled. These authors posit that automatic processes involve selection of stimuli without conscious awareness. These processes are considered effortless, fast and can be carried out concurrently with other processes without compromising performance: responses are considered reflexive and involuntary. Controlled processes, on the other hand, involve selection with awareness; these processes are conscious, laborious, and difficult to carry out. Responses are considered conscious and voluntary. The other dimension originates from the work of Jonides (1981) and refers to whether selection is exogenous or endogenous. Exogenous selection occurs when certain external stimuli trigger selection; this type of selection may occur when the individual does not have any specific goals in a familiar environment. Endogenous selection occurs from what people know about an environment and what they want to achieve. In this type of selection, individuals search the environment for information relevant to specific goals or intentions.

By integrating the work of Schneider and Shiffrin (1977) and Jonides (1981), Trick and colleagues' (2004) proposed two dimensions, with a total of four modes of attention. The first is *reflex* and refers to an automatic process with exogenous origins that occurs in all environments. In this mode, stimuli are selected without awareness in an involuntary, effortless, unconscious and innate fashion. Next, *habit* refers to an automatic process with endogenous origins, occurring in familiar environments; selection in this mode is common to all people. In this mode

of attention, stimuli are selected without awareness due to their familiarity as a result of repeated encounters; thus this mode varies largely due to individual history. A third mode, *exploration* refers to a controlled process with exogenous origins. Here selection is conscious and occurs under easy driving conditions when there are no specific goals. Finally, *deliberation* refers to controlled selection with endogenous origins. Like *exploration*, *deliberation* involves conscious awareness but occurs mostly under difficult, unknown driving conditions, where there are driving goals.

Experts and the driving public alike are in agreement that many automobile crashes are caused by problems of attention (e.g., Patten, Kircher, Ostlund, & Nilsson, 2004). There is no question that attention is involved in driving as it is a multifactorial task requiring that drivers perceive and make decisions regarding a constant flow of changing stimuli. Several models of attention have been proposed (i.e., Broadbent, 1958; Posner & Petersen, 1990; Triesman, 1964) as well as a framework through which the relationship between attention processes and driving can be conceptualized. Although these models point to very precise processes, the driving task occurs in a dynamic environment and involves a myriad of variables making it more difficult for researchers to find empirical support for these theories of attention within the driving context. Regardless, based on this brief review there seem to be at least two broad mechanisms involved, notably, perceiving and responding. Accordingly, in driving, visual information must be perceived, processed, and responded to, often in the form of a manoeuvre.

#### *Attention through a cognitive aging lens*

Age differences in attention have been studied extensively in the cognitive aging literature. Broadly, the field of cognitive aging is concerned with changes in cognitive processes, or the mechanisms underlying these processes, that occur as a function of age. While

a number of abilities have been shown to remain constant or improve with age, such as vocabulary and language comprehension, others show decline (Baltes, Staudinger & Lindenbergh, 1999; Horn & Hofer, 1992). Researchers have noted that decreases in processing capacity (Salthouse, 1985), the ability to inhibit task-irrelevant information in the immediate environment (Hasher & Zacks, 1988), the ability to rapidly process perceptual information (Salthouse, 1996) and the ability to maintain and operate on information in working memory (Craig, Anderson, Kerr & Li, 1982) are all associated with the aging process.

Within this literature, attention has been divided into two broad categories that are equally relevant to driving: selective and divided attention. Selective attention refers to the ability to both focus on information of relevance to the organism and exclude or ignore information that is task irrelevant (Kramer & Kray, 2006). In the context of driving a motor vehicle, selective attention is necessary, for example, when driving on a busy highway focusing on relevant road signs and traffic while ignoring irrelevant billboards and buildings. Early work by Rabbitt (1965) established the groundwork in this area, offering the hypothesis that aging was associated with a decrease in the ability to ignore irrelevant information. A number of cognitive paradigms have been used to explore age difference in this process. For example, in the Stroop task, participants are instructed to articulate the colour in which a word is present and the words can either be compatible with the ink colour or incompatible with the ink colour. Among all participants, RTs increase when the ink colour and the word meaning are incompatible. In comparison to younger adults, however, older adults showed larger interference effects, suggesting poorer selective attention (e.g., Davidson, Zacks & Williams, 2003). Similarly, the stop-signal paradigm, a task in which participants are given a signal to inhibit the primary task response (e.g., refrain from responding to a visual display when a tone is presented) is also a

source of evidence showing decrements in selective attention among older adults (e.g., Kramer et al., 2009; Bédard et al., 2002).

Divided attention involves the ability to concurrently attend and process information from a wide area of the visual field or concurrently perform or switch among different tasks (Kramer & Kray, 2006). In the context of driving a motor vehicle, a driver must scan for other vehicles and pedestrians and, concurrently, maintain control over the vehicle. Like selective attention, several experimental paradigms have been developed to examine age-differences in divided attention. For example, the task switching paradigm involves rapid switching between two or more RT tasks allowing for the separation of distinct attentional control components and their interactions (Kramer & Madden, 2008). Research in this area finds that although all age groups demonstrate a greater general RT cost to switching, the cost is significantly greater for older adults (Kramer & Madden, 2008).

A reliable research finding within the discipline of cognitive aging, and a critical factor to consider in research on attention, is the phenomenon of general age-related slowing. Age-related slowing, characterized by a decrease in processing speed among older adults, is a well-established empirical phenomenon. This relationship is well-illustrated by Brinley (1965) who administered 18 separate tasks comprising verbal, arithmetic and perceptual content areas to younger and older adults and plotted older adults' mean RTs for each task as a function of younger adults' mean RTs; older adults' RTs were on the Y axis and younger adults' RTs were on the X axis. The result was a highly linear relationship with a correlation of  $R=.95$  and a slope of 1.50, often referred to as the Brinley plot. The implication of Brinley's (1965) work was that older adults' RT performance is monotonically increased relative to that of younger adults regardless of the task requirements designed to elicit age differences. Given that tasks that assess

attention often measure RT, it has been proposed that the differences between young and older adults on tasks of attention may be attributed to processing speed alone. According to Brinley's (1965) findings, so long as the task condition RTs for young and older adults are monotonically related there is no reason to draw explanations based on specific task requirements such as attentional demand. Indeed, in a meta-analysis of 20 studies that administered the Stroop task, Verhaeghen and De Meersman (1998) did not find evidence of age-differences in Stroop performance once age-related slowing had been taken into account.

The measurement of attention among older adults is inextricably linked with the examination of RTs in various experimental conditions and, as a consequence, is potentially confounded by age-related slowing. To overcome this methodological limitation, over the years researchers have proposed a variety of analytic procedures that separate the effects of age from the systematic relationships expressed in the Brinley plot (e.g., Faust, Balota, Spieler, & Ferraro, 1999; Madden, Pierce, & Allen, 1992). For example, it has been proposed that younger adult RTs may be transformed so as to reflect the degree of age-related slowing presented in the Brinley plot resulting in the younger adults values being matched to those of the older adults on the basis of general slowing (Kramer & Madden, 1998). If age differences continue to be significant after this transformation there is evidence indicating that the age-difference is independent of processing speed. More commonly, however, age-related slowing is accounted for by statistically controlling an independent measure of processing speed; this approach is referred to as the statistical control approach but is also known as the shared influence approach (Salthouse, 2000). In this method, an out-of-context measure of processing speed is obtained in addition to the cognitive measure of interest. Then, statistical procedures such as analysis of covariance, hierarchical regression and structural equation modeling are applied to the dataset to

estimate the unique age-related variance in task performance that remains after the variance associated with processing speed has been accounted for (Salthouse, 2000). In the method, it is assumed that the contribution of generalized slowing can be estimated from the degree of attenuation in the age-related variance in the primary task that is provided by statistically controlling for the effects of a simpler assessment of speed.

In summary, the field of cognitive aging is a rich literature of paradigms and findings demonstrating age differences in attentional processes. Given that most measures of attention collect RT in response to various conditions, and that older adults exhibit age-related slowing, it is necessary to control for baseline RT in some manner when contrasting attention between age groups.

#### *Evidence of the involvement of attention*

A significant body of literature establishes a direct link between the lack of attention and driving outcomes. For example, in an effort to determine the specific driver behaviors that lead to crashes, a large study examining 723 crashes was conducted (Hendricks, Fell, & Freedman, 1999). MVCs were evaluated in terms of the crash scene, roadway characteristics and vehicle type. Most crashes were attributed to driver actions; of these driver attention accounted for the greatest percentage of MVCs. Moreover, studies of commercial drivers of all ages also found an association between selective attention problems and increased crash rate (Barrett, Mihal, Panek, Sterns, & Alexander, 1977). Errors in attention have also been cited as the most common factor in left-turn accidents, a trend that is even more pronounced among older adults (Keskinen et al., 1998; Larsen & Kines, 2002).

In a large-scale longitudinal study commissioned by the National Highway Traffic Safety Administration, entitled the “100-Car Naturalistic Driving Study”, participants were given no

specific instructions other than to drive naturally on a day-to-day basis for a period of approximately one year (Dingus et al., 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Their dataset included more than 3 million kilometers, 43 thousand hours of temporal data, 241 primary and secondary drivers, and data from a highly sophisticated instrumentation system including five video cameras as well as vehicle state sensors. One of their most striking findings relates to inattention as a source of driver error. For these authors, inattention was operationally defined as including distraction from a secondary task, driving-related inattention to the forward roadway (e.g., blind spot checks), moderate to extreme drowsiness, and other non-driving-related eye glances. Their results indicated that almost 95 percent of lead-vehicle crashes and minor collisions were due to some form of inattention. Their findings, however, found very little regarding age differences specific to older adults as participants were selected on the basis of whether they performed a daily commute; in the end only 11% of the sample was over 55 years of age and maintained employment.

An examination of the literature pertaining to crashes indicates that inattention has been a well-established cause of MVCs particularly among older adults. Laboratory assessments of attention, consisting of computer-based or paper-pencil, have also been found to be significantly associated with driving outcomes. More precisely, the correlation between Trail-Making part B, a paper-pencil based test that draws on visual attention and task-switching capabilities, has been examined and correlates moderately with driving outcomes (De Raedt & Ponjaert-Kristoffersen, 2001; Stutts, 1998). Moreover, Bédard and colleagues (2006) investigated the relationship between inhibition of return (IOR) and driving safely in a sample of older adults. In short, IOR refers to a fundamental search mechanism where the speed and accuracy with which an object is detected are first briefly enhanced immediately after the object is attended; then detection speed

and accuracy are impaired. Seeing as driving heavily relies on appropriate visual search patterns, these authors hypothesized some relationship between a computerized assessment of inhibition of return and an on-road assessment of driving skill. Their results supported their hypothesis and revealed that IOR significantly predicted driving evaluation scores.

More recently, Weaver, Bédard, McAuliffe, and Parkkari (2009) sought to explore the concurrent validity between Posner and Petersen's (1990) Attention Network Task (ANT), driving performance and the UFOV in a sample consisting of drivers ranging from 18 to 83 years of age. The ANT is a computerized task providing scores in alerting, orienting, and executive function elements of attention. Their results indicated that both the ANT and other laboratory tests of attention (i.e., the Useful Field of View) were more or less equivalent (i.e.,  $R^2 = .56$  and  $R^2 = .54$ , respectively) in predicting driving outcomes (i.e., the number of errors on a simulated driving assessment).

The Useful Field of View (UFOV) task is a computerized task of attention which was developed by Ball and colleagues (1988) and attempts to quantify the span of attention within the visual field and consists of three subtests of attention (i.e., processing speed, divided attention, and selective attention). Among older individuals, the UFOV task has been shown to be highly associated with driving outcomes such as performance on an on-road assessment (Myers, Ball, Kalina, Roth, & Goode, 2000). As previously discussed, the cognitive processes that are assessed via the UFOV task, namely processing speed and attentional mechanisms, have been found to be involved in driving performance in older adults. However, the ultimate goal in developing a task such as the UFOV is to make a valid prediction with regards to an individual's driving competence and overall crash risk.

In an attempt to determine the relatedness between UFOV performance, crash, and a number of other variables related to driving among older adults, Ball, Owsley, Sloane, Roenker, and Bruni (1993) recruited 302 participants aged 55 years and older living in Alabama. The mean age of participants was 71 years. Participants were administered a five-part protocol. First, visual sensory function was assessed by means of a series of tests including visual acuity, contrast sensitivity, disability glare, stereopsis, colour discrimination, and visual field sensitivity. Second, mental status was assessed by the Mattis Organic Mental Status Syndrome Examination, a test designed specifically to assess cognitive status in the elderly. Third, the UFOV was administered. Fourth, all participants received a detailed eye examination by an ophthalmologist in order to determine overall eye health. Finally, a driving habits questionnaire was administered concerning participants' behaviours such as driving exposure, avoidance of potentially challenging driving situations, and self-report number of crashes. Their results indicated that variables related to vision were related to crash but mediated by the UFOV task. The best predictors of crash were the UFOV task ( $R=.52$ ) and mental status ( $R=.34$ ). Mental status and UFOV were also correlated with one another ( $.48$ ). The results of Ball and colleagues (1993) suggest that a measure of attention, namely the UFOV, as well as mental status is highly related to crash frequency among older drivers.

In a meta-analysis conducted by Clay and colleagues (2005), electronic databases were combed for studies related to the UFOV task. In total, eight studies met their criteria which included a sample of adults aged 55 or greater, no overlapping data sources, and an objective, rather than self-report, assessment of driving performance. Their results indicated that poor performance on the UFOV was associated with driving performance in a driving simulator, an on-road assessment course, and, most strikingly, crash frequency (Clay et al., 2005).

Thus far attention has been discussed in the context of attentional capacities predicting driving outcomes. One frequently used method to capture the attentional demand of the driving task is the peripheral detection task (PDT) (e.g., Harms & Patten, 2003; Patten et al., 2004). The peripheral detection task (PDT) method has been used in several field and high fidelity simulator studies and has shown itself to be a sensitive measure of divided attention. In this method participants respond to a visual stimulus (e.g., a light emitting diode or quickly appearing shape) placed in the peripheral area of the driver's line of forward sight. Reaction times to the secondary-task stimuli are then recorded.

In a driving simulator study conducted by Cyr and colleagues (2006), older and younger participants were subjected to scenarios which included surprising events of varying complexity. A PDT paradigm was employed in which triangles were strategically placed during complex events and reaction times were recorded. The results indicated significantly longer reaction times to the PDT among the older cohort in response to complex driving events suggesting a reduced ability among older drivers to divide their attention. Studies that employ instrumented vehicles find similar results. For example, in a two-part on-road experiment, Verwey (2000) had participants respond to the PDT during varying on-road events. The results indicated that older drivers had less processing resources than younger drivers and that these differences were even more pronounced in complex on-road situations like intersections. Patten, Kircher, Östlund, Nilsson, and Svenson (2006) had 75 drivers complete a route of varying complexity in an instrumented vehicle. The effect of route complexity was assessed through a peripheral detection task and self-report level of difficulty. Their results indicated a decremented effect of route complexity for the experienced group determined by the performance on the secondary

task. Taken together, the PDT has been shown to be indicative of divided attention while driving and to provide an accurate attentional capture that fluctuates in accordance to route complexity.

### *Cognitive workload*

The PDT has been used extensively to evaluate visual attentional changes resulting from traffic conditions. Previous authors agree that the sudden presentation of a visual stimulus may produce a stimulus-driven attentional capture (Theeuwes & Godijn, 2001; Yantis & Jonides, 1984). Many authors, however, refer to performance on the PDT as an indicator of cognitive workload (e.g., Jahn, Oehme, Krems, & Gelau, 2005; Patten et al., 2004). Workload is a rather general term that refers to the overall level of mental resources that are required when completing a task (Gartner & Murphy, 1979; Wickens & Hollands, 2000). As a result of a greater number of stimuli to attend, attentional resources may become overcommitted leading to a greater chance of making a driving error (i.e., MVC). Given that driving is an exceedingly visual task, it follows that the associated mental demand would result from the taxing of attentional resources (Verwey, 2000). In terms of well-established models of attention, workload refers to all of the mental resources required to perceive, select, and respond to driving related stimuli.

Indicators of workload include primary measures, secondary measures, physiological measures and subjective measures (Zhang, Owechko, & Zhang, 2004). Reaction time to the PDT, then, represents a secondary task measure of cognitive workload. Differences in primary task measures in response to roadway scenarios have also been documented. Greater variability in lane position, reduced speed, and delayed braking responses are found to be indicators of greater cognitive workload in response to complex driving environments (Törnros & Bolling, 2005; Törnros & Bolling, 2006).

Physiological indicators of workload have also been recorded. Stinchcombe, Weaver, Johnson and Bédard (2007), for example, demonstrated increases in heart-rate responses when mid-aged participants were subjected to a series of complex and surprising driving events. In an eye-movement analysis, Chapman and Underwood (1998) observed narrowed visual search patterns in response to highly complex roadway environments. They concluded that such complex driving situations place enormous workload demands on drivers causing the visual acquisition process to become overloaded.

Subjective workload estimates consist of self-report measures of workload in which participants indicate the overall difficulty of a task (Gawron, 2000). One of the most widely researched self-report measures of subjective workload is the NASA Task Load Index (NASA-TLX) (Hart & Staveland, 1988). This scale is a multi-dimensional subjective workload rating technique in which task demands are objectively quantified in terms of magnitude and importance. The NASA-TLX is composed of six subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration level) each of which is placed on a 21-point likert scale with low to high anchors (Hart & Staveland, 1988).

With regards to the psychometric value of the measure, several authors report its reliability and validity (Corwin et al., 1989; Nataupsky & Abbott, 1987). For example, Battiste and Bortolussi (1988) reported significant workload effects as well as a test-retest correlation of  $R=.78$ . In terms of validity, in a study that involved 247 participants, Hart and Staveland (1988) concluded that the NASA-TLX offers a sensitive indicator of overall workload as it differed among tasks of various cognitive and physical demands.

The NASA-TLX has been used in a variety of environments including on-road and simulated driving (Laberge, Scialfa, White, & Caird, 2004; Rudin-Brown & Noy, 2002). Similar

to other estimates of workload, the results of these studies indicate significant age differences, with older adults indicating greater subjective workload, as well as a decremented effect of route complexity on workload (McPhee, Scialfa, Ho, & Caird, 2004).

The concept of cognitive workload is clearly intertwined with that of attention and, since the literature concludes that attention is the single most salient cognitive process involved in driving, it follows that an increase in the complexity of a driving event adds to the cognitive workload and results in poorer performance on a divided attention task. Given the age-associated failings in visual attention, it also follows that older adults perform more poorly on within-task measures of divided attention and report greater cognitive load in relation to their younger counterparts (Cyr et al., 2006). The literature is recognizing that, because increased crash risk among older drivers is largely due to attentional limitations, complex driving events which further tax attentional resources and increase cognitive workload may be major contributors to MVCs. What remains unclear, however, is where older adults' attentional failures lie. More precisely, it is uncertain whether older drivers exhibit a failure to perceive stimuli or whether they fail to appropriately respond to driving-related stimuli.

#### *The role of complexity*

Thus far, the driving task and attentional demands associated with driving have been operationalized and discussed. Many studies also reveal that driving environment plays a role in determining performance as it taxes attentional resources. Thus, it seems that the challenges faced by older drivers are not solely due to the driving task or age-related changes in cognitive function, but rather to an interaction between these two variables and the complexity of the driving environment. This is evidenced in older drivers' crash profiles (e.g., left-hand turns) as

well as in their compensatory behaviours (e.g., lowering their speeds and avoidance of peek times).

Many authors have concentrated on the role of road complexity in driver performance. The findings typically indicate that a greater number of visual stimuli (e.g., billboards, road signs, buildings, oncoming vehicles, etc.) results in poorer driving performance (Cairney & Gunatillake, 2000; Horberry, Anderson, Regan, Triggs, & Brown, 2006). Other studies have equated complexity with the type of road condition (i.e., rural vs. urban) (e.g., Chapman & Underwood, 1998), or the degree to which driving scenarios present an element of novelty or surprise (e.g., Chapman & Underwood, 1998; Cyr et al., 2009 ; Cyr et al., 2006). Taking into consideration that older adults are implicated in MVCs that involve intersections and congested areas it follows that their difficulties result from the large amount of visual information as well as the extent to which they are required to maneuver their vehicles.

Fastenmeier (1995) presents a taxonomy whereby the driving environment may be operationalized in terms of the degree to which a particular scenario contains information processing as well as vehicle handling elements. Fastenmeier (1995) highlights the following characteristic of traffic situations as crucial for complexity: the demand they put on drivers' information processing and/or vehicle handling capabilities. According to this approach, driving contexts may be subdivided into two elements, that of 1) information processing, and that of 2) vehicle handling. Each of the two elements has two levels, high and low. Simply, four combinations of elements are possible yielding four types of situations: high demands on information processing and high demands on vehicle handling; high demands on information processing and low demands on vehicle handling; low demands on information processing and high vehicle handling; and, finally, low demands on information processing and low vehicle

handling. Fastemeier's (1995) classification essentially describes two ways in which the driving environment may tax a driver's attention, namely through increased perceptual complexity (i.e., information processing) and through the responding element (i.e., vehicle handling). This taxonomy has been used in numerous empirical contributions as a way to categorize driving events (e.g., Jahn, Oehme, Krems & Gelau, 2005; Mayser, Piechulla, Weiss, König, 2003; Patten, Kircher, Östlund, & Nilsson, 2004; Vogel, Kircher, Alm, & Nilsson, 2003).

Patten and colleagues (2004) examined the effects of route complexity and mobile phone use on drivers' workload. To this end, mid-aged drivers performed a mobile phone task and responded to a PDT while driving an instrumented vehicle. The course was selected so as to have low handling and low information processing according to Fastenmeier's (1995) classification scheme. The reason for this was that the authors wanted to diminish the amount of extraneous stimuli on the effects of the phone conversation. Their results indicated a significant decrease in PDT responses as a result of the phone conversation.

Moreover, Jahn, Oehme, Krems and Gelau (2005) sought to investigate the sensitivity of the PDT in estimating driver workload. To this end, participants completed an on-road assessment course which was later subdivided according to Fatenmeier's (1995) classification scheme. Responses to the PDT followed alongside complexity; in sections judged more demanding PDT responses were slower. The authors conclude that the PDT is an appropriate method of assessing the cognitive demands of driving in scenarios of varying complexity.

### *Research questions*

The introduction to this thesis has provided justification for the study of older drivers and points to a decline in attentional capacity as the basis for increased crash risk. A number of common crash situations, notably rear-end and crossing path scenarios, have been outlined and

driving situations have been operationalized in terms of vehicle handling and information processing complexity. Previous research also indicates that the associated attentional demands may be measured by means of a PDT.

Given that common crash situations have been outlined and that attentional demands increase with complexity, it seems plausible that the common crash situations are somehow too complex for older individuals' attentional capacities. More specifically, given the increased crash rate in these situations, it seems likely that the extreme handling and information processing complexity over-commits attentional resources which, in turn, leads to MVC. Thus the goal of this thesis was to investigate the attentional demands of driving events of varying handling and information processing complexity in young, mature and older drivers.

The first study sought to determine whether attentional demands of common crash situations fluctuate according to Fastenmeier's (1995) classification scheme. To this end, a convenience sample of undergraduate students completed a series of scenarios that varied according to handling and information processing demands. The PDT was employed to estimate the amount of attention required to complete the scenario. It was hypothesized that by increasing the salience of handling and information processing variables, PDT performance would decrease.

Next, the second study sought to examine this effect in samples of mid-aged and older drivers. Given the age-related attention deficits, the second study sought to investigate whether the effects observed in the first study were magnified in the older adult population. To this end, mid-aged adults and older adults completed the same protocol as in the first study and differences were reported in terms of both age and complexity level.

Finally, the first two studies examined the attentional demands of vehicle handling and information processing in young, mid-aged and older adults. The protocol for the first two studies was highly systematic, repetitive and far removed from an actual driving course. Thus, the purpose of the third study was to examine age differences in attention in response to environmental complexity in a virtual context that has greater ecological validity. In study 3, participants complete a simulated driving assessment course in which PDT events were presented at various road situations. Road events were then segmented in terms of their complexity. It was hypothesized that if attention does indeed fluctuate in response to complexity in the way that was demonstrated in the first two studies, this will also be shown in the reactions of the drivers to the PDT in the simulated driving course.

## CHAPTER 2

## STUDY 1

Driving in dangerous territory: complexity and road-characteristics influence attentional demand

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### Abstract

Car driving related attentional demands fluctuate according to route complexity and are found to be highly associated with motor vehicle collisions (MVCs). The purpose of the current study was to explore the inherent attentional demands of scenarios that approximate common crash configurations. Sixty drivers completed a series of 20 simulated driving scenarios incorporating either rear-end or crossing path situations. For each scenario, the complexity of the driving environment was systematically manipulated in terms of vehicle handling and information processing elements. The attentional demands of each scenario were assessed by means of a peripheral detection task (PDT) as well as through a subjective measure of overall difficulty. Our results showed a reduction in PDT performance at intersections where information processing is increased as well as when handling maneuvers behind a lead vehicle were required. The results point to the appropriateness of the PDT as a sensitive measure of cognitive workload. The implications of these findings for future research and safety initiatives are discussed.

Keywords: Attention, workload, driving, complexity, motor vehicle collision, PDT

## 1. Introduction

In many parts of the world, driving is a primary means of transportation which also represents a public safety concern due to the possibility of a motor-vehicle collision (MVC). A great deal of research points to roadway characteristics as a key factor in the occurrence of MVCs (Abdel-Aty, Keller, & Brady, 2005; Abdel-Aty & Radwan, 2000; Karlaftis & Golias, 2002). In a national initiative by the U.S. Department of Transportation, all police-reported crashes that occurred in 2000 were analyzed in terms of their crash type, physical setting, and their pre-crash scenarios. In total, over six million MVCs resulting in more than 41,000 fatalities and over three million injured individuals were analyzed (Najm, Sen, Smith, & Campbell, 2003). The results of this initiative indicated that the two types of MVC that occurred with the greatest frequency were rear-end type (i.e., the front of a following vehicle strikes the rear of a lead vehicle) and crossing paths type (i.e., one moving vehicle cuts across the path of another), representing 28% and 25% of all crashes respectively.

Other research, however, points to individual characteristics as being the primary contributor to MVCs. More specifically, it is widely acknowledged that the construct of attention plays a significant role in driving performance (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Patten, Kircher, Ostlund, & Nilsson, 2004; Recarte & Nunes, 2003). Generally, attention can be described as the cognitive process of selectively concentrating on one aspect of the environment while ignoring other elements (Kramer, Wiegmann, & Kirlik, 2007). Experts and the driving public alike agree that many automobile crashes are caused by problems of attention (Goodman, Tijerina, Bents, & Wierwille, 1999; Utter, 2001). Problems of attention involve drivers failing to attend to relevant information (impaired divided attention) and a failure to ignore irrelevant information (impaired selective attention) (Trick, Enns, & Vavrik, 2004).

A significant body of literature establishes a direct link between attention and driving outcomes. For example, in an effort to determine the specific driver behaviours that lead to crashes, a large study examining 723 crashes was conducted (Hendricks, Fell, & Freedman, 1999). MVCs were evaluated in terms of the crash scene, roadway characteristics and vehicle type. Most crashes were attributed to driver actions and of these actions driver attention accounted for the greatest percentage of MVCs. Moreover, studies of commercial drivers of all ages also found an association between selective attention problems and increased crash rate (Barrett, Mihal, Panek, Sterns, & Alexander, 1977). Attention failures have also been cited as the most common factor in left-turn accidents (Keskinen, Ota, & Katila, 1998; Larsen & Kines, 2002).

Supporting evidence also comes from cognitive assessments of attention in relationship to driving performance. More specifically, tasks of attention such as Trail Making, Useful Field of View (UFOV), Inhibition of Return Task, and the Attention Network Task have all been linked to driving outcomes (Ball et al., 1998; Bédard et al., 2006; Goode et al., 1998; Weaver, Bédard, McAuliffe, & Pakkari, 2009). In a meta-analysis conducted by Clay and colleagues (2005), electronic databases were combed for studies that incorporated the UFOV task in their assessment. In total, eight studies met their criteria which included a sample of adults aged 55 or greater, no overlapping data sources, and an objective, rather than self-report, assessment of driving performance. Their results indicated that poor performance on the UFOV was associated with driving performance in a driving simulator, an on-road assessment course, and, most strikingly, crash frequency (Clay et al., 2005).

Given that there are well documented road characteristics in which MVCs are more common and that attention is also significantly related to crash, there seems to be an interaction

between environmental complexity and driver characteristics (i.e., attentional capacities) leading to crashes. Several authors have attempted to explore this relationship (e.g., Horberry et al., 2006; Patten et al., 2004; Tornros & Bolling, 2006). For instance, Patten and colleagues (2006) sought to examine the effects of route complexity on attention. To this end the researchers had 37 experienced and 38 inexperienced drivers complete a route with sections of varying complexity in an instrumented vehicle. The effects of route complexity were assessed through the workload approach where secondary task performance is used to measure the degree of attention required to drive (Jahn, Oehme, Krems, & Gelau, 2005). Their results indicated a significant effect of route complexity on attention as determined by poorer performance on the secondary task. The findings of Patten and colleagues (2006) indicate that greater driving environment complexity requires more attentional resources which, in turn, lead to difficulty in dividing attention between driving and the secondary task.

A recent age-comparison study by Cantin, Lavallière, Simoneau, and Teasdale (2009) used an auditory secondary task to examine challenges facing older drivers in a driving simulator. In their study 10 older and 10 younger drivers completed a simulated drive that encompassed elements of varying complexity (i.e., straight roads, intersections and overtaking maneuvers). Driving demands were measured by means of a secondary auditory task as well as by examining the primary driving performance (e.g., lane position, speed, etc). Their findings indicated that primary and secondary task performance worsened as complexity increased. Interestingly, despite fairly concrete evidence regarding situations where crashes occur, these authors did not include crossing path scenarios; participants in this study were instructed to drive straight through all intersections. Moreover, these authors assumed that the selected events were inherently different in comparison to one another in terms of their complexity. However, it is not

clear in this study what aspects of scenarios made them more complex and this, in turn, leaves unexplained why certain scenarios resulted in greater driving difficulty and increased crash risk.

Taken as a whole, the aforementioned research indicates that: 1) MVC largely fall under crossing path and rear-end types; 2) failures in attention are greatly associated with driving performance and crash; and 3) the attentional demands of a given road section fluctuate according to its complexity. What remains unclear in the research to date is how the complexity of these common crash scenarios taxes attentional resources. More specifically, of interest is what elements of these scenarios tax attention sufficiently to increase crash risk.

For that reason, the primary goal of the current study was to explore the relationship between attention and elements of the roadway environment common to typical crash scenarios. The current study submitted drivers to simulated scenarios resembling those most frequently cited in the crash literature with the aim of understanding the ‘attentional’ challenges posed by such circumstances. Consistent with the literature, attentional demands were assessed using the cognitive workload approach in which participants responded to a dual task while driving and subsequently completed a self-report measure of overall difficulty. It was hypothesized that vehicle handling and information processing are two critical elements of scenarios and increasing their salience would, in turn, negatively affect participants’ attention. Specifically, in highly complex scenarios, participant responses to a secondary task were predicted to be poorer (i.e., slower) than in scenarios of lower complexity.

A secondary goal of this study was to examine the appropriateness of the secondary task to assess attention. Previous research indicates that the driving task deteriorates when a secondary task is performed simultaneously (Strayer & Johnston, 2001). Given that the secondary task is visual in nature in this study, we questioned whether the addition of secondary

visual task would place an added strain on attentional resources, thereby inappropriately increasing the complexity of the driving task and potentially undermining our results.

Accordingly, half of participants responded to a secondary task while driving whereas the other half did not and responses on a subjective measure of workload were then contrasted between the two groups.

## 2. Method

### *2.1 Participants*

Participants consisted of a convenience sample of sixty young adults (28 males, 32 females) enrolled in an Introductory Psychology course at the University of Ottawa. Inclusion criteria were possession of a valid driver's license and good physical and mental health.

Participants reported being in good health with no neurological, psychiatric or substance abuse problems. The mean participant age was 18.62 years. All 60 participants completed the testing for this particular study. All participants received course credit in exchange for their participation. They all read and completed an informed consent form, consistent with the guidelines and requirements of the University of Ottawa's research ethics board. All participants completed the protocol and there were no instances of simulator adaptation syndrome.

### *2.2 Apparatus*

A high fidelity STISIM driving simulator (Build 2.08.04) produced by Systems Technology Inc. was used to examine the behavioural reactions of participants in simulations. The STISIM driving simulator displays a virtual roadway environment on three wide screens by means of three NEC projectors, giving the driver a field of view of 135 degrees. The STISIM simulator projects the scene onto three screens measuring 75cm x 90cm each and displays at a rate of 30 frames per second. The simulator seat, steering wheel, and pedals are mounted on a

metal structure. The participants are seated 144cm from where the image is displayed. The room in which the simulator is housed measures 2.5 meters by 3.2 meters. The simulator is a tool for generating laboratory tasks relevant to the psychomotor and cognitive demands of real-world driving. The simulator allows for the design of urban and suburban roadway environments including interactive vehicles on all lanes, buildings, traffic control devices, and pedestrians through advanced vehicle dynamics and image generation. The virtual environment is supplemented with realistic audio effects providing acceleration cues. Instructions to the drivers (e.g., turn left/right, lane change, maintain speed, etc.) were given through the speakers linked with the driving simulator. Also, the STISIM Drive software includes an optional peripheral detection task (PDT), which consists of stimuli appearing in the periphery. Participants were required to manually detect the stimulus on either the left or right sides of their field of view as soon as it was perceived by signalling left (downward motion) or right (upward motion) with the signaller located to the left of the steering wheel. The software runs on 4 Windows XP operating system and Intel x86 Model 15 Family computers with a processing speed of 2394 mhz (four systems required). The testing room is connected to an adjacent control room where the experimenter operates the simulator program and monitors the driver's reactions.

### *2.3 Scenarios*

Participants completed five 1 km base scenarios in four separate versions that differed in complexity (20 km in total were driven). Base scenarios were composed of either crossing-path type or rear-end type and each contained a critical event. In order to assess the degree of cognitive load generated by the complexity manipulation, the 20 km testing drive was split into individual 1 km segments. In each scenario, the critical event (i.e., an intersection or a passing manoeuvre) was located at 500 m. For the purpose of developing a sound and relevant

experimental design, roadway elements were operationalized according to Fastenmeier's (1995) classification scheme, emphasizing the degree to which a particular scenario contains information processing as well as vehicle handling elements. This two-dimension taxonomy breaks down the process of driving from the driver's perspective in terms of vehicle handling (high and low) and information processing (high and low). Consequently, four complexity combinations are possible ranging from low on both dimensions on one end to high on both dimensions on the other. Using this taxonomy, we produced four derivatives of each of the five base scenarios.

The information processing manipulation consisted of two levels (i.e., high vs. low). The high level was constructed so as to mimic an urban city-centre with traffic, parked cars, pedestrians, and tall office buildings; the intersections were controlled by a traffic light. Oncoming traffic was presented at the intersection. In the low level, the scenario was constructed so as to have as little visual information as possible. In particular, there were no buildings, trees, parked cars or pedestrians; the intersections consisted of a stop sign. The two levels of the information processing manipulation are shown graphically in Figure 1.

The manoeuvring manipulation also consisted of two levels (i.e., high vs. low). The high level consisted of a series of four lane changes; the low level consisted of no lane changing. In the high manoeuvring condition, participants were asked to lane change at 200 meters, 400 meters, 600 meters, and 800 meters (i.e., four lane changes). In the case of the high vehicle handling condition, the roadways were always four lanes (two on each side of the dividing line) whereas there were only two lanes in the low vehicle handling condition.

These manipulations were combined and resulted in four distinct scenarios: 1) High demands on information processing and high demands on vehicle handling, 2) High demands on

information processing and low demands on vehicle handling, 3) Low demands on information processing and high demands on vehicle handling, and 4) Low demands on information processing and low demands on vehicle handling.

*Crossing path (Left turn at intersection with traffic in front)*

Participants were instructed to turn left at an intersection with oncoming traffic. In the low information processing condition participants were presented with a vehicle driving in the opposite direction that did not respect the stop light. In the high information processing condition participants approached an intersection with oncoming traffic and made the left turn when they felt it was safe.

*Crossing path (Left turn at intersection with traffic on left)*

Participants were instructed to turn left at the intersection and were presented with a vehicle coming from the left of them that did not respect stop light/sign.

*Crossing path (Straight at intersection with traffic on right)*

Participants were instructed to go straight at the intersection and were presented with a vehicle coming from the right of them that did not respect the stop light/sign.

*Rear-end (Car following scenario)*

Participants were instructed to follow a lead vehicle as closely as possible without crashing into it. In the high manoeuvring condition, participants were also asked to follow the vehicle's lane position as it lane changed four times.

*Rear-end (Car passing scenario)*

Participants were instructed to follow a lead vehicle as closely as possible without crashing into it. At 450 m from the start of the scenario, participants were asked to pass (overtake) the lead vehicle.

#### *2.4 Measure of Attentional Demand*

Half of the participants were randomly assigned to a PDT condition, in which PDT stimuli appeared at various times; the other half of the participants were assigned to a non-PDT condition in which no PDT stimuli appeared. The PDT stimulus consisted of a red triangle appearing on either the left or right side of the participant's periphery (25 degrees on either side of the driver). The PDT stimulus was presented until the participant responded making the appropriate signal with the signaler. For example, if the PDT stimulus appeared on the right side, participants would signal upwards; if, on the other hand, the stimulus appeared on the left side, participants would signal downwards. The PDT stimulus disappeared after the participant had made a response *or* a maximum presentation time of five seconds had been reached. The PDT data points consisted of the latency to respond to the stimulus and are therefore referred to as a response time (RT). Within each of the twenty individual 1 km scenarios, two PDT events were presented: one PDT event was presented during the critical event at 505 meters, and is hereafter referred to as the *Target* PDT. A second PDT occurred either at 250 meters (i.e., prior to the critical event) *or* at 750 meters (i.e., subsequent to the critical event) and is hereafter referred to as the *Non-target* PDT. The location (250 m or 750 m) of the *Non-target* PDT was randomized between scenarios to maintain an element of novelty.

#### *2.5 Measure of Subjective Workload*

The NASA Task Load Index (TLX) was employed as a measure of subjective cognitive load. The NASA-TLX is a standard subjective workload measure and it is regarded to be the most sensitive and reliable measure to assess subjective workload (Hart & Staveland, 1988). This instrument is comprised of six subscales (mental demand, temporal demand, physical demand, effort, frustration, performance) with possible scores ranging from one to 21. In order to generate

a global estimate of cognitive workload, subscales of the NASA-TLX were summed (Byers, Bittner, & Hill, 1989).

### *2.6 Procedure*

Prior to arriving at the laboratory, participants were randomly assigned to the PDT condition or the non-PDT condition. Once they arrived at the lab, participants completed an informed consent document. They subsequently completed a 10-minute orientation session of increasing complexity on the driving simulator, allowing them to familiarize themselves with manoeuvring in the simulator. Next, all participants were presented with a 1 km baseline scenario in which the simulator adjusted the speed and steering automatically. Participants were told to keep their feet off of the pedals, and hold the steering wheel in a fixed position, responding to the dual task when it was presented.

Thereafter, participants completed the 20 scenarios described above. The presentation of the scenario was randomized between participants using the RAND command in Excel to generate a completely random order of presentation. Participants were instructed to maintain a speed of 50 km/h throughout. In scenarios where they were required to follow a vehicle, participants were asked to ignore the speed requirement and simply follow the lead vehicle as closely as possible at the velocity at which it was travelling. Following each 1 km scenario, participants completed the NASA-TLX questionnaire.

### *2.7 Analysis*

The main goal of this study was to explore the cognitive load associated with situations where crashes commonly occur (i.e., crossing path and rear-end type). To generate a reliable estimate of participants' performance at crossing path and rear-end scenarios, PDT RTs were averaged within these categories. Specifically, four PDT RTs representing the complexity

manipulations (i.e, information processing complexity and vehicle handling complexity) were computed for crossing path type scenarios and rear-end type. The NASA-TLX results were also aggregated using this method. The succeeding analyses were conducted with these scores.

To explore the effect of complexity on the attention demands in the two types of scenarios, the PDT data were submitted to two (i.e., one for each type of scenario) 2x2 repeated measures ANOVAs where both information processing complexity and handling complexity were considered within factors. To determine the effect of complexity and completion of a secondary task on self-reported workload, NASA-TLX total scores were submitted to two (i.e., one for each type of scenario) 2x2x2 mixed ANOVA where PDT (presence or absence) was considered a between factor and information processing complexity (high vs. low) and handling complexity (high vs. low) were considered within factors. For each scenario type, two ANOVAs were conducted each with either two or three factors; to minimize familywise error rate resulting from the number of contrasts, a conservative alpha of .01 was selected (Howell, 2010).

### 3. Results

The sample consisted of 60 undergraduate students with valid drivers' licenses. The mean age of participants was 18.62 years with a minimum age of 17 years and a maximum age of 23 years (SD=1.37). Forty six percent of the sample was male while 54% was female.

The scenarios utilized in this study were selected based on the crash literature and were designed to be highly complex and challenging. To demonstrate that these events were indeed challenging over and above the regular demands of driving, an average of the *Non-target* PDT RTs and the *Target* PDT RTs was computed for rear-end and crossing path scenarios that contained low information processing and low handling complexity. The difference was significant with the *Target* PDT RT being significantly longer than the *Non-target* PDT RT

(Mean difference=.33, SD=0.54),  $t(29)=3.44$ ,  $p=.002$ , indicating that the critical events were indeed cognitively challenging.

### *3.1 Crossing path scenarios.*

The results of the ANOVA using the PDT response time scores within the crossing path scenarios revealed a significant effect of information processing,  $F(1, 29)=119.56$ ,  $p<.001$ , yet no effect of handling was observed,  $F(1, 29)=.104$ ,  $p=.750$ , and the interaction did not reach significance,  $F(1, 29)= 1.28$ ,  $p=.267$  (Table 1). The mean PDT response time for the high information processing condition was 2.57 (SD= .130) whereas the mean value for the low information processing condition was 1.55 (SD=.090) suggesting that greater information processing complexity at crossing path scenarios significantly increases attentional demand as demonstrated in delayed PDT responses.

The results from the NASA-TLX data indicated a non-significant effect of the presence of PDT events,  $F(1, 58)=.551$ ,  $p=.461$ , indicating that participants in the PDT condition did not report higher subjective ratings of workload than individuals in the non-PDT condition. Significant effects for information processing complexity,  $F(1, 58)=16.33$ ,  $p<.001$ , and handling complexity,  $F(1,58)= 33.12$ ,  $p<.001$ , were observed; however, there were no significant interactions between presence of PDT and information processing,  $F(1, 58)=.921$ ,  $p=.341$ , presence of PDT and handling,  $F(1, 58)=.396$ ,  $p=.532$ , information processing and handling,  $F(1, 58)=.756$ ,  $p=.388$ , as well as between presence of PDT, information processing and handling,  $F(1,58)=.756$ ,  $p=.388$  (Table 1). These results suggest that greater information processing and handling complexity resulted in higher rating of subjective workload as measured by the NASA-TLX for the crossing path scenarios.

### 3.2 Rear-end scenarios.

The set of analyses for the rear-end scenarios are the same as for the crossing path scenarios. The effects of information processing and vehicle handling on PDT performance in the rear-end scenarios did not reach significance,  $F(1, 29)=4.23$ ,  $p=.051$  and  $F(1, 29)=4.08$ ,  $p=.053$ , respectively. A clear significant interaction between information processing and handling complexity was observed,  $F(1, 29)=11.42$ ,  $p=.002$ , indicating that the effect of handling on PDT performance depends on information processing complexity. Post-hoc analysis showed a statistically significant effect of handling complexity in the high-information processing complexity condition only,  $t(29)=3.175$ ,  $p=.004$  (Table 2). This finding suggests that for rear-end scenarios, the high handling complexity results in decreases in PDT performance only when information processing complexity is also elevated.

In terms of the NASA-TLX data, the results indicated a non-significant effect of the presence of a PDT,  $F(1, 58)=.803$ ,  $p=.374$ , indicating that participants in the PDT condition did not report higher subjective ratings of workload than individuals in the non-PDT condition (Table 2). Significant effects of handling complexity,  $F(1, 58)=20.26$ ,  $p<.001$ , were observed. The information processing complexity factor was deemed non significant at the alpha level of .01,  $F(1,58)<.001$ ,  $p=.983$ , and so were the interactions between presence of the PDT and handling,  $F(1, 58)=.906$ ,  $p=.345$ , presence of the PDT and information processing,  $F(1, 58)=4.12$ ,  $p=.047$ , information processing and handling,  $F(1,58)=3.64$ ,  $p=.061$ , as well as between presence of the PDT, information processing and handling,  $F(1, 58)=2.66$ ,  $p=.108$ . These findings indicate that greater handling complexity resulted in higher rating of subjective workload as measured by the NASA-TLX for the rear-end scenarios.

#### 4. Discussion

The purpose of this study was to explore the attentional demands of selectively attending to stimuli in the driving environment (i.e., information processing) and producing maneuvering responses (i.e., vehicle handling). Our primary hypothesis was that if the challenge of common crash configurations was related to information processing and handling complexity, changes in attentional requirements would follow suit and be reflected in reaction to PDT stimuli and on the subjective assessment of cognitive load. Our findings supported this hypothesis and are consistent with the literature in that in driving environments of higher complexity responses to a secondary task become slower (Cantin et al., 2009; Jahn et al., 2005; Patten et al., 2004; Verwey, 2000).

More precisely, the results revealed that within the crossing path scenarios, participants reported greater demands when the information processing and handling complexity were increased. The objective measure also indicated a deficit in PDT performance solely when the information processing complexity was increased. Other research finds that drivers do take longer to respond to stimuli at intersections and that MVCs at intersections are largely attributed to failing to pay attention to traffic signs and other vehicles (Liu & Lee, 2006). Moreover, authors have concluded that the challenge posed by intersections is due to their highly visual nature; it is the visually cluttered nature of intersections that decreases reaction time, increases attentional demands, and leads to MVCs (Chang, Lin, Fung, Hwang, & Doong, 2008). Indeed, these results clearly show that when the amount of stimuli at intersections is systematically increased, participants exhibit greater workload. Moreover, these results illustrate that in the context of scenarios involving intersections, vehicle handling does not seem to increase cognitive load.

With regards to the effect of vehicle handling in the crossing path scenarios, however, an alternative explanation may be that this manipulation was not appropriately placed to induce noticeable changes in driver workload at the event as participants were required to lane change 250 meters before and after the event. More specifically, the PDT occurred during the intersection while the maneuvering manipulation occurred outside of the intersection (i.e., closer to the start and finish of the scenario). Increasing the handling complexity of a specific event such as an intersection or passing another vehicle poses a challenge but could be accomplished by reducing the width of the intersection so as to have the driver manoeuvre with greater precision or to introduce obstacles that the driver would have to avoid.

Regarding the rear-end type scenarios, participants reported greater workload when the handling requirements were increased but not when perceptual elements were increased. Interestingly, deficits in PDT performance resulting from higher handling complexity were exclusively observed when perceptual complexity was also elevated. The literature indicates that drivers exhibit faster response times on straight roads when following a vehicle than at intersections (Chang et al., 2008). This difference is likely due to the driver solely having to focus on a lead vehicle when driving on a straight road, as in the case of rear-end scenarios, as opposed to scanning for traffic signals and cross traffic, as in the case of crossing path scenarios (Chang et al., 2008). In such circumstances, avoidance manoeuvres such as braking and swerving, must be quickly carried out in order to safely avoid a MVC with the vehicle ahead of the driver. Overall, our findings corroborate the notion that the visual clutter of rear-end scenarios is not as salient as the maneuvering elements. However when additional handling maneuvers are required, augmented perceptual complexity seems to elevate the attentional demand of the event.

The secondary goal of the present study was to examine the relative influence of adding an extraneous secondary task. Many studies have found a decrement in visual attention as a result of performing a secondary task (Patten et al., 2004; Shinar, Tractinsky, & Compton, 2005; Strayer & Johnston, 2001); our goal, however, was to employ a secondary task as a measure workload in response to changes in driving demands. Seeing as the PDT consisted of a visual stimulus and that one of our manipulations was also related to visual complexity (i.e., information processing), it follows that the addition of such a task might be expected to significantly increase subjective reports of difficulty, thereby extending the attentional demands of the task over-and-above those of driving alone. However, in examining the subjective workload data, we observed no significant increase in subjective reports of workload. By and large, both the NASA-TLX and the PDT showed a similar pattern of results. Clearly, these findings indicate the appropriateness of the secondary task employed in our study in examining objective workload in this population as the secondary task employed here did not sufficiently increase participants' workload so as to lead them to report increased difficulty. Moreover, consistent with the literature, the NASA-TLX and PDT workload estimates proved to have adequate or greater levels of reliability (e.g., Harms & Patten, 2003; Martens & van Winsum, 2000) and to be sensitive to changes in workload brought about by varying environmental complexity (e.g., van Winsum, Martens, & Herland, 1999; Jahn, Oehm, Krems & Gelau, 2005).

Cantin and colleagues (2009) examined age-related differences in response to driving environments of varying complexity. Their findings indicated that among all participants, secondary task performance decreases when complexity increases. Regarding age, these authors found that age differences in secondary task performance were observed only in complex environments. Our findings were based on a convenience sample of undergraduate university students with a mean age of approximately 19 years. These observations give rise to new set of

enquiries. Given Cantin and colleagues' (2009) findings as well as the finding that older adults have particular difficulty with attention and intersections (Bédard et al., 2006; Langford & Koppela, 2006), it seems plausible that the results of younger drivers presented here would be magnified in an older sample.

Interestingly, although Cantin and colleagues' (2009) data illustrated a trend of increased cognitive workload among young participants', they failed to report significant effects of complexity within the young sample, a finding that is contrary to those presented here. This inconsistency may have been a function of the measure of cognitive load being inappropriately placed to measure significant fluctuations resulting from complexity among young adults. For example, Cantin and colleagues (2009) measured cognitive load while approaching an intersection rather than during an intersection as presented here. Indeed, although crossing path scenarios are the second most common type of collision, it is probable that the most complex and challenging element of these scenarios is moving in front of other road users (i.e., in the center of the intersection) rather than approaching this critical point. An alternative explanation is simply that the size of their sample of young adults (N=10) may have been insufficiently large to reveal statistically significant differences in changes of driving complexity.

The research conducted by Cantin and colleagues (2009) as well as other research in the field (e.g., Harms & Patten, 2003) differed from the present study in at least one fundamental aspect. Specifically, previous research had participants drive a continuous scenario whereas the present study had them complete multiple 1 km segments. In this case, a series of short scenarios were selected so as to systematically manipulate the complexity of each scenario as well as to gather estimates of subjective workload. Although the scenarios employed here were different from one another, their basic structure (i.e., 1 km in length with a critical event

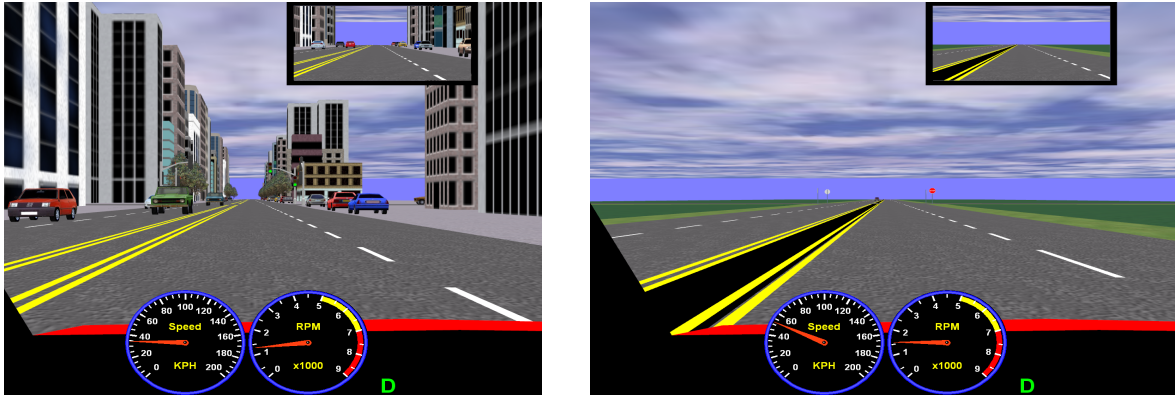
occurring at 500 m) remained consistent and resulted in the scenarios possessing some degree of predictability. Our results did, however, reveal statistically significant differences in cognitive workload resulting from complexity suggesting that the magnitude of the results may have been even greater had the scenarios been less predictable.

The present study possesses a number of strengths that complement the literature on attention, complexity and driving. More specifically, several studies have examined the environmental demands on primary and secondary driver performance (Patten et al., 2004; Verwey, 2000; Tornos & Bolling, 2006). These studies conclude that complex environments place greater cognitive demand on drivers, requiring more attentional resources than those that are less complex. Unlike previous studies, however, the present study subjected drivers to scenarios known to be challenging and systematically manipulated their handling and information processing complexity. We found that in scenarios involving an intersection, perceptual complexity was the most taxing element. In scenarios involving one other lead vehicle, however, perceptual and handling complexity were found to interact, showing the interdependent nature of these driving elements (i.e., information processing and vehicle handling) in some circumstances.

Our findings have a number of implications for both research and safety initiatives. For example, the design of this study was executed based on Fastenmeier's (1995) classification scheme of driving situations. Indeed, the majority of the results behaved according to the classification scheme in that cognitive workload fluctuated in response to vehicle handling and information processing complexity. Thus, this study provides empirical support for the framework and points to its usefulness in understanding the challenges posed by the driving environment. Next, despite the repetitive nature of the methodology utilized in the present study,

the PDT was able to capture differences in cognitive workload resulting from manipulations in the driving environment. Thus, consistent with previous literature, these results point to the PDT as a sensitive measure of cognitive workload for research pertaining to driving and attention (e.g., Harms & Patten, 2003; Patten et al., 2006).

In terms of safety, studies typically assess overt indicators of driving performance, such as lane position, speed, and adherence to traffic rules, as indicator of overall driving safety (e.g., de Winter, de Groot, Mulder, Wieringa, Dankelman & Mulder, 2009; Bélanger, Gagnon & Yamin, 2010). However, these primary indicators are not a direct reflection of drivers' ability to perceive hazardous stimuli and respond safely in a dangerous driving situation. This study consisted of a convenience sample of young, inexperienced drivers, an age group whose crash involvement is typically attributed to their attitudes and lack of experience rather than to their cognitive resources (Stevenson, Palamara, Morrison, & Ryan, 2001). The driving difficulties of other populations, such as older adults, however, stem from impairments in cognitive processes such as attention (Ross et al., 2009). It seems reasonable to suspect that for such populations, the measurement of cognitive workload through the PDT may appropriately be applied to an assessment situation; rather than simply assessing overt driving performance, the PDT would allow for the measurement of one's cognitive capacity to process and respond to the driving environment and thereby better discriminate between safe and unsafe drivers. Future research would benefit from further investigating the correlation between safety and PDT performance among populations whose driving errors result from cognitive deficits. The relevance to safety could be further increased if PDT performance was examined at situations where information processing and handling requirements are both elevated.



*Figure 1.* Example of a high information processing scenario (left) and low information processing scenario (right)

		<i>Handling Complexity</i>			
		<i>High</i>		<i>Low</i>	
		<i>TLX</i>	<i>PDT</i>	<i>TLX</i>	<i>PDT</i>
<i>Information Processing Complexity</i>	<i>High</i>	<i>M=39.847</i> <i>SE=2.666</i>	<i>M=2.610</i> <i>SE=.149</i>	<i>M=34.283</i> <i>SE=2.295</i>	<i>M=2.526</i> <i>SE=.162</i>
	<i>Low</i>	<i>M=35.956</i> <i>SE=2.665</i>	<i>M=1.475</i> <i>SE=.105</i>	<i>M=31.589</i> <i>SE=2.417</i>	<i>M=1.622</i> <i>SE=.104</i>

*Table 1. Mean TLX and PDT values for crossing path scenarios*

		<i>Handling Complexity</i>			
		<i>High</i>		<i>Low</i>	
		<i>TLX</i>	<i>PDT</i>	<i>TLX</i>	<i>PDT</i>
<i>Information Processing Complexity</i>	<i>High</i>	M=41.350 SE=2.831	M=1.887 SE=.184	M=38.517 SE=2.680	M=1.241 SE=.091
	<i>Low</i>	M=43.575 SE=2.675	M=1.222 SE=.098	M=36.242 SE=2.443	M=1.435 SE=.127

*Table 2. Mean TLX and PDT values for rear-end scenarios*

## References

- Abdel-Aty, M. A., Keller, J., & Brady, P. A. (2005). Analysis of Types of Crashes at Signalized Intersections by Using Complete Crash Data and Tree-Based Regression *Transportation Research Record: Journal of the Transportation Research Board*, 1908, 37-45.
- Abdel-Aty, M. A., & Radwan, A. E. (2000). Modeling traffic accident occurrence and involvement. *Accident Analysis and Prevention*, 32(5), 633-642.
- Abe, G., & Richardson, J. (2004). The effect of alarm timing on driver behaviour: an investigation of differences in driver trust and response to alarms according to alarm timing. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4-5), 307-322.
- Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis and Prevention*, 30(3), 313-322.
- Barrett, G. V., Mihal, W. L., Panek, P. E., Sterns, H. L., & Alexander, R. A. (1977). Information-processing skills predictive of accident involvement for younger and older commercial drivers. *Industrial Gerontology*, 4, 173-182.
- Bédard, M., Leonard, E., McAuliffe, J., Weaver, B., Gibbons, C., & Dubois, S. (2006). Visual attention and older drivers: the contribution of inhibition of return to safe driving. *Experimental Aging Research*, 32(2), 119-135.
- Bélanger, A., Gagnon, S. & Yamin, S. (2010). Capturing the serial nature of older drivers' responses towards challenging events: A simulator study. *Accident Analysis and Prevention*, 42(3), 809-817.

- Byers, J. C., Bittner, A. C., & Hill, S. G. (1989). Traditional and raw task load index (TLX) correlations: Are paired comparisons necessary? In A. Mital (Ed.), *Advances in Industrial Ergonomics and Safety* (pp. 481-485): Taylor & Francis.
- Cantin, V., Lavallière, M., Simoneau, M., & Teasdale, N. (2009). Mental Workload when driving in a simulator: Effects of age and driving complexity. *Accident Analysis and Prevention, 41* (4), 763-771.
- Clay, O. J., Wadley, V. G., Edwards, J. D., Roth, D. L., Roenker, D. L., & Ball, K. (2005). Cumulative Meta-analysis of the Relationship Between Useful Field of View and Driving Performance in Older Adults: Current and Future Implications. *Optometry and vision science, 82*(8), 724-731.
- Chang, S-H., Lin, C-Y., Fung, C-P., Hwang, J-R., Doong, J-L. (2008). Driver performance assessment: effects of traffic accident location and alarm content. *Accident Analysis and Prevention, 40*, 1637–1643.
- de Winter, J. C. F., de Groot, S., Mulder, M., Wieringa, P. A., Dankelman, J., Mulder, J. A. (2009). Relationships between driving simulator performance and driving test results. *Ergonomics, 52*(2), 137-153.
- Fastenmeier, W. (1995). Autofahrer und Verkehrssituation. Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Strassenverkehrssysteme. *Köln: Verlag TÜV Rheinland GmbH; Bonn: Deutscher Psychologenverlag.*
- Goode, K. T., Ball, K., Sloane, M. E., Roenker, D. L., Roth, D. L., Myers, R. S., et al. (1998). Useful field of view and other neurocognitive indicators of crash risk in older adults *Journal of Clinical Psychology in Medical Settings, 5*(4), 425-440.

- Goodman, M. J., Tijerina, L., Bents, F. D., & Wierwille, W. W. (1999). Using cellular phones in vehicles: safe or unsafe? *Transportation Human Factors*, 1, 3-42.
- Harms, L & Patten, C. (2003). Peripheral detection task as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area, *Transportation Research Part F*, 6, 23-36.
- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TL (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 239-250). Amsterdam: North Holland Press.
- Hendricks, D. L., Fell, J. C., & Freedman, M. (1999). *The relative frequency of unsafe driving acts in serious traffic crashes*. Washington, DC: National Highway Traffic Safety Administration.
- Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention*, 38(1), 185-191.
- Howell, D. C., (2010). *Fundamental Statistics for the Behavioral Sciences (6<sup>th</sup> ed)*. Thomson/Wadsworth: Belmont, CA.
- Jahn, G., Oehme, A., Krems, J. F., & Gelau, C. (2005). Peripheral detection as a workload measure in driving: effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(3), 255-275.
- Karlaftis, M. G., & Golias, I. (2002). Effects of road geometry and traffic volumes on rural roadway accident rates. *Accident Analysis and Prevention*, 34(3), 357-365.

- Kramer, A. F., Cassavaugh, N., Horrey, W. J., Becic, E., & Mayhugh, J. L. (2007). Influence of age and proximity warning devices on collision avoidance in simulated driving. *Human Factors*, 49 (5), 935-949.
- Keskinen, E., Ota, H., & Katila, A. (1998). Older drivers fail in intersections: speed discrepancies between older and younger drivers. *Accident Analysis and Prevention*, 30(3), 323-330.
- Keifer, R. J., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., & Shulman, M. (1999). *Forward collision warning systems: Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems*. (Rep. No. DOT-HS-808-964). Washington, DC: U.S. Department of Transportation.
- Kramer, A. F., Wiegmann, D. A., & Kirlik, A. (2007). *Attention: from theory to practice*. New York: Oxford University Press.
- Langford, J., & Koppela, S. (2006). Epidemiology of older driver crashes – Identifying older driver risk factors and exposure patterns. *Transportation Research Part F: Traffic Psychology and Behaviour*, 9(5), 309-321.
- Larsen, L., & Kines, P. (2002). Multidisciplinary in-depth investigations of head-on and left-turn road collisions. *Accident Analysis and Prevention*, 34(3), 367-380.
- Liu, B-S., & Lee, Y-H. (2006). In-vehicle workload assessment: effects of traffic situations and cellular telephone use. *Journal of Safety Research*, 37, 99-105.
- Maltz, M., & Shinar, D., (2007). Imperfect in-vehicle collision avoidance warning systems can aid distracted drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(4), 345-357.

- Martens, M. H., & van Winsum, W. (2000). *Measuring distraction: the peripheral detection task*. Soesterberg, Netherlands: TNO Human Factors.
- Najm, W. G., Sen, B., Smith, J. D., & Campbell, B. N. (2003). *Analysis of light vehicle crashes and pre-crash scenarios based on the 2000 General Estimates System* Washington, DC: National Highway Traffic Safety Administration, US Department of Transportation.
- Patten, C. J., Kircher, A., Ostlund, J., & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention*, 36(3), 341-350.
- Patten, C. J., Kircher, A., Ostlund, J., Nilsson, L., & Svenson, O. (2006). Driver experience and cognitive workload in different traffic environments. *Accident Analysis & Prevention*, 38(5), 887-894.
- Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology Applied*, 9(2), 119-137.
- Ross, L. A., Clay, O. J., Edwards, J. D., Ball, K., Wadley, V. G., Vance, D. E., et al. (2009 ). Do older drivers at-risk for crashes modify their driving over time? *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 64(2), 163-170.
- Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention*, 37(2), 315-326.
- Stevenson, M. R., Palamara, P., Morrison, D., & Ryan, G.A., (2001) Behavioral Factors as Predictors of Motor Vehicle Crashes in Young Drivers. *Traffic Injury Prevention*, 2(4), 247-254.

- Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular phone. *Psychological Science, 12*, 462-466.
- Tornros, J., & Bolling, A. (2006). Mobile phone use – effects of conversation on mental workload and driving speed in rural and urban environments. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*, 298-306.
- Trick, L. M., Enns, J. T., & Vavrik, J. (2004). Paying attention behind the wheel: a framework for studying the role of attention in driving. *Theoretical Issues in Ergonomics Science, 5*(5), 385-424.
- Utter, D. (2001). *Passenger Vehicle Cell Phone Use Results from the Fall 2000, National Occupant Protection Use Survey*. Washington, D.C: National Highway Traffic Safety Administration.
- Van Winsum, W., Materns, M. H., & Herland, L. (1999). *The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance*. Soeterberg, Netherlands: TNO Human factors.
- Verwey, W. B. (2000). On-line driver workload estimation. Effects of road situation and age on secondary task measures. *Ergonomics, 43*(2), 187-209.
- Weaver, B., Bédard, M., McAuliffe, J., & Pakkari, M. (2009 ). Using the Attention Network Test to predict driving test scores. *Accident Analysis & Prevention, 41*(1), 76-83.

## CHAPTER 3

## STUDY 2

Aging and driving in a complex world: exploring age differences in attentional demand while  
driving

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### Abstract

We investigated the relationship between attention and road complexity in a convenience sample of older drivers. The study sought to examine the impact of age-associated changes in attention in response to situations with an elevated risk of crash. Scenarios were manipulated in terms of handling and information processing complexity. Twenty-six older drivers and 30 mid-aged drivers completed a series of 20 simulated driving scenarios incorporating either rear-end or crossing path situations. For each scenario, the complexity of the driving environment was systematically manipulated in terms of vehicle handling and information processing elements. The attentional demands of half of the scenarios were assessed by means of a peripheral detection task (PDT) as well as through a subjective measure of overall difficulty. The results indicated that when information processing demands were increased, through the addition of traffic, and buildings, all participants exhibited greater workload regardless of age. Additionally, older adults who completed the PDT rated one of the scenarios with high information processing and vehicle handling complexity as posing a greater challenge. The results confirm the impact of environmental complexity on the attention of all drivers but suggest that the PDT may not be the most appropriate means of assessing attentional demands among older drivers, particularly when the driving complexity is elevated.

Keywords: Attention, aging, driving, complexity, motor vehicle collision, PDT

## Aging and driving in a complex world: exploring age differences in attentional demand while driving

Driving an automobile has become associated with more than simply a method of transportation. Instead, it is now perceived as a contributing factor to self-esteem, independence and quality of life, especially in developed countries, where driving is a primary means of mobility (Liddle, Turpin, Carlson & McKenna, 2008; Mezuk & Rebok, 2008). But despite their convenience and widespread use, motor vehicles present undeniable safety concerns. Transport Canada's annual report revealed that in 2007 there were over 138,470 road collisions, with approximately 2,750 of them resulting in fatalities (Transport Canada, 2008). In Britain, there were 230,902 road casualties reported in 2008, and of those 2,538 were fatal (Great Britain Department of Transport, 2009). Research indicates that most of these motor vehicle collisions (MVCs) occur at similar situations. Specifically, after analyzing the circumstances surrounding all police-reported collisions, the U.S. Department of Transportation concluded that the two most frequent types of collisions were rear-end crashes and crossing-path crashes (Najm, Sen, Smith, & Campbell, 2003). Many authors contend that the highly complex nature of road situations increases cognitive workload which, in turn, leads to MVCs (e.g., Horberry et al., 2006; Patten et al., 2006).

These statistics regarding the number of crashes and fatalities are striking and point to the inherent risks associated with driving a motor vehicle as well as the related public safety concerns. In an attempt to better understand the role of complexity and cognitive workload in the occurrence of MVCs, the authors of the present manuscript developed a series of simulated scenarios resembling those most frequently cited in the crash literature (Stinchcombe & Gagnon, 2010). In one such study, we developed five 1 km simulated scenarios that incorporated

crossing-path and rear-end components (i.e., three crossing-path and two rear-end); each scenario was manipulated according to Fastemeier's (1995) taxonomy in which driving situations are characterized in terms of vehicle handling (i.e., high or low) and information processing (i.e., high or low). To explore the effect of complexity on cognitive workload, a sample of inexperienced young drivers completed a measure of subjective cognitive workload (i.e., NASA TLX) after each scenario, while a subset of participants were presented with a peripheral detection task (PDT) as a measure of objective workload at a critical point during the scenario. The results of our study demonstrated the effect of information processing and vehicle handling complexity on cognitive workload as evidenced by a greater latency to respond to the PDT and higher subjective workload scores in response to highly complex situations. Moreover, the results pointed to the relevance of the PDT as a measure of objective cognitive load to assess differences in environmental complexity in a sample of young adults as demonstrated by non significant differences between individuals who completed the PDT and those who did not.

The abovementioned framework proved to be both valid and worthwhile for examining the effect of complexity in common crash situations. As Stinchcombe and Gagnon (2010) was the first study to utilize this particular experimental paradigm, we utilized a convenience sample of inexperienced drivers. However, not all drivers are at equal risk of being implicated in MVCs. When considering mileage-based crash rates, older adults are implicated in more MVCs than younger adults (Lyman, Ferguson, Braver & Williams, 2002; Stamatiadis, 1996; Stamatiadis & Deacon, 1997). Older drivers are more likely to be involved in MVCs that occur in good weather, during daylight hours, at intersections, and when making turns (Langford & Koppela, 2006; McGwin & Brown, 1999). Moreover, older drivers are usually involved in multi-vehicle crashes, especially at intersections, characterized by errors related to failure to

yield right of way, difficulties merging into traffic, changing lanes, leaving a parking position, and reversing (Hakamies-Blomqvist, 1993). What is more, due to greater frailty and reduced tolerance to injury, older drivers are more likely to experience casualties in the form injury or death (Augenstein, 2001). Many authors contend that the mileage-based overrepresentation of older adults in MVCs is due to functional changes associated with age-related health conditions (e.g., Raitanen, Törmäkangas, Mollenkopf, & Marcellini, 2003; Ross et al., 2009).

Given that older adults experience an increased risk of MVCs, a significant body of research has been dedicated to understand both the specific cognitive processes involved as well as their interaction with the driving environment. The research has consistently shown that the cognitive process of attention significantly contributes to on-road performance and the risk of MVCs among older adults (e.g., Horberry, Anderson, Regan, Triggs, & Brown, 2006; Patten, Kircher, Ostlund, & Nilsson, 2004). Problems with driver attention can be defined as failure by the driver to pay attention to the correct stimuli, or conversely, failure of the driver to ignore irrelevant stimuli (Trick, Enns, & Vavrik, 2004). For example, a measure of visual attention, entitled the Useful Field of View task (UFOV), has been shown to have a high correlation to crash involvement among older adults (Goode et al., 1998; Ball, Beard, Roenker, Miller & Griggs, 1988). Moreover, studies have shown that older drivers are implicated in MVCs in highly complex scenarios, such as at left-turns, where attention is a critical process necessary for crash avoidance (Staplin & Fisk, 1991; Robertston & Vanlaar, 2008; Mayhew et al., 2006; Summala & Mikkola, 1994). A recent study by Cantin and colleagues (2009) examined age-related difference in cognitive load in response to environmental complexity. Their study revealed that cognitive workload increased in line with road complexity for all ages and that older drivers' workload was significantly greater than the comparison group.

The literature regarding older adults and driving indicates that 1) older drivers are at an increased risk for MVCs, 2) their increased risk is partly attributed to a decrease in cognitive function, notably in attention and 3) older drivers are most often implicated in crashes at highly complex situations, such as intersections. Given that our previous experimental paradigm proved to be sensitive to changes in cognitive workload of young drivers in response to environmental demands, we sought to utilize this protocol to explore the driving challenges of older drivers. Precisely, the purpose of the present study was to examine the impact of age-associated changes in attention in response to scenarios of varying handling and perceptual complexity on cognitive workload. Since previous literature has found changes in attention in response to handling and perceptual complexity in a young sample, we hypothesized that these differences would be even more pronounced within an older population. Moreover, given that older adults are known to experience age-related deficits in attention, it seems plausible that the PDT might interact with their reduced attention. Thus, a secondary goal is to explore the appropriateness of a visual secondary task as a measure of attentional demand for this population.

## Method

### *2.1 Participants*

The final sample consisted of 26 older drivers aged 65 and over (21 males, 5 females, mean age = 70.62), and 30 mid-aged drives aged 25 to 45 (18 males, 12 females, mean age = 29.90). Four older adults did not complete the testing protocol due to the onset of Simulator Adaptation Syndrome, a type of motion sickness which can occur in a driving simulator (Rizzo, Sheffield, Stierman & Dawson, 2003).

Mid-aged participants were recruited through posters stationed around the University of Ottawa's downtown campus. Mid-aged drivers were required to possess a valid driver's license and to have at least five years of driving experience. Regarding older participants, because research indicates that older drivers are particularly susceptible to Simulator Adaptation Syndrome, and that prior exposure to the driving simulator minimizes the risk of simulator adaptation syndrome (Rizzo, Sheffield, Stierman & Dawson, 2003), the older cohort was recruited from a database of individuals who had successfully participated in a previous simulator study. They were also required to have a valid driver's license and at least five years of driving experience. Additionally, older participants were screened for cognitive impairment using the Mini Mental Status Exam (Folstein, Folstein & McHugh, 1975) and were found to be non-impaired (receiving a minimum score of 27). All participants were compensated \$20 for their participation in the study.

## *2.2 Apparatus*

The apparatus and experimental procedure described here are akin to those detailed in Stinchcombe and Gagnon (2010) with some slight deviations due to the use of an older sample of drivers in the present study. A high fidelity STISIM driving simulator (Build 2.08.04) produced by Systems Technology Inc. was used to examine the behavioural reactions of participants in simulations. The STISIM driving simulator displays a virtual roadway environment on three wide screens by means of three NEC projectors, giving the driver a field of view of 135 degrees. The STISIM simulator projects the scene onto three screens measuring 75cm x 90cm each and displays at a rate of 30 frames per second. The simulator seat, steering wheel, and pedals are mounted on a metal structure. The participants are seated 144cm from where the image is displayed. The room in which the simulator is housed measures 2.5 meters by 3.2 meters. The

simulator is a tool for generating laboratory tasks relevant to the psychomotor and cognitive demands of real-world driving. The simulator allows for the design of urban and suburban roadway environments including interactive vehicles on all lanes, buildings, traffic control devices, and pedestrians through advanced vehicle dynamics and image generation. The virtual environment is supplemented with realistic audio effects providing acceleration cues.

Instructions to the drivers (e.g., turn left/right, lane change, maintain speed, etc.) were given through the speakers linked with the driving simulator. Also, the STISIM Drive software includes an optional peripheral detection task (PDT), which consists of stimuli appearing in the periphery. Participants were required to manually detect the stimulus on either the left or right sides of their field of view as soon as it was perceived by signaling left (downward motion) or right (upward motion) with the signaler located to the left of the steering wheel. The software runs on 4 Windows XP operating system and Intel x86 Model 15 Family computers with a processing speed of 2394 Mhz (four systems required). The testing room is connected to an adjacent control room where the experimenter operates the simulator program and monitors the driver's reactions.

### *2.3 Scenarios*

Participants completed five 1 km base scenarios in four separate versions that differed in complexity (20 km in total were driven). Base scenarios were composed of either crossing-path type or rear-end type and each contained a critical event. In order to assess the degree of cognitive load generated by the complexity manipulation, the 20 km testing drive was split into individual 1 km segments. In each scenario, the critical event (i.e., an intersection or a passing manoeuvre) was located at 500 m. For the purpose of developing a sound and relevant experimental design, roadway elements were operationalized according to Fastenmeier's (1995)

classification scheme, emphasizing the degree to which a particular scenario contains information processing as well as vehicle handling elements. This two-dimension taxonomy breaks down the process of driving from the driver's perspective in terms of vehicle handling (high and low) and information processing (high and low). Consequently, four complexity combinations are possible ranging from low on both dimensions on one end to high on both dimensions on the other. Using this taxonomy, we produced four derivatives of each of the 5 base scenarios.

The information processing manipulation consisted of two levels (i.e., high vs. low). The high level was constructed so as to mimic an urban city-centre with traffic, parked cars, pedestrians, and tall office buildings; the intersections were controlled by a traffic light. On-coming traffic was presented at the intersection. In the low level, the scenario was constructed so as to have as little visual information as possible. In particular, there were no buildings, trees, parked cars or pedestrians; the intersections consisted of a stop sign. The two levels of the information processing manipulation are shown graphically in Figure 1.

The vehicle handling manipulation also consisted of two levels (i.e., high vs. low). The high level consisted of a series of four lane changes; the low level consisted of no lane changing. In the high vehicle handling condition, participants were asked to lane change at 200 meters, 400 meters, 600 meters, and 800 meters (i.e., four lane changes). In the case of the high vehicle handling condition, the roadways were always four lanes (two on each side of the dividing line) whereas there were only two lanes in the low vehicle handling condition.

These manipulations were combined and resulted in four distinct scenarios: 1) High demands on information processing and high demands on vehicle handling, 2) High demands on information processing and low demands on vehicle handling, 3) Low demands on information

processing and high demands on vehicle handling, and 4) Low demands on information processing and low demands on vehicle handling.

*Crossing path (Left turn at intersection with traffic in front)*

Participants were instructed to turn left at an intersection with oncoming traffic. In the low information processing condition participants were presented with a vehicle driving in the opposite direction that did not respect the stop light. In the high information processing condition participants approached an intersection with oncoming traffic and made the left turn when they felt it was safe.

*Crossing path (Left turn at intersection with traffic on left)*

Participants were instructed to turn left at the intersection and were presented with a vehicle coming from the left of them that did not respect stop light/sign.

*Crossing path (Straight at intersection with traffic on right)*

Participants were instructed to go straight at the intersection and were presented with a vehicle coming from the right of them that did not respect the stop light/sign.

*Rear-end (Car following scenario)*

Participants were instructed to follow a lead vehicle as closely as possible without crashing into it. In the high vehicle handling condition, participants were also asked to follow the vehicle's lane position as it lane changed four times.

*Rear-end (Car passing scenario)*

Participants were instructed to follow a lead vehicle as closely as possible without crashing into it. At 450 m from the start of the scenario, participants were asked to pass (overtake) the lead vehicle.

#### *2.4 Measure of Attentional Demand*

Half of the participants were randomly assigned to a PDT condition, in which PDT stimuli appeared at various times; the other half of the participants were assigned to a non-PDT condition in which no PDT stimuli appeared. The PDT stimulus consisted of a red triangle appearing on either the left or right side of the participant's periphery (25 degrees on either side of the driver). The PDT stimulus was presented until the participant responded making the appropriate signal with the signaler. For example, if the PDT stimulus appeared on the right side, participants would signal upwards; if, on the other hand, the stimulus appeared on the left side, participants would signal downwards. The PDT stimulus disappeared after the participant had made a response or a maximum presentation time of five seconds had been reached. The PDT data points consisted of the latency to respond to the stimulus and are therefore referred to as a response time (RT). Within each of the twenty individual 1 km scenarios, two PDT events were presented: one PDT event was presented during the critical event at 505 meters, and is hereafter referred to as the Target PDT. A second PDT occurred either at 250 meters (i.e., prior to the critical event) or at 750 meters (i.e., subsequent to the critical event) and is hereafter referred to as the Non-target PDT. The location (250 m or 750 m) of the Non-target PDT was randomized between scenarios to maintain an element of novelty.

#### *2.5 Measure of Subjective Workload*

The NASA Task Load Index (TLX) was employed as a measure of subjective cognitive load. The NASA-TLX is a standard subjective workload measure and it is regarded to be a highly sensitive and reliable measure to assess subjective workload (Hart & Staveland, 1988). This instrument is comprised of six subscales (mental demand, temporal demand, physical demand, effort, frustration, performance) with possible scores ranging from one to 21. In order to

generate a global estimate of cognitive workload, subscales of the NASA-TLX were summed (Byers, Bittner, & Hill, 1989).

## 2.6 Procedure

Prior to arriving at the laboratory, participants were randomly assigned to the PDT condition or the non-PDT condition. Once they arrived at the lab, participants completed an informed consent document. They subsequently completed a 10-minute orientation session of increasing complexity on the driving simulator, allowing them to familiarize themselves with basic driving manoeuvres in the simulator. Next, all participants were presented with a 1 km baseline scenario in which the simulator adjusted the speed and steering automatically. Participants were told to keep their feet off of the pedals, and hold the steering wheel in a fixed position, responding to the dual task when it was presented.

Thereafter, participants completed the 20 scenarios described above. The presentation of the scenario was randomized between participants using the RAND command in Excel to generate a completely random order of presentation. Participants were instructed to maintain a speed of 50 km/h throughout. In scenarios where they were required to follow a vehicle, participants were asked to ignore the speed requirement and simply follow the lead vehicle as closely as possible at the velocity at which it was travelling. Following each 1 km scenario (including the baseline scenario), participants completed the NASA-TLX questionnaire; each participant completed 21 NASA-TLX questionnaires in this protocol.

## 2.7 Analysis

The main goal of this study was to explore age-differences in the cognitive load associated with situations where crashes commonly occur (i.e., crossing path and rear-end type). It was hypothesized that older drivers' workload would be greater than that of younger drivers

after controlling for differences in baseline response time. To test this hypothesis, the final eight PDT RTs from the baseline RT scenario (driven before the formal driving assessment) were then averaged to create a composite RT score. The mean PDTs for each age group in the baseline scenario were .705 seconds for older drivers and .723 for mid-aged drivers. To generate accurate workload scores, independent of baseline responses, baseline PDT RTs were subtracted from PDT RTs responses during the scenarios thereby creating a difference score; these difference scores were used in the succeeding analyses.

To generate a reliable estimate of participants' performance at crossing path and rear-end scenarios, PDT RTs were averaged within these categories. Specifically, four PDT RTs representing the complexity manipulations (i.e., information processing complexity and vehicle handling complexity) were computed for crossing path type scenarios and rear-end type. The NASA-TLX results were also aggregated using this method. The succeeding analyses were conducted with these scores.

To explore the effects of age and scenario complexity on the attention demands in the two types of scenarios, the PDT data were submitted to two (i.e., one for each type of scenario) 2x2x2 mixed ANOVAs where age (mid-aged or older) was considered a between factor and both information processing complexity and handling complexity were considered within factors. To determine the effect of complexity and completion of a secondary task on self-reported workload, NASA-TLX total scores were submitted to two (i.e., one for each type of scenario) 2x2x2x2 mixed ANOVA where PDT (presence or absence) and age (mid-aged or older) were considered a between factors and information processing complexity (high vs. low) and handling complexity (high vs. low) were considered within factors.

## Results

The scenarios utilized in this study were selected based on the crash literature and were designed to be complex and challenging. To demonstrate that these events were indeed challenging over and above the regular demands of driving, an average of the Non-target PDT RTs and the Target PDT RTs was computed for rear-end and crossing path scenarios that contained low information processing and low handling complexity. The difference was significant with the Target PDT RT being significantly longer than the Non-target PDT RT (Mean difference=.31, SD=0.35),  $t(29)=4.79$ ,  $p<.001$ , indicating that the critical events were indeed cognitively challenging.

### *3.1 Crossing path scenarios.*

The results of the ANOVA using the PDT response time scores within the crossing path scenarios revealed a significant effect of information processing complexity,  $F(1, 28)=35.18$ ,  $p<.001$ , where the mean PDT response time for the high information processing scenario was 2.24 (SD=.194) whereas the mean value for the low information processing condition was 1.22 (SD=.167). This finding suggests that greater information processing complexity at crossing path scenarios significantly increased cognitive workload as demonstrated in delayed PDT responses. A significant effect of vehicle handling was also observed,  $F(1, 28)=5.85$ ,  $p=.022$ . There was no significant main effect of age group,  $F(1, 28)=3.23$ ,  $p=.083$ , showing no difference in PDT RTs between groups after controlling for baseline responses. The interactions between information processing and age group,  $F(1, 28)=1.07$ ,  $p=.309$ , information processing and vehicle handling,  $F(1, 28)=.643$ ,  $p=.429$ , as well as information processing, vehicle handling, and age group,  $F(1, 28)=2.24$ ,  $p=.146$ , did not reach statistical significance, however, a significant interaction between vehicle handling complexity and age group was observed,  $F(1,$

28)=8.48,  $p=.007$  (Table 1). To further explore the nature of this interaction, simple main effects were assessed by conducting age-comparisons at each level of vehicle handling (i.e., high vs. low). In the high vehicle handling condition, the results indicated a non-significant difference in PDT RTs between older and mid-aged drivers,  $F(1, 28)=.603$ ,  $p=.444$ . In the low vehicle handling condition, however, a significant effect of age group was observed,  $F(1, 28)=6.716$ ,  $p=.015$ , showing that older drivers exhibited significantly greater cognitive workload in the low vehicle handling condition only.

In terms of the NASA-TLX data, the results indicated a non-significant effect of the presence of a PDT,  $F(1, 52)=1.87$ ,  $p=.177$ , indicating that participants in the PDT condition did not report higher subjective ratings of workload than individuals in the non-PDT condition (Table 2). The results also indicated a non-significant effect of age group  $F(1, 52)=2.95$ ,  $p=.092$ , suggesting that subjective ratings of workload did not differ significantly between groups. In addition, significant main effects of information processing,  $F(1, 52)=18.98$ ,  $p<.001$ , and vehicle handling,  $F(1, 52)=27.64$ ,  $p<.001$  were observed. Of greatest interest, however, was a significant four-way interaction involving information processing complexity, vehicle handling complexity, age group and PDT condition,  $F(1, 52)=5.73$ ,  $p=.020$ . Results of the simple main effects revealed significant effects of both information processing,  $F(1, 13)=5.43$ ,  $p=.037$ , and vehicle handling,  $F(1, 13)=13.67$ ,  $p=.003$ , for older adults in the PDT condition only. More specifically, only older adults in the PDT condition rated the high information processing and vehicle handling complexity as subjectively more difficult than the low complexity scenarios (See Table 1).

### *3.2 Rear-end scenarios.*

As indicated above, the set of analyses for the rear-end scenarios are the same as for the crossing path scenarios. The main effect of information processing complexity on PDT RTs

reached significance,  $F(1, 27)=40.38, p<.001$ , where the high information processing scenarios resulted in significantly longer RTs ( $M=1.43, SD=.154$ ) in comparison to the low information processing scenarios ( $M=.628, SD=.138$ ). No main effects of vehicle handling complexity,  $F(1, 27)=1.01, p=.323$ , or age group,  $F(1, 27)=2.36, p=.136$ , were observed. Moreover, none of the interactions reached significance (Table 2).

The results of the NASA-TLX data again showed no effect of age group,  $F(1, 52)=2.38, p=.129$ , or PDT condition,  $F(1, 52)=1.96, p=.167$ , indicating that there were no differences in subjective workload between age groups or between PDT conditions. The results did reveal a significant main effect of visual complexity  $F(1, 52)=15.07, p<.001$ , where the high information processing scenarios resulted in significantly greater subjective workload ( $M=36.49, SD=2.40$ ) in comparison to the low information processing scenarios ( $M=32.47, SD=2.16$ ). Similarly, a significant main effect of vehicle handling complexity was observed  $F(1, 52)=25.61, p<.001$ , where drivers rated the high complexity scenarios as more demanding ( $M=36.74, SD=2.35$ ) in comparison to the low complexity scenarios ( $M=32.22, SD=2.20$ ). These findings indicate that greater handling and information processing complexity resulted in higher rating of subjective workload as measured by the NASA-TLX for the rear-end scenarios.

### Discussion

The purpose of this study was to explore the challenges of older drivers using a paradigm that proved relevant in a previous study. A number of noteworthy findings emerged.

Our findings are largely consistent with our previous paper (i.e., Stinchcombe and Gagnon, 2010), showing that the paradigm employed here is useful to understand the changes in cognitive load that occur in response to environmental complexity. The paradigm is especially robust when examining the effect of information processing demands. This can be seen by the

consistent effect of information processing complexity on objective and subjective measures of cognitive workload in both crossing path and rear-end scenarios.

The effect of vehicle handling complexity was not as consistent. In our previous study we found no effect of handling complexity on objective workload in crossing path and rear-end scenarios; however, handling effects were observed in the subjective workload data. In the present study, the effect of handling complexity on objective workload was, in fact, observed in the crossing path scenario while not for the rear-end scenarios. Consistent with our previous results, the effects of handling complexity were also observed when examining the subjective data of the present study. Rather than interpreting these results showing no effect of vehicle handling on workload, we suggest that the location of the vehicle handling manipulation may have been inappropriate. More specifically, the handling manipulation occurred outside of the critical event (i.e., closer to the start and finish of the scenario) and, as such, was not synchronized with the point of greatest complexity in each scenario. This interpretation may also explain the differing results from the subjective and objective workload measures. The subjective measure (i.e., NASA-TLX) provided a workload rating of the entire scenario, including the handling manipulation, while the objective measure (i.e., PDT) captured the workload associated with one specific moment in time. As such, using this manipulation we successfully increased handling complexity for the entire scenario rather than the specific point of greatest interest. Future research that utilizes a similar methodology could effectively manipulate handling complexity of a specific event, such as an intersection, by introducing an obstacle around which the driver would manoeuvre.

To explore the impact of age-associated changes in attention on cognitive workload, we contrasted cognitive workload estimates between age groups in each type of scenario. Overall

we observed no main effects of age group in our results, indicating that, contrary to our hypothesis, compared to mid-aged participants, older adults did not experience significantly greater cognitive workload in response to scenarios of higher complexity. These findings are not overly surprising given the nature of our sample. Specifically, the older adults who volunteered for our study were highly educated (i.e., 16 years of formal education which corresponds to University degree), primarily composed of individuals in the young-old category (Mean age 70.62 years) and reported no health problems. Research indicates that older adults most at risk of MVCs are those with several chronic conditions and those older than 70 years (Foley et al., 2001; Marottoli, Cooney, Wagner, Doucette & Tinetti, 1994;).

Although the scenarios were designed to be complex, our results suggest that the scenarios were not sensitive enough to show age differences in attention and cognitive workload. In fact, it is highly unlikely that the real driving environment is perceived by the driver as being dichotomously low or high complexity, as was presented here for the purpose of experimentation. Instead, given the multitude of driving contexts that exist, even in a constrained geographic region, it is certainly more appropriate to consider complexity as existing on a continuum. Indeed, the literature indicates that older drivers are most significantly overrepresented in motor vehicle crashes involving undetected crossing vehicles at intersections (Braitman et al., 2007; Caird et al., 2005; Retting et al., 2003; Staplin et al., 1998a, 1998b). Additionally, a large study involving immediate investigation of 1357 fatal multi-vehicle collisions by an on-site expert team determined that of the five largest categories of primary causal factors, only failures of attention increased with driver age (Summala and Mikkola, 1994). Given that we failed to observe main effects of age in response to complexity, it is plausible that

our so-called high complex scenarios may be situated on the lower end of this complexity continuum.

Nevertheless, through the examination of simple main effects, our findings did indeed reveal notable age differences in cognitive workload in the crossing path scenarios. More precisely, in the low vehicle handling condition in the crossing path scenarios, older adults exhibited significantly longer PDT RTs in comparison to the mid-aged drivers. Although a curious finding, one interpretation is that in the high handling condition, participants were asked to interact more with the driving environment by following the commands to change lanes; this interaction may have resulted in increased vigilance.

An additional difference between mid-aged and older drivers was observed. Precisely, only older adults in the PDT condition deemed the crossing path scenarios with high information processing and vehicle handling complexity as posing a greater challenge than the low complexity scenarios. This finding is intriguing, as we did not observe a main effect of the presence of the PDT in this study or our previous study. However, this finding reveals that the addition of completing the PDT in an already complex environment, poses a significant challenge for the older adults only, leading them to judge these situation as more difficult when the PDT is added. To measure older adults' cognitive workload in complex situations it may be relevant to have participants complete a secondary task that does not contribute to the handling and information processing demands of the driving task. One such task is a cued auditory response such as the one employed by Cantin, Lavallière, Simoneau & Teasdale (2009). In their study, Cantin and colleagues (2009) measured participants' latency to respond to an auditory stimulus by verbally responding with the word "top". They indicate that an auditory stimulus was employed so as to avoid structural interference with the driving task. On the other hand, if

our sample of older drivers subjectively report that cognitive workload when complexity was elevated, it is an indication that the task was definitely more challenging but not to the point where the PDT objective performance would be altered. This later interpretation fits well with the complexity continuum interpretation expressed earlier.

In combination with the previous results of Stinchcombe & Gagnon (2010), the findings reported here support the usefulness of systematically manipulating environmental demands according to Fastenmeier's (1995) classification scheme and assessing these demands by means of the PDT task. These studies offer a systematic approach to the examination of the interaction between exogenous factors (i.e., the driving environment) and endogenous factors (i.e., age and attention) as well as their impact of an indicator of performance (i.e., PDT). It is clear from these studies that increasing the complexity of situations where MVCs commonly occur leads to increases in cognitive workload for all drivers.

Given that driving complexity likely exists on a continuum, as proposed above, as a next step, it would be of interest to examine the manner in which cognitive load fluctuates in naturalistic everyday driving circumstances that are associated with a broader continuum of complexity. Moreover, given that the ultimate goal is to better understand the nature of MVCs, a final step in this line of research would be to explore how changes in cognitive workload in response to complexity relate to driving errors and driving safety.

## References

- Ball, K., Beard, B., Roenker, D. L., Miller, R., & Griggs, D. (1988). Age and visual search: expanding the useful field of view. *Journal of the Optical Society of America A*, 5, 2210-2219.
- Braitman, K. A., Kirley B. B., Ferguson S., & Chaudhary N. K. (2007) Factors leading to older drivers' intersection crashes. *Traffic Injury Prevention*, 8, 267–274.
- Byers, J. C., Bittner, A. C., & Hill, S. G. (1989). Traditional and raw task load index (TLX) correlations: Are paired comparisons necessary? In A. Mital (Ed.), *Advances in Industrial Ergonomics and Safety* (pp. 481-485): Taylor & Francis.
- Caird, J. K., Edwards, C. J., Creaser, J. I. & Horrey, W. J. (2005). Older Driver Failures of Attention at Intersections: Using Change Blindness Methods to Assess Turn Decision Accuracy. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 47(2), 235-249.
- Cantin, V., Lavallière, M., Simoneau, M., & Teasdale, N. (2009). Mental Workload when driving in a simulator: Effects of age and driving complexity. *Accident Analysis and Prevention*, 41(4), 763-771.
- Fastenmeier, W. (1995). Autofahrer und Verkehrssituation. Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Strassenverkehrssysteme. *Köln: Verlag TÜV Rheinland GmbH; Bonn: Deutscher Psychologenverlag*.
- Foley, D. J. Heimovitz, H. K., Guralnik, J. M. & Brock, D. B., (2002). Driving Life Expectancy of Persons Aged 70 Years and Older in the United States. *American Journal of Public Health*, 92(8), 1284-1289.
- Folstein M. F., Folstein S. E. & McHugh P.R. (1975). "Mini-mental state". A practical method

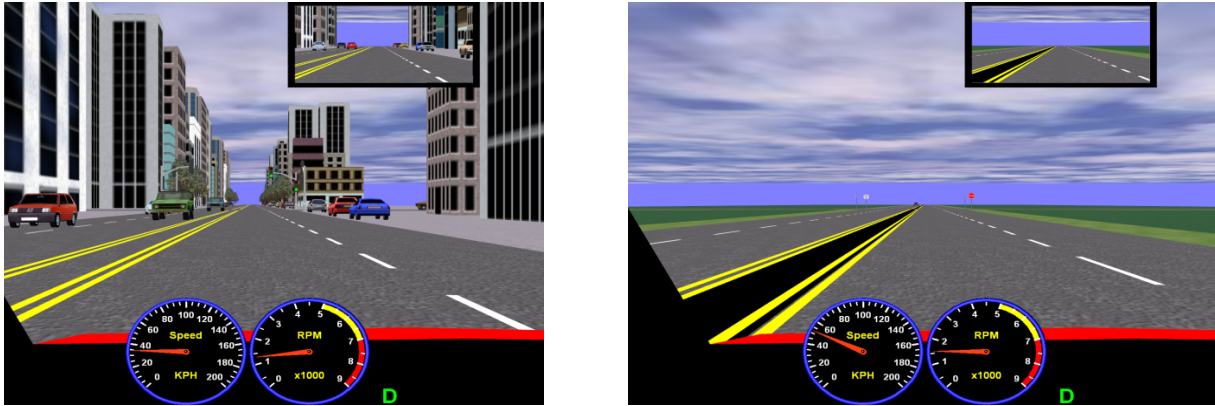
- for grading the cognitive state of patients for the clinician. *Journal of psychiatric research*, 12(3), 189-198.
- Great Britain Department of Transportation. (2009). Road Casualties in Great Britain Main Results: 2008. *Transport Statistics*: DfT: London.
- Goode, K. T., Ball, K., Sloane, M. E., Roenker, D. L., Roth, D. L., Myers, R. S., et al. (1998). Useful Field of View and other neurocognitive indicators of crash risk in older adults *Journal of Clinical Psychology in Medical Settings*, 5(4), 425-440.
- Hakamies-Blomqvist, L. (1993). Fatal accidents of older drivers. *Accident Analysis and Prevention*, 25(1), 19-27.
- Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention*, 38(1), 185-191.
- Langford, J., & Koppela, S. (2006). Epidemiology of older driver crashes – Identifying older driver risk factors and exposure patterns. *Transportation Research Part F: Traffic Psychology and Behaviour*, 9(5), 309-321.
- Liddle, J., Turpin, M., Carlson, G. & McKenna, K. (2008). The needs and experiences related to driving cessation for older people. *British Journal of Occupational Therapy*, 71(9), 379-388.
- Lyman, S., Ferguson, S., Braver, E. & Williams, A. (2002). Older Driver Involvements in Police-Reported Crashes and Fatal Crashes: Trends and Projections. *Injury Prevention*, 8, 116-120.
- McGwin, G.Jr, & Brown, D.B. (1999). Characteristics of traffic crashes among young, middle aged, and older drivers. *Accident Analysis and Prevention*, 31(2), 181-198.

- Marottoli, R. A., Cooney, L. M., Wagner, D. R., Doucette, J. & Tinetti, M. E. (1994) Predictors of automobile crashes and moving violations among elderly drivers. *Annals of Internal Medicine*, 121, 842–846.
- Mayhew, D.R., Simpson, H.M. & Ferguson, S.A. (2006). Collisions involving senior drivers: high-risk conditions and locations. *Traffic Injury Prevention*, 7, 117–124.
- Mezuk, B. & Rebok, G. W. (2008). Social Integration and Social Support Among Older Adults Following Driving Cessation. *Journal of Gerontology*, 63B(5), S298-S303.
- Michael, R. L. & Meuter, R., (2006). *Sustained attention and hypovigilance: The effect of environmental monotony on continuous task performance and implications for road safety*. Australasian Road Safety Research, Policing Education Conference 2006.
- Najm, W. G., Sen, B., Smith, J. D., & Campbell, B. N. (2003). *Analysis of light vehicle crashes and pre-crash scenarios based on the 2000 General Estimates System* Washington, DC: National Highway Traffic Safety Administration, US Department of Transportation.
- Patten, C. J., Kircher, A., Östlund, J., Nilsson, L. & Svenson, O. (2006). Driver experience and cognitive workload in different traffic environments. *Accident Analysis and Prevention*, 38, 887-894.
- Raitanen, T., Törmäkangas, T., Mollenkopf, H., & Marcellini, F. (2003). Why do older drivers reduce driving? Findings from three European countries. *Transportation Research Part F*, 6(2), 81-95.
- Rizzo, M., Sheffield, R. A., Stierman, L. & Dawson, J. (2003). Demographic and driving performance factors in simulator adaptation syndrome. *Symposium conducted at the Second International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, Park City, Utah*.

- Robertson, R. & Vanlaar, W. (2008). Elderly drivers: Future Challenges? *Accident Analysis and Prevention*, 40, 1982-1986.
- Ross, L. A., Clay, O. J., Edwards, J. D., Ball, K. K., Wadley, V. G., Vance, D. E., Cissell, G. M., Roenker, D. L & Joyce, J. J. (2009). Do older drivers at-risk for crashes modify their driving over time? *The Journals of Gerontology: Series B, Psychological Sciences and Social Sciences* 64(2), 163-70.
- Stamatiadis, N. (1996). Gender effect on the accident patterns of elderly drivers. *Journal of Applied Gerontology*, 15, 8–22.
- Stamatiadis, N., & Deacon, J. A. (1995). Trends in highway safety: Effects of an aging population on accident propensity. *Accident Analysis and Prevention*, 27, 443- 459.
- Staplin, L. & Fisk, A.D. (1991). A cognitive engineering approach to improving signalized left-turn intersections. *Human Factors*, 33, 559-572.
- Staplin, L., Lococo, K. & Byington, S. (1998). *Older driver highway design handbook*. Washington, DC: Federal Highway Administration, US Department of Transportation, (Publication no. FHWA-RD-97-135).
- Stinchcombe, A. & Gagnon, S. (2010). Driving in dangerous territory: Complexity and road-characteristics influence attentional demand. *Transportation Research Part F: Traffic Psychology and Behaviour*, 13 (6), 388-396.
- Summala, H. & Mikkola, T. (1994). Fatal Accidents Among Car and Truck Drivers: Effects of Fatigue, Age, and Alcohol Consumption. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 36(2), 315-326.
- Thiffault, P., & Bergeron, J. (2003). Monotony of road environment and driver fatigue: A simulator study. *Accident Analysis and Prevention*, 35(3), 381-391

Transport Canada. (2008). *Transportation in Canada: An Overview* (TP 14816). Retrieved from [http://www.tc.gc.ca/media/documents/policy/overview\\_1.pdf](http://www.tc.gc.ca/media/documents/policy/overview_1.pdf).

Trick, L. M., Enns, J. T., & Vavrik, J. (2004). Paying attention behind the wheel: a framework for studying the role of attention in driving. *Theoretical Issues in Ergonomics Science*, 5(5), 385-424.



*Figure 1.* Example of a high information processing scenario (left) and low information processing scenario (right).

		<i>Handling Complexity</i>				
		<i>High</i>		<i>Low</i>		
		<i>TLX</i>	<i>PDT</i>	<i>TLX</i>	<i>PDT</i>	
<i>Visual Complexity</i>	<i>High</i>	Older	$M=28.74$ $SE=3.17$	$M=2.29$ $SE=0.32$	$M=25.74$ $SE=2.84$	$M=2.93$ $SE=0.29$
		Mid-aged	$M=36.41$ $SE=3.00$	$M=2.04$ $SE=0.32$	$M=32.12$ $SE=2.69$	$M=1.69$ $SE=0.29$
	<i>Low</i>	Older	$M=25.83$ $SE=3.09$	$M=1.18$ $SE=0.25$	$M=21.75$ $SE=2.71$	$M=1.64$ $SE=0.26$
		Mid-aged	$M=32.20$ $SE=2.93$	$M=0.91$ $SE=0.25$	$M=27.76$ $SE=2.57$	$M=1.15$ $SE=0.26$

*Table 1. Mean NASA and mean PDT difference values for crossing path scenarios*

		<i>Handling Complexity</i>				
		<i>High</i>		<i>Low</i>		
		<i>TLX</i>	<i>PDT</i>	<i>TLX</i>	<i>PDT</i>	
<i>Visual Complexity</i>	<i>High</i>	Older	$M=34.13$ $SE=3.69$	$M=1.19$ $SE=0.25$	$M=30.80$ $SE=3.51$	$M=1.47$ $SE=0.26$
		Mid-aged	$M=38.97$ $SE=2.32$	$M=1.12$ $SE=0.25$	$M=38.99$ $SE=3.32$	$M=1.22$ $SE=0.25$
	<i>Low</i>	Older	$M=31.77$ $SE=3.34$	$M=0.87$ $SE=0.27$	$M=27.43$ $SE=3.25$	$M=0.65$ $SE=0.14$
		Mid-aged	$M=39.00$ $SE=3.16$	$M=0.55$ $SE=0.26$	$M=31.65$ $SE=3.08$	$M=0.43$ $SE=0.14$

Table 2. Mean NASA and mean PDT difference values for rear-end scenarios

## CHAPTER 4

## STUDY 3

Fluctuating attentional demand in a simulated driving assessment: the roles of age and driving complexity

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## ABSTRACT

**Objective:** The purpose of the study was to explore age differences in attentional demand in response to driving situations of varying complexity within the context of a simulated assessment protocol. It was hypothesized that as road complexity increased, an indicator of attentional demand (i.e., latency to respond to a secondary task) would increase and, independent of the road complexity, older adults would exhibit greater attentional demand in comparison with younger and mid-aged drivers. **Methods:** Drivers from three age categories (i.e., young, mid-aged and older) completed an assessment protocol in a STISIM driving simulator during which participants responded to a series of strategically-placed secondary tasks (i.e., peripheral detection task; PDT). Situations where secondary tasks occurred were grouped according to whether they were straight road, crossing path, or lane change events. Two global indices of driving safety as well as several cognitive measures external to the driving simulator were also collected. **Results:** The results supported the hypothesis in that complex driving situations elicited greater attentional demand among drivers of all ages. Older adults showed greater attentional demand in comparison to young and mid-aged adults even after controlling for baseline response time. Older drivers also scored poorer on a global measure of driving safety. **Conclusions:** The findings are highly consistent with the literature on road complexity and attention showing that increased driving complexity is associated with poorer performance on tasks designed to concurrently assess attention, an effect that is more pronounced for older drivers. The results point to intrinsic and extrinsic factors that contribute to motor-vehicle collisions (MVCs) among older drivers. The relevance of these findings is discussed in relation to interventions and future research aimed at improving road safety.

Keywords: older drivers, psychology, safety, evaluations, peripheral detection task, assessment,

## INTRODUCTION

Driving a motor vehicle is a primary means of transportation in many Western countries including Canada and the United States and, as such, is often synonymous with freedom and independence<sup>1,2</sup>. Driving allows individuals to reach employment, access critical services, and maintain social contacts. Research suggests that safe driving relies heavily on both physical and cognitive capacities. For example, physical capacities, such as reduced neck rotation, may impair the ability of the driver to turn their head to see relevant stimuli in the periphery, an action necessary for safe driving in complex traffic situations<sup>3,4</sup>. In terms of cognitive capacities, research has reliably shown that the cognitive process of attention is a significant determinant of safe driving and the risk for motor vehicle collision (MVC)<sup>5,6</sup>.

Research on driving and attention has categorized attention-related driving errors as a failure to pay attention to the safety-relevant stimuli (e.g., oncoming vehicles, traffic lights, etc) or conversely, failure to ignore safety-irrelevant stimuli (e.g., advertisements, buildings, etc)<sup>7</sup>. Empirical evidence supporting the role of attention in safe driving comes from a variety of sources. For example, Hendricks, Fell, and Freedman<sup>8</sup> evaluated MVCs in terms of the crash scene, roadway characteristics and vehicle type. They attributed the majority of MVCs to driver actions, and, of these driver actions, attention accounted for the greatest proportion of MVCs. Moreover, studies of commercial drivers of all ages also found an association between problems with selective attention and increased crash rate<sup>9</sup>. In a large-scale longitudinal study commissioned by the National Highway Traffic Safety Administration, Dingus and colleagues<sup>10</sup> found that that almost 95 percent of lead-vehicle crashes and minor collisions were due to some form of inattention.

Aging has been associated with a number of cognitive changes that affect driving performance, one of which is a reduction in attentional capacity<sup>11</sup>. As evidence, a large body of literature shows that performance on the Useful Field of View (UFOV) task (i.e., a measure of processing speed and attention) is highly associated with driving outcomes among older adults such as performance on an on-road assessment and rate of MVCs<sup>5, 6, 12</sup>. The association between driving performance and attention among older adults is also supported by data on the frequency and location of MVCs. In comparison to other age groups, older drivers are more often involved in MVCs that occur in good weather, during daylight hours, at intersections, and when making turns<sup>13, 14</sup>. Moreover, older drivers are usually involved in multi-vehicle crashes, especially at intersections, characterized by errors related to failure to yield right of way, difficulties merging into traffic, changing lanes, leaving a parking position, and reversing<sup>15</sup>. In a large study that investigated 1357 fatal multi-vehicle MVCs, Summala and Mikkola<sup>16</sup> found that the only causal factor that increased with age was failures of attention. Similarly, errors in attention have also been cited as the most common factor in left-turn accidents, a trend that is even more pronounced among older adults<sup>17, 18</sup>. Most recently, Clarke, Ward, Bartle, and Truman<sup>19</sup> examined police reports from 2000 crashes involving older drivers in the UK. These authors found that older adults were most implicated in MVCs at intersections and when failing to yield the right of way, issues that are attributed to decrements in attention. Taken together, these research findings suggest that an interaction exists between extrinsic factors (i.e., the driving environment) and intrinsic factors (i.e., attention and age) which, in turn, impacts safe driving.

Following this line of thinking, Stinchcombe and Gagnon executed two studies that sought to systematically elucidate the nature of this interaction. In the first study, five 1km simulated scenarios that incorporated crossing-path and rear-end components (i.e., three

crossing-path and two rear-end) were developed; each scenario was manipulated according to Fastemeier's<sup>20</sup> taxonomy of driving complexity in which driving situations are characterized in terms of vehicle handling (i.e., high or low) and information processing (i.e., high or low). The results of the study showed the effect of information processing and vehicle handling complexity on attentional demand as evidenced by a greater latency to respond to a secondary task (peripheral detection task; PDT) and higher subjective workload scores (i.e., a measure of overall difficulty) in response to highly complex situations<sup>21</sup>. More recently, this framework was applied to understanding the driving challenges of older adults<sup>22</sup>. In particular, older and mid-aged drivers completed the abovementioned protocol and differences in attentional demand were contrasted between age groups. While the results of the second study were consistent in showing an effect of driving complexity on attentional demand, no main effects of age were observed. Based on these results, it was determined that, although experimentally sound, the 1km scenarios that were presented to participants may not have been sufficiently complex to reveal age-differences in attentional demand. Moreover, the repetitive and discontinuous nature of these scenarios led to a protocol that was removed from the varying degrees of complexity associated with naturalistic driving. As such, it was of interest to re-examine the interaction between the driving environment and attention in a context that subjected participants to the driving demands associated with naturalistic driving.

Traditional driving assessments subject drivers to a variety of driving situations including situations that are known to be related to the occurrence of MVCs (e.g. intersections, congested streets, merging, etc). Driving assessments evaluate both knowledge of traffic rules and drivers' skill to respond in different circumstances. From a research perspective, driving assessments possess a number of advantages including being standardized, allowing for direct comparison of

performance indicators between participants. On-road driving assessments are regarded as the ‘criterion standard’ for licensing new drivers and have been the most widely accepted method for determining driving competency<sup>23</sup>. Researchers have utilized results from on-road driving assessments as an outcome variable indicative of overall driving performance<sup>24-26</sup>. The reliability and validity of the on-road assessment have also been examined with success<sup>27, 28</sup>. In one study, for example, researchers examined the psychometric properties of an on-road assessment for older drivers and found that their results offered evidence for its inter-rater reliability and construct validity as a sensitive assessment tool<sup>29</sup>.

Given the widespread application of on-road assessments among decision makers responsible for issuing drivers’ licenses as well as their desirable psychometric profile, there has been great interest in replicating the on-road assessment within a driving simulator context. Driving simulators are becoming increasingly popular in both research and applied contexts due largely to their ability to present drivers with a variety of driving-related stimuli in a standardized, safe, and controlled environment<sup>30</sup>. Bédard and colleagues<sup>31</sup> examined the psychometric characteristics of a standardized driving simulator assessment protocol patterned after a real-world assessment course. The results of their study showed a high-degree of inter-rater reliability as well as a significant association between scores recorded by a rater and those collected automatically by the driving simulator. In a recent study by Shechtman, Classen, Awadzi and Mann<sup>32</sup>, performance of young and older drivers in simulated and on-road driving environments was examined. Both the vehicle type (i.e., on-road vs. simulator) and intersection type (i.e., left turn vs. right turn) were treated as independent variables whereas errors documented by a rater were treated as the dependent variable. The results showed a non-significant effect of vehicle type for a variety of driving errors including lane maintenance and

visual scanning errors, pointing to the validity of the driving simulator as an assessment tool indicative of real-world driving. Similarly, Lee, Cameron and Lee<sup>24</sup> compared the driving performance of 129 older drivers in a driving simulator and on the road, and found a significant positive correlation between the two environments, further supporting the validity of the simulated assessment protocol.

The previous literature suggests that 1) attention is a critical cognitive factor involved in safe driving, particularly among older adults, and 2) attentional demand is significantly impacted by the complexity of the driving environment. The previous study by Stinchcombe and Gagnon<sup>22</sup> was unsuccessful in showing a main effect of age on attentional demand while driving which we attribute to the repetitiveness, brevity, and artificial nature of the scenarios. Moreover, while the 1km scenarios previously administered were based on common crash situations, they were not designed to mirror an assessment protocol comprising a reliable set of every-day driving situations, through which driving safety may be reliably assessed and contrasted between subjects.

As such, the purpose of this study was to explore age differences in attentional demand in response to driving situations of varying complexity within the context of a simulated assessment protocol. Precisely, we sought to explore how the complexities within situations where crashes commonly occur influence attention among drivers of three age cohorts (i.e., young, mid-aged and older). Also, given that attention has been linked to overall driving safety, we sought to explore the degree of relatedness between overall performance on a simulated driving assessment and external cognitive measures related to attention. It was anticipated that as road complexity increases, an indicator of attentional demand (i.e., latency to respond to the peripheral detection task; PDT) would also increase, and independent of the road complexity,

older adults would exhibit greater attentional demand in comparison with younger and mid-aged drivers.

## **METHODS**

### **Participants**

The final sample consisted of 109 participants from three age groups: older drivers aged 65 and over (23 participants; 19 males, 4 females, mean age = 69.9), mid-aged drivers aged 25 to 45 (30 participants; 18 males, 12 females, mean age = 29.6), and younger drivers aged 18 to 24 (56 participants; 28 males, 28 females, mean age = 18.5). Five participants (one young adult and four older adults) did not complete the testing protocol due to the onset of Simulator Adaptation Syndrome, a type of motion sickness which can occur in a driving simulator<sup>33</sup>. Younger participants consisted of first-year University students enrolled in an Introductory Psychology course at the University of Ottawa, Canada; they received course credit in exchange for their participation. They were required to possess a valid driver's license. Mid-aged participants were recruited through posters hung throughout the University of Ottawa. Mid-aged drivers were required to possess a valid driver's license and to have at least five years of driving experience. Regarding older participants, because research indicates that older drivers are particularly susceptible to Simulator Adaption Syndrome, and that prior exposure to the driving simulator minimizes the risk of simulator adaptation syndrome<sup>33</sup>, the older group was recruited from a database of individuals who had successfully participated in a previous simulator study. They were also required to have a valid driver's license and at least five years of driving experience. Additionally, older participants were screened for cognitive impairment using the Mini Mental Status Exam<sup>34</sup> and were found to be non-impaired (i.e., scored 27 or greater). All mid-aged and older participants were compensated \$20 for their participation in the study. Younger

participants had completed a mean of 13.41 years of formal education; mid-aged participants had completed a mean of 18.61 years of formal education; while older participants had completed a mean of 16.21 years of formal education.

### **Apparatus**

The apparatus described here is akin to that detailed in a previous study by Stinchcombe and Gagnon <sup>21</sup>. A high fidelity STISIM driving simulator (Build 2.08.04) produced by Systems Technology Inc. was used to examine the behavioural reactions of participants while driving. The STISIM driving simulator displays a virtual roadway environment on three wide screens by means of three NEC projectors, giving the driver a field of view of 135 degrees. The STISIM simulator projects the scene onto three screens measuring 75cm x 90cm each and displays at a rate of 30 frames per second. The simulator seat, steering wheel, and pedals are mounted on a metal structure. The participants are seated 144cm from where the image is displayed. The room in which the simulator is housed measures 2.5 meters by 3.2 meters. The simulator is a tool for generating laboratory tasks relevant to the psychomotor and cognitive demands of real-world driving. It allows for the design of urban and suburban roadway environments including interactive vehicles on all lanes, buildings, traffic control devices, and pedestrians through advanced vehicle dynamics and image generation. The virtual environment is supplemented with realistic audio effects providing acceleration cues. Instructions to the drivers (e.g., turn left/right, lane change, etc.) were given through the speakers linked with the driving simulator. The software runs on 4 Windows XP operating system and Intel x86 Model 15 Family computers with a processing speed of 2394 Mhz (four systems required). The testing room is connected to an adjacent control room where the experimenter operates the simulator program and monitors the driver's reactions.

## **Measure of Attentional Demand**

Attention was assessed by means of the cognitive workload method, a procedure where participants complete a secondary task while driving and latency to respond in seconds is recorded<sup>21, 35</sup>. The STISIM Drive software includes an optional peripheral detection task (PDT), which consists of stimuli (i.e., a red triangle) appearing in the periphery. Participants were required to manually detect the stimulus on either the left or right sides of their field of view as soon as it was perceived by signaling left (downward motion) or right (upward motion) with the signaler located to the left of the steering wheel. Consistent with previous literature, if the participant did not react within five seconds, the dual task would be scored as having taken five seconds (i.e., the maximum presentation time)<sup>36, 37</sup>.

## **Assessment Scenario**

The assessment scenario employed was programmed to mirror an assessment course administered by a provincial regulatory body in Canada, and was an identical course to that utilized by Weaver and colleagues<sup>38</sup>. It lasted a distance of 12.3 kilometres and involved two- and four-lane roads, stretches of highway, and typical driving situations of varying complexity. The simulation was displayed in full colour, and travelling noises from other traffic could be heard as the participant was driving. A rear-view mirror was provided in the centre-right portion of the screen, which actively displayed what was occurring behind the driver. See Figure 1 for screen captures from the assessment course. To measure attentional demand, twenty-seven PDT events were presented at various positions throughout the course of the assessment to assess all elements of the driving scenario.

As described in Bédard and colleagues<sup>31</sup>, two additional measures were recorded during the simulated drive. First, the experimenter recorded the number of demerit points using an

instrument that is used by a provincial regulatory body in Canada. Second, the simulator automatically recorded the number of driving mistakes (i.e., simulator-recorded errors). Mistakes included center-line crossing, road edge excursion, failure to stop at a stop sign or red light, speeding (>5km/h over the speed limit), illegal turns, off-road crashes, and vehicle collisions. The sum of frequency counts for these measures is reported as the total simulator-recorded errors.

### **Procedure**

Upon arrival to the laboratory, each participant signed a consent form after being briefed about the details of the study. From there, participants drove through a 10-minute orientation session in the driving simulator, followed by a measure of their baseline response time to the PDT. The 10-minute orientation session exposed participants to situations of increasing complexity, which allowed participants to become familiar with the manoeuvring and graphics associated with the simulator. The baseline response time scenario consisted of a one kilometre stretch of straight road with no traffic, where the vehicle's speed and steering was automatically adjusted, and 16 PDTs appeared, one at a time. Specifically, four PDTs were first presented on the left side followed by four PDTs presented on the right and, finally, eight PDTs which were presented randomly on either the left or the right side. Participants then drove through the formal 12 kilometre assessment course, where they were instructed to drive as they would normally, respecting all traffic signs and adhering to the rules of the road. Twenty-seven strategically-placed PDT events occurred throughout the assessment course. Upon completion of the assessment course, participants completed a number of external cognitive tasks including the UFOV<sup>5</sup>, Trail Making A and B<sup>39,40</sup>, as well as simple and choice response time tasks<sup>41</sup>. The Trail Making task is a paper and pencil based assessment of visual attention requiring

participants to connect 25 consecutive targets. In Trail Making A, participants are asked to connect numbers in ascending order while in Trail Making B, participants are asked to alternate between numbers and letters (i.e., 1-A-2-B, etc); time to complete each task is recorded. Simple response time and choice response time is assessed by means of a computerized task programmed in E-Prime Version 1.1.4.4 (Psychology Software Tools Inc.). Each response time task is composed of 60 trials and each trial lasts a maximum of five seconds. The simple response time task consists of pressing the space bar when a black triangle appears in the center of the computer screen. In the choice response time, participants are required to fixate on two circles that are consistently displayed on the screen. They are asked to press the “1” key on the numeric keyboard when the left circle changes to a square or press the “3” key when the right circle changes to a square. Latency to respond is recorded. Older adults completed all components of the UFOV (i.e., processing speed, divided attention and selective attention) task while younger and mid-aged participants solely completed the third component. Only the third UFOV component was administered for all participants because previous research has shown that young and mid-aged adults perform at ceiling levels on the first two components of the UFOV <sup>42</sup>

### **Classification of PDT tasks**

The literature indicates that the most frequent types of MVCs are rear-end types, crossing-paths types, off-road collisions, and lane change collisions <sup>43</sup>. As such, each of the 27 PDT events was categorized as occurring at 1) a straight road (referring to rear-end collisions), 2) a crossing-path situation, or 3) a lane change. Within the three categories, each PDT location was further defined in terms of its overall complexity, which included the number of relevant visual stimuli and the difficulty of the manoeuvre. For the category *Straight Roads*, four specific

situations were defined: vehicles in front and behind, vehicles in front, vehicles behind, or no vehicles. For the category *Crossing Paths*, five situations were defined: left turn at an intersection, right turn at an intersection, pre-intersection, post-intersection, or straight through an intersection. *Lane Changes* were compared with a baseline of *Straight Roads* with no vehicles. Each of the PDTs was classified according the specific situation in which they appeared; PDT latencies (in seconds) were then averaged within the three overarching categories.

After initial inspection of the descriptive data it was evident that the second PDT latency (i.e., *Crossing Paths*, pre-intersection) was exceptionally slow for all participants; the second PDT mean response time (RT) was 3.8 seconds in comparison to a mean RT of 1.7 seconds for the other events in the same category. Upon visual inspection of the event itself, we discovered that the presentation of the second PDT overlapped with a red stop sign, making the red triangle imperceptible. Thus, the second PDT was eliminated from the analysis. The classifications of the remaining 26 PDTs can be found in Table 1.

## RESULTS

### External Measures Related to Attention

Age differences among external measures related to attention were explored by executing a series of between subjects ANOVAs, treating age group as the independent variable (i.e., young, mid-aged, and older) and performance on each of the cognitive tasks as the dependent variables (UFOV, simple response time, choice response time, Trail Making A and Trail Making B). The results indicated significant effects of age on all the cognitive tasks (see Table 2). Post-hoc analysis, applying the Bonferonni correction to minimize Type I error, indicated that older adults exhibited significantly poorer scores on the third UFOV subtest (i.e., selective attention) in

comparison to both mid-aged and younger participants ( $p<.001$ ), longer simple response time in comparison to younger participants only ( $p=.012$ ), longer choice response time in comparison to mid-aged and younger participants ( $p<.001$ ), poorer performance on Trail Making A in comparison to mid-aged and younger participants ( $p<.001$ ), and poorer performance on Trail Making B in comparison to mid-aged participants only ( $p=.002$ ). All subsequent post-hoc analyses were conducted applying the Bonferonni correction.

### **Demerit Points**

Participants' performance was scored by the experimenter while they drove through the assessment course using the procedure outlined by Bédard and colleagues<sup>31</sup>. At a later date, a blind rater assessed performance by accessing a playback of each participants' simulated drive. The results of the two assessments were then correlated to determine the level of inter-rater reliability for the demerit-point assessment. The results indicated a significant positive correlation of  $r=.82$ ,  $p<.001$ , suggesting a high degree of inter-rater reliability. A composite score was then computed representing the average between the two ratings.

To determine whether there were age differences in demerit points, an analysis of variance was conducted comparing demerit points among the three age groups; the result was statistically significant,  $F(2, 105)=4.06$ ,  $p=.02$ . Post-hoc analysis was then conducted and the results indicated that older adults received significantly more demerit points than mid-aged ( $p=.04$ ) and younger ( $p=.006$ ) participants. No differences were observed between mid-aged and younger drivers ( $p=.62$ ) in terms of demerit points. Means and standard deviations are presented in Table 3.

### **Simulator Recorded Errors**

Simulator recorded errors were also examined by way of an analysis of variance with age group as a between subjects factor. The results indicated a non-significant effect of age on overall errors recorded by the simulator,  $F(2, 105)=.408, p=.666$  (see Table 3). Simulator errors were also examined within each category. Statistically significant effects of age were noted in the frequency of stop signs missed,  $F(2, 108)=5.23, p=.009$ , but not in road edge excursions ( $p=.316$ ), crossing the centerline ( $p=.102$ ), and exceeding the speed limit ( $p=.424$ ). Post-hoc analysis indicated that older drivers missed significantly more stop signs in comparison to young drivers ( $p=.006$ ) only.

### **External Measures Related to Attention and Simulator Performance**

Given that driving relies heavily on attention, it was of interest to examine the degree of relatedness between overall driving performance in the simulator and external cognitive measures related to attention. To this end, Trail Making A and B, simple and choice response time, as well as UFOV scores were correlated with demerit points and simulator recorded errors for each of the three age groups separately. The complete results are presented in Table 4. The most notable findings are as follows. Among mid-aged drivers, choice response time was significantly correlated with demerit points ( $r=.384, p=.044$ ) and simulated recorded errors ( $r=.397, p=.036$ ) while simple reaction time was significantly associated with simulated recorded errors only ( $r=.508, p=.006$ ). Among older drivers, simulator recorded errors and demerit score were highly associated ( $r=.765, p<.001$ ). In addition demerit points were significantly positively correlated with the second component of the UFOV (i.e., divided attention) ( $r=.619, p=.002$ ).

### **Baseline PDT Analyses**

The following analyses were executed to explore the effect of both age and scenario complexity on cognitive load by comparing PDT performance. Prior to completing these analyses, however, it was necessary to examine whether differences in PDT scores while driving could be attributed simply to baseline performance. To obtain an indication of baseline response time to the PDT within the driving simulator, the final eight PDT RTs from the baseline RT scenario (driven before the formal driving assessment) were averaged to create a composite RT score which was then compared between age groups using a one-way ANOVA. The results showed a non-significant effect of age,  $F(2, 107)=1.065, p=.349$ , indicating no baseline differences in response time to the PDT. Thus, any observed differences in PDT performance while driving may be attributed to the relationship between age and road complexity. The mean PDTs for each age group in the baseline scenario were .705 seconds for older drivers, .723 for mid-aged drivers, and .756 for younger drivers. The mean PDTs for each group in the assessment scenario were 2.56 seconds for older, 1.98 for mid-aged, and 1.90 seconds for younger drivers. A difference score was computed by subtracting participants' baseline PDT score from each of the 27 PDT scores throughout the scenario; all succeeding analyses were executed based on this difference score.

### **Straight Roads**

To explore the relationship between age and complexity within the *Straight Roads* category, a  $3 \times 4$  mixed ANOVA was employed, where age group (i.e., young, mid-aged, and older) was considered the between factor and the specific road situation in the category (in this case, the location of other traffic on the road) was considered the within factor. The results are presented in Table 5 and revealed a significant effect of both age,  $F(2, 109)=21.74, p<.001$ , and traffic location,  $F(3, 327)=14.03, p<.001$ , and a non-significant interaction,  $F(6, 327)=.46$ ,

$p=.841$ . The results are displayed graphically in Figure 2. To further examine the differences in attentional demand between situations, all pairwise contrasts between events were executed. Notable results included that the attentional demand associated with having vehicles in front and behind the driver was significantly greater than when there were no vehicles (mean RT difference=.216,  $p=.021$ ), when vehicles were in front of the driver (mean RT difference= .387,  $p<.001$ ) and when vehicles were behind the drivers (mean RT difference= .433,  $p<.001$ ). In order to further explore age-differences in attentional demand, post-hoc procedures were conducted. The results showed that older drivers exhibited significantly greater attentional demand in comparison to both younger (mean RT difference =.611 seconds) and mid-aged (mean RT difference =.559 seconds) participants, but no significant differences were observed between younger and mid-aged participants.

### **Crossing Paths**

Next, to explore age related differences in crossing path situations, a  $3 \times 5$  mixed ANOVA was executed where age was the between factor and the type of manoeuvre at the intersection (i.e., pre-intersection, post intersection, left turn, right turn, or drive straight through the intersection) was treated as the within factor. The results revealed a statistically significant interaction between the two variables,  $F(8, 436)=2.22$ ,  $p=.025$ , as well as a significant effect of age,  $F(2, 109)=18.06$ ,  $p<.001$ , and type of manoeuvre,  $F(4, 436)=121.06$ ,  $p<.001$  (see Figure 3). This interaction indicates that for the crossing path scenarios, the effect of age depends on which manoeuvre is being executed. To further understand the nature of the interaction, simple main effects were performed. To this end, five distinct one-way ANOVAs examining age differences at each manoeuvre were executed (Table 6). The results indicated significant age differences at each of the manoeuvres with the exception of the left turns. The post-hoc analysis confirmed age

differences in attentional demand with older drivers exhibiting greater demand than both younger and mid-aged drivers for all manoeuvres except left turns at intersections; there were, in fact, no significant age differences in attentional requirements at the left turns (see Table 7). No significant differences between young and mid-aged drivers at any of the manoeuvres were observed.

Each of the five situations were also contrasted between one another at each level of age. The results were consistent across all age groups; all drivers exhibited significantly longer PDT RTs in response to both left and right turns in comparison to all other events; no differences in PDT RTs were observed between left and right turns among all age groups. These latter findings suggest that making left and right turns are the most cognitively demanding elements of intersections among all drivers. The ANOVA data for these three road categories are summarized in Table 6.

### **Lane Changes**

A  $3 \times 2$  mixed ANOVA was also used to analyse the *Lane Change* category where age was treated as a between factor and manoeuvre (i.e., lane change versus a no lane change situation of *Straight Roads*, no vehicles) was considered a within factor. The results indicated a significant effect of age,  $F(2, 109) = 15.34, P < .001$ , a significant effect of lane change,  $F(1, 109) = 9.34, p = .003$ , and a non-statistically significant interaction,  $F(2, 109) = 1.26, p = .303$  (see Figure 4). Given that the manoeuvre factor consisted of only two levels, these results indicate that lane changing elicits greater cognitive load for all age groups in comparison to driving straight. Regarding age differences, post-hoc analysis revealed that older drivers exhibited significantly more attentional demand than both young (mean RT difference = .749 seconds) and mid-aged drivers (mean RT difference = .594 seconds).

## DISCUSSION

The purpose of this study was to explore age differences in attentional demand in response to driving situations of varying complexity within the context of a simulated assessment protocol. Specifically, with use of the driving simulator and an embedded measure of attention (i.e., the PDT), we examined how the complexity within naturalistic driving situations affects attentional demand in drivers of three age groups: young, mid-aged, and older. Given that the literature on aging and driving indicates that MVCs among this group result from an interaction between cognitive (i.e., attention) and environmental (i.e., driving complexity) factors, it was hypothesized that as road complexity increased, as would attentional demand. In addition, in comparison to young and mid-aged drivers, older drivers' attentional demand would be greatest.

Three categories of on-road events were identified and the subsequent analyses were grouped accordingly. To mitigate the influence of age-related changes in speed of processing on the interpretation, baseline RTs were subtracted from PDT RTs resulting in a difference score that was used as the dependent variable in all analyses examining attentional demand while driving.

In terms of on road complexity, the results did indeed point to differences in attentional demand within each category of events, independent of age. Within events characterized as occurring on *straight roads*, it was found that attentional demand was greatest when vehicles were both in front and behind the driver. Next, within events categorized as *crossing paths* it was found that both left and right turns resulted in significantly more attentional demand. Unsurprisingly, lane changing was also found to be more demanding than driving straight.

These findings are highly consistent with the literature on road complexity and attention showing that increased driving complexity is associated with poorer performance on tasks

designed to concurrently assess attention<sup>44-46</sup>. Patten and colleagues<sup>46</sup>, for example, sought to examine the effects of route complexity on attention through the use of an instrumented vehicle and PDT task. They found that greater driving environment complexity requires more attentional resources which, in turn, lead to difficulty dividing attention between driving and the secondary task. Fastenmeier<sup>47</sup> described the driving environment as consisting of two components which together constitute driving complexity: information processing and vehicle handling. Indeed, our results demonstrated that, in the context of the *straight roads* situations, when information processing was elevated with vehicles being both in front and behind the driver, attentional demands were greatest. Similarly, we found that performing a manoeuvre, such as changing lanes, placed greater demands on the driver than simply driving straight. All of the *crossing path* situations involved an information processing component (e.g., stop lights, other vehicles) while a segment of them (i.e., left and right turns) also required a complex manoeuvre. Interestingly, it was the situations that combined both of these features that elicited the longest PDT responses from all participant groups, indicating the greatest level of attentional requirement. These findings support our previous findings that demonstrated greatest attentional demand at crossing path scenarios where both handling and information processing complexity were increased<sup>21</sup>. Moreover, research on MVC involvement indicate that drivers take longer to respond to stimuli at intersections and that MVCs at intersections are largely attributed to failing to pay attention to traffic signs and other vehicles<sup>48</sup>.

Reliable effects of age in attentional demand were documented in the three categories of road events. Specifically, main effects of age were observed in both *straight roads* and *lane changes* with older adults exhibiting significantly greater attentional demand in comparison to younger groups. In the *crossing paths* events, older adults were found to exhibit significantly

greater attentional demand in comparison to young and mid-aged drivers, with the sole exception of at left turns; there were no age differences in attentional demand observed at left turns. These findings confirm our suspicion that our previous protocol<sup>21,22</sup> was overly simplistic, and that a scenario's ability to differentiate between age groups is improved if it presents participants with driving events characteristic of naturalistic driving and if it is based on an assessment course previously used to assess driving safety in a reliable and valid manner. Additionally, these findings are directly in line with a recent study by Cantin and colleagues<sup>35</sup> who examined age-related differences in responses to environmental complexity. The study found that attentional demands increased alongside road complexity for all ages and the impact on older drivers was greatest.

Unlike previous studies that have assessed attentional demand by means of a secondary task, one advantage of the protocol described here was the presentation of an assessment protocol which allowed for the collection of global measures of driving safety (i.e., demerit points and simulator recorded errors). Given that driving is heavily reliant on attention, it was also hypothesized that measures external to the driving simulator but related to attention would be associated to these global indicators of overall driving performance. Indeed, three distinct patterns emerged representing the three age-groups. Among young adults, no significant correlations were observed between external cognitive tasks and overall driving performance. This finding was not surprising given that errors among this cohort are rarely attributed to declines in attention, but are instead attributed to other factors such as lack of experience and risk-taking behaviours<sup>49</sup>. Among mid-age drivers significant correlations between measures of response time (i.e., simple response time and choice response time) and outcome measures of driving performance were noted. Finally, among older adults, one of the most striking

correlations was between the UFOV subtest 2 (i.e., divided attention) and demerit points. This latter finding suggests that driving performance among older adults is most associated with the cognitive process of divided attention.

We found a significant effect of age on demerit points where older adults received significantly more demerit points in comparison to younger cohorts during the simulated assessment. Surprisingly, no differences in global simulator-recorded errors were observed between age groups. However, when examining categories of simulator-recorded errors, older adults were found to exceed a greater number of stop signs in comparison to other age groups. The discrepancy between the two measures may be attributed to differing degrees of sensitivity. Specifically, the driving simulator documents errors when driving manoeuvres meet highly specific pre-programmed criteria for what constitutes an error, whereas the demerit point system may identify a wide variety of errors not captured by the simulator. Some examples of errors captured by the demerit system but overlooked by the simulator include tailgating, failing to yield the right of way, or stopping too far from an intersection.

Curious was the observation that baseline PDT responses showed no differences between age groups and yet, statistically significant age differences in measures external to the simulator (e.g., simple and choice response time, Trail Making A, Trail Making B) did emerge in the data, showing older adults to be slower. This inconsistency pointed to the possibility that the striking age differences in attentional demand may have simply been an artifact of slower processing speed among older adults. As a follow-up analysis and to confirm the validity of these findings, all of the aforementioned analyses on PDT RT were re-examined with choice response time as a covariate; the effect of age on PDT RT remained unchanged even after choice response time had

been partialled out of the analysis, adding further support to the notion of increased age being associated with greater attentional demand while driving.

An additional unforeseen finding was the non-significant effect of age while turning left at an intersection, particularly considering that the literature shows an overrepresentation of older adults in MVCs occurring while turning left<sup>53,54</sup>. When examining common MVC configurations in the broader literature, however, we observed that the most frequently reported MVCs among all ages occur at intersections (i.e., crossing paths), representing 28% of all crashes<sup>43</sup>. Given that the literature shows crossing paths to be most difficult for all age groups, as evidenced by them being most frequently reported type of crash, and that participants had a maximum of five seconds to respond to the PDT, it seems reasonable to suspect that this finding may be due to a ceiling effect. More precisely, had the PDT presentation time been extended beyond 5 seconds, it is reasonable to hypothesize that age differences in left turns may have emerged.

While this study was successful in demonstrating significant age differences in attention in response to driving events, it is not without limitations. One such limitation is the nature of the sample of older drivers. For example, unlike the younger and mid-aged sample, males were overrepresented in the older sample of drivers. The older sample also consisted primarily of individuals in the young-old category of older adults (i.e., between the ages of 65 and 74 years) and it is plausible that the magnitude of the effects reported here may not be generalizable to individuals older than 75 years. In addition, the literature indicates that physical and mental health as well as education are a protective factor against cognitive decline associated with aging<sup>50,51</sup>. All of the participants in this study reported to be in good physical and mental health. The lowest level of education attainment in the sample of older drivers was a high school diploma of

which only four individuals possessed; the remaining individuals possessed college, bachelor, Master's and PhD credentials. This distribution of education within the sample is in stark contrast with the broader Canadian population in that of adults between the ages of 65 and 74 years, 38% do not possess a high school diploma while 21% solely possess a high school diploma<sup>52</sup>. It is clear from these data that our sample of older drivers was not representative of the typical older Canadian driver in terms of a number of demographic variables which may limit the generalizability of the results.

In combination with previous research<sup>21, 22</sup>, these results indicate that there are at least two categories of variables that contribute to safe driving: those that exist within the driver (i.e., intrinsic variables) and those that exist within the driving environment (i.e., extrinsic variables). Many interventions aimed at improving safety among older drivers have focused on those variables that exist within the individual. For example, Ball, Edwards and Ross<sup>55</sup> found that speed of processing training improved outcomes related to driving and everyday functions among older adults. Moreover, there is great interest in developing sensitive assessment tools that discriminate safe and unsafe older drivers. For example, the Canadian Driving Research Initiative for Vehicular Safety in the Elderly (Candrive) is a 5 year longitudinal study involving approximately 1,000 older drivers with the goal of developing a screening tool, allowing clinicians to identify which older drivers are unsafe to continue operating a motor vehicle or require further evaluation<sup>56</sup>.

It is important to reiterate that the group of older drivers that participated here were healthy and highly functional and, yet, exhibited striking decrements in a measure of attention in response to driving events as compared to younger groups. Focusing on intrinsic variables, one could maintain the research objective of developing interventions that would bring older drivers'

performance on the PDT task in line with their younger counterparts through training or determine a threshold at which PDT performance is indicative of unsafe driving through assessment.

While the abovementioned approaches are critical lines of research that will inevitably contribute to enhanced road safety, they address only part of the issue. Precisely, extrinsic factors, such as the complexity the roadway environment, must also be considered and there may be strategies to improve situations, such as intersections, so as reduce the handling and information processing complexity and, simultaneously, mitigate the attentional demand associated with the event. Classen and colleagues<sup>57</sup>, for example, have shown that highway design can be improved to facilitate safe driving among older drivers.

The driving simulator is arguably the single best instrument for undertaking such research, as it allows for the measurement of fluctuations in attention that occur in response to systematic manipulations of the driving environment. Like many developed countries, population aging in Canada will represent a permanent demographic shift, resulting in a greater proportion of older road users who may require accommodations to remain safe while driving<sup>58</sup>. In the same way that older adults may benefit from modifications to their home environments to facilitate continued independence, this study makes the case for research that seeks to modify extrinsic factors such as roadway complexity to reduce driving demands and assist populations with reduced attentional capacity, such as older adults, to maintain mobility and independence through driving.

## REFERENCES

1. Mezuk B, Rebok GW. Social Integration and Social Support Among Older Adults Following Driving Cessation. *Journal of Gerontology*. 2008;63B(5):S298-S303.
2. Liddle J, Turpin M, Carlson G, McKenna K. The needs and experiences related to driving cessation for older people *British Journal of Occupational Therapy*. 2008;71(9):379-388.
3. Anstey KJ, Wood J, Lord S, Walker JG. Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev*. Jan 2005;25(1):45-65.
4. Marottoli RA, Richardson ED, Stowe MH, Miller EG, Brass LM, L.M. Cooney Jr. et al. Development of a test battery to identify older drivers at risk for self-reported adverse driving events. *Journal of the American Geriatric Society*. 1998;46:562-568.
5. Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR. Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Vision Science* 1993(34):3110–3123.
6. Ball K, Owsley C, Stalvey B, Roenker DL, Sloane ME, Graves M. Driving avoidance and functional impairment in older drivers. *Accid Anal Prev*. May 1998;30(3):313-322.
7. Trick LM, Enns JT, Vavrik J. Paying attention behind the wheel: a framework for studying the role of attention in driving. *Theoretical Issues in Ergonomics Science*. 2004;5(5):385-424.
8. Hendricks DL, Fell JC, Freedman M. *The relative frequency of unsafe driving acts in serious traffic crashes*. Washington, DC: National Highway Traffic Safety Administration;1999.

9. Barrett GV, Mihal WL, Panek PE, Sterns HL, Alexander RA. Information-processing skills predictive of accident involvement for younger and older commercial drivers. *Industrial Gerontology*. 1977;4:173-182.
10. Dingus TA, Klauer SG, Neale VL, Petersen A, Lee SE, Sudweeks J, et al. *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment*. Washington, DC: National Highway Traffic Safety Admin. (NHTSA).2006.
11. Hoffman L, McDowd JM, Atchley P, Dubinsky R. The role of visual attention in predicting driving impairment in older adults. *Psychol Aging*. Dec 2005;20(4):610-622.
12. Myers RS, Ball KK, Kalina TD, Roth DL, Goode KT. Relation of useful field of view and other screening tests to on-road driving performance. *Percept Mot Skills*. Aug 2000;91(1):279-290.
13. Langford J, Koppela S. Epidemiology of older driver crashes – Identifying older driver risk factors and exposure patterns. *Transportation Research Part F: Traffic Psychology and Behaviour*. 2006;9(5):309-321.
14. McGwin G Jr, Brown DB. Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis and Prevention*. 1999;31:181-198.
15. Hakamies-Blomqvist L. Aging and fatal accidents in male and female drivers. *J Gerontol*. Nov 1994;49(6):S286-290.
16. Summala H, Mikkola T. Fatal Accidents among Car and Truck Drivers: Effects of Fatigue, Age, and Alcohol Consumption *Human Factors: The Journal of the Human Factors and Ergonomics Society*. 1994;36(2):315-326.
17. Larsen L, Kines P. Multidisciplinary in-depth investigations of head-on and left-turn road collisions. *Accident Analysis and Prevention*. 2002;34(3):367-380.

18. Keskinen E, Ota H, Katila A. Older drivers fail in intersections: speed discrepancies between older and younger drivers. *Accid Anal Prev.* 1998;30(3):323-330.
19. Clarke DD, Ward P, Bartle C, Truman W. Older drivers' road traffic crashes in the UK. *Accid Anal Prev.* Jul 2010;42(4):1018-1024.
20. Fastenmeier W. Autofahrer und Verkehrssituation. Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Strassenverkehrssysteme. Köln: Verlag TÜV Rheinland GmbH; Bonn: Deutscher Psychologenverlag. 1995.
21. Stinchcombe A, Gagnon S. Driving in dangerous territory: complexity and road-characteristics influence attentional demand. *Transportation Research Part F: Traffic Psychology and Behaviour.* 2010;13(66):388-396.
22. Stinchcombe A, Gagnon S. Aging and driving in a complex world: exploring age differences in attentional demand while driving *Transportation Research Part F: Traffic Psychology and Behaviour.* submitted.
23. Odenheimer GL, Beaudet M, Jette AM, Albert MS, Grande L, Minaker KL. Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. *J Gerontol.* Jul 1994;49(4):M153-159.
24. Lee HC, Cameron D, Lee AH. Assessing the driving performance of older adult drivers: on-road versus simulated driving. *Accid Anal Prev.* Sep 2003;35(5):797-803.
25. Roenker DL, Cissell GM, Ball KK, Wadley VG, Edwards JD. Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors.* Summer 2003;45(2):218-233.

26. Korner-Bitensky N, Sofer S. The DriveABLE Competence Screen as a predictor of on-road driving in a clinical sample. *Australian Occupational Therapy Journal*. 2009;56(3):200-205.
27. Carr D, Jackson TW, Madden DJ, Cohen HJ. The effect of age on driving skill. *Journal of the American Geriatric Society*. 1992;40:567-573.
28. Shechtman O, Awadzi KD, Classen S, Lanford DN, Joo Y. Validity and critical driving errors of on-road assessment for older drivers. *Am J Occup Ther*. Mar-Apr 2010;64(2):242-251.
29. Kay L, Bundy A, Clemson L, Jolly N. Validity and reliability of the on-road driving assessment with senior drivers. *Accid Anal Prev*. Mar 2008;40(2):751-759.
30. Boyle LN, Lee JD. Using driving simulators to assess driving safety. *Accid Anal Prev*. 2010;42(3):785-787.
31. Bédard M, Parkkari M, Weaver B, Riendeau J, Dahlquist M. Assessment of driving performance using a simulator protocol: Validity and reproducibility. *American Journal of Occupational Therapy*. 2010;64:336-340.
32. Shechtman O, Classen S, Awadzi KD, Mann W. Comparison of Driving Errors Between On-the-Road and Simulated Driving Assessment: A Validation Study. *Traffic Injury Prevention*. 2009;10:379-385.
33. Rizzo M, Sheffield, R. A., Stierman, L. & Dawson, J. Demographic and driving performance factors in simulator adaptation syndrome. *Symposium conducted at the Second International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. Vol Park City, Utah 2003.

34. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of psychiatric research*. 1975;12(3):189-198.
35. Cantin V, Lavallière M, Simoneau M, Teasdale N. Mental workload when driving in a simulator: Effects of age and driving complexity. *Accid Anal Prev*. 2009;41:763-771.
36. Cyr A-A, Yamin S, Bélanger A, Gagnon S, Hing M, Marshall S. Effect of old age on dual task performance during driving simulations of varying complexities. *Advances in Transportation Studies: an International Journal*. 2006;Special Issue:31-44.
37. Cyr A-A, Stinchcombe A, Gagnon S, Marshall S, Man-Son-Hing M, Finestone H. Driving difficulties of brain-injured drivers in reaction to high-crash-risk simulated road events: A question of impaired divided attention? *Journal of Clinical and Experimental Neuropsychology*. 2009;31(4):472-482.
38. Weaver B, Bédard M, McAuliffe J, M. P. Using the attention network test to predict driving test scores. *Accid Anal Prev*. 2009;41:76-83.
39. Stutts J. Do Older Drivers with Visual and Cognitive Impairments Drive Less? *Journal of the American Geriatrics Society*. 1998;46(7):854-861.
40. De Raedt R, Ponjaert-Kristoffersen I. Short cognitive/neuropsychological test battery for first-tier fitness-to-drive assessment of older adults. *The Clinical Neuropsychologist*. 2001;15(3):329-336.
41. Marottoli RA, Richardson ED, Stowe MH, et al. Development of a test battery to identify older drivers at risk for self-reported adverse driving events. *Journal of the American Geriatric Society*. 1998;46:562-568.

42. Stinchcombe A, Weaver B, Johnson M, Bédard M. Heart rate response to simulated driving and UFOV. *Annual meeting of the Stisim Drive User Group*. Vol Cambridge, Massachusetts. 2006.
43. Najm WG, Sen B, Smith JD, Campbell BN. *Analysis of light vehicle crashes and pre-crash scenarios based on the 2000 General Estimates*. Washington, DC: National Highway Traffic Safety Administration, US Department of Transportation;2003.
44. Horberry T, Anderson J, Regan MA, Triggs TJ, Brown J. Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accid Anal Prev*. 2006;38(1):185-191.
45. Patten CJ, Kircher A, Ostlund J, Nilsson L. Using mobile telephones: cognitive workload and attention resource allocation. *Accid Anal Prev*. 2004;36(3):341-350.
46. Patten CJ, Kircher A, Ostlund J, Nilsson L, Svenson O. Driver experience and cognitive workload in different traffic environments. *Accid Anal Prev*. 2006;38(5):887-894.
47. Fastenmeier W. Autofahrer und Verkehrssituation. Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Strassenverkehrssysteme. Köln: Verlag TÜV Rheinland GmbH; Bonn: Deutscher Psychologenverlag. 1995.
48. Liu BS, Lee YH. In-vehicle workload assessment: effects of traffic situations and cellular telephone use. *J Safety Res*. 2006;37(1):99-105.
49. Macdonald WA. *A review of information on young driver performance characteristics and capacities*: Monash University Accident Research Centre;1994.

50. Kliegel M, Zimprich D, Rott C. Life-long intellectual activities mediate the predictive effect of early education on cognitive impairment in centenarians: a retrospective study. *Aging Ment Health*. Sep 2004;8(5):430-437.
51. Muscari A, Giannoni C, Pierpaoli L, et al. Chronic endurance exercise training prevents aging-related cognitive decline in healthy older adults: a randomized controlled trial. *Int J Geriatr Psychiatry*. Oct 2010;25(10):1055-1064.
52. Statistics Canada. Highest Certificate, Diploma or Degree (14), Age Groups (10A) and Sex (3) for the Population 15 Years and Over of Canada, Provinces, Territories, Census Metropolitan Areas and Census Agglomerations, 2006 Census - 20% Sample Data. 2006; <http://www.statcan.gc.ca>. Accessed April 12, 2011.
53. Staplin L, Fisk AD. A cognitive engineering approach to improving signalized left turn intersections. *Hum Factors*. Oct 1991;33(5):559-571.
54. Mayhew DR, Simpson HM, Ferguson SA. Collisions involving senior drivers: high-risk conditions and locations. *Traffic Inj Prev*. Jun 2006;7(2):117-124.
55. Ball K, Edwards JD, Ross LA. The impact of speed of processing training on cognitive and everyday functions. *J Gerontol B Psychol Sci Soc Sci*. Jun 2007;62 Spec No 1:19-31.
56. Candrive. Canadian Driving Research Initiative for Vehicular Safety in the Elderly. 2011; <http://www.candrive.ca>.
57. Classen S, Shechtman O, Stephens B, Davis E, Bendixen R, Belchior P, Sandhu M, Justiss M, Posse C, McCarthy, D, Mann, W. The impact of roadway intersection design on driving performance of young and senior adults: Preliminary results. *Topics in Geriatric Rehabilitation*. 2006; 22(1):18-26.

- 58.** Special Senate Committee on Aging. *Canada's Aging Population: Seizing the Opportunity*. Ottawa, Ontario: The Senate;2009.

*Figure 1.* STISIM driving simulator.



Figure 2. Average response times between age groups in the *Straight Roads* category of road situation, with four types of situation in which the PDT appeared.

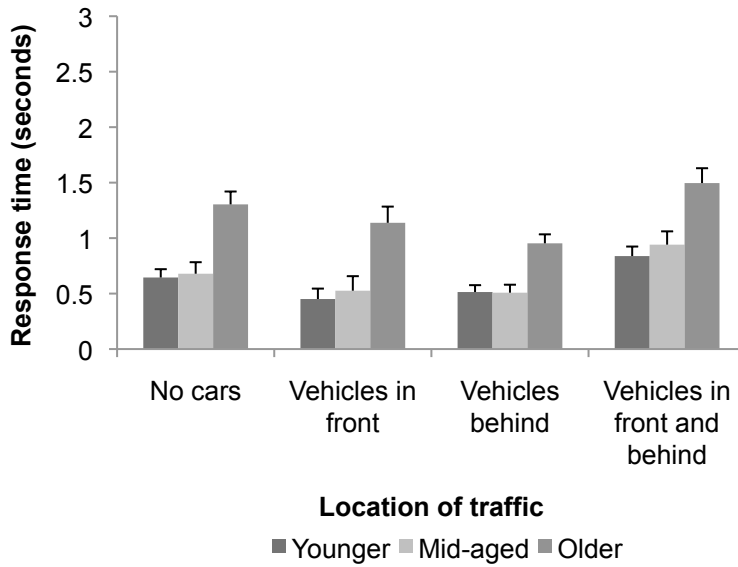


Figure 3. Average response times between age groups in the *Crossing Paths* category of road situation, with five types of situation in which the PDT appeared.

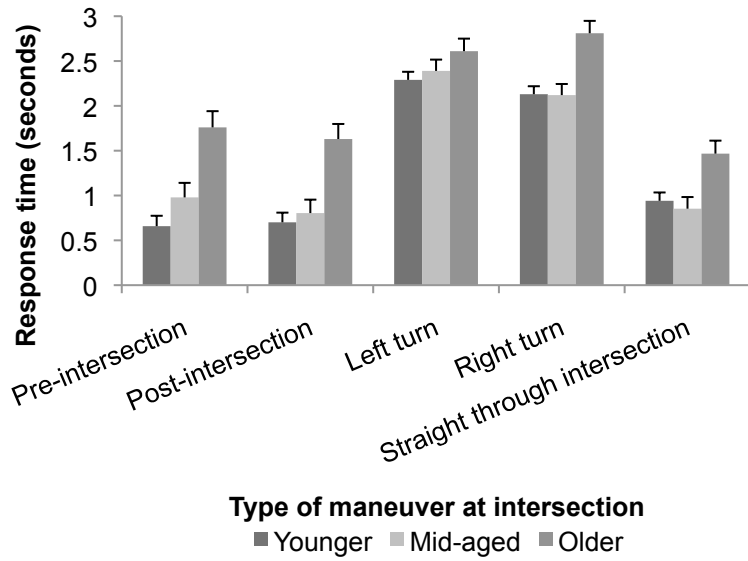


Figure 4. Average response times between age groups in the *Lane Change* category of road situation, compared against a baseline of *Straight Road, No Vehicles*.

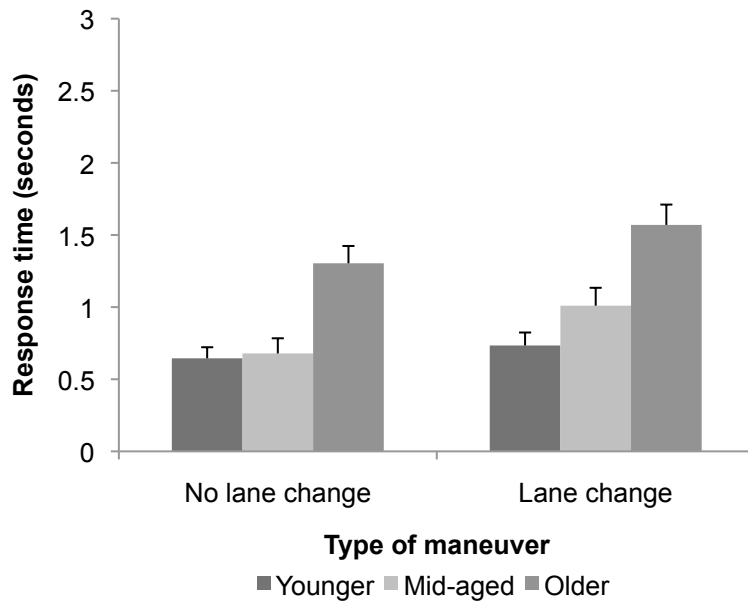


Table 1

*Mean response times and standard deviations in seconds of 26 PDTs classified by road situation*

Category	PDT featured	RT (mean)	SD
<b>Straight Roads</b>			
No vehicles	3, 7, 10	.878	.059
Vehicles in front	16, 18	.716	.074
Vehicles behind	9, 13, 21	.660	.041
Vehicles in front and behind	1, 24	1.1	.068
<b>Crossing Paths</b>			
Straight through intersection	14, 22	1.147	.092
Pre-intersection	4, 15	1.058	.085
Post-intersection	5, 27	2.422	.070
Left turn	17, 20, 23	2.363	.070
Right turn	6, 12, 19, 25	1.088	.074
<b>Lane Changes</b>			
None	8, 11, 26	.878	.059
Straight road, no vehicles	3, 7, 10	1.10	.069

Table 2

*Average performance across groups on attention and response time tests*

Task	Age group	Mean	SD	F (p)
Selective attention (UFOV)				23.92 (<.001)
	Young	86.29	63.03	
	Mid-aged	81.42	86.06	
	Older	193.90	55.99	
Simple RT				6.37(.002)
	Young	226.80	24.99	
	Mid-aged	245.33	34.44	
	Older	247.23	29.08	
Choice RT				32.30(<.001)
	Young	314.80	39.39	
	Mid-aged	322.65	42.22	
	Older	445.66	128.00	
Trail Making A				35.41(<.001)
	Young	24.89	5.51	
	Mid-aged	26.73	7.24	
	Older	39.70	10.81	
Trail Making B				6.21(.003)
	Young	59.98	22.36	
	Mid-aged	50.97	14.65	
	Older	63.39	20.80	

*Note.* RT (response time) and SD (standard deviation) are measured in seconds.

Table 3

*Mean and standard deviations of demerit points and simulator recorded errors*

Age group	Mean	SD	F (p)
Demerit points			4.06(.020)
Young	54.18	23.04	
Mid-aged	57.33	26.24	
Older	73.80	39.33	
Simulator recorded errors			.408(.666)
Young	26.63	6.43	
Mid-aged	25.83	6.56	
Older	25.14	8.06	

Table 4

*Correlations between driving performance and external measures*

Age group	Variable	Demerit points r (p)	Simulator errors r (p)
Young	Demerit points	-	-
	Simulator errors	-.102(.454)	-
	UFOV 3	-.127(.361)	-.052(.711)
	Simple RT	.261(.055)	-.105(.446)
	Choice RT	.253(.065)	-.197(.150)
	Trail Making A	-.176 (.199)	.162(.236)
	Trail Making B	-.068(.624)	.188(.170)
Mid-aged	Demerit points	-	-
	Simulator errors	.273(.145)	-
	UFOV 3	-.115(.553)	-.052(.790)
	Simple RT	.141 (.475)	.508(.006)*
	Choice RT	.384(.044)*	.397(.036)*
	Trail Making A	.002(.990)	.118(.534)
	Trail Making B	-.005(.978)	.148(.435)
Older	Demerit points	-	-
	Simulator errors	.765(<.001)*	-
	UFOV 1	.293(.174)	.014(.951)
	UFOV 2	.619(.002)*	.349(.112)
	UFOV 3	.302(.162)	.274(.218)
	Simple RT	.190(.384)	.183(.416)
	Choice RT	.215(.324)	.088(.696)
	Trail Making A	-.060(.787)	-.097(.666)
	Trail Making B	.277(.200)	.184(.413)

Table 5

*Significance values for mixed ANOVA analyses on dual task response times on straight roads, crossing paths, and lane changes sections*

Road situation	Factors	<i>F</i> value	Significance
Straight roads	Within group (location of traffic)	14.03	<.001
	Between groups (age)	21.74	<.001
	Location of traffic × age group	.46	.841
Crossing paths	Within group (type of manoeuvre)	121.06	<.001
	Between groups (age)	18.06	<.001
	Type of manoeuvre × age group	2.22	.025
Lane changes	Within group (lane change present)	9.34	.003
	Between groups (age)	15.34	<.001
	Lane change present × age group	1.26	.303

Table 6

*One-way ANOVAs examining the interaction effect in the Crossing Paths sections*

Crossing Paths situation	df	Mean Square	<i>F</i> value	Significance
Pre-intersection	2	10.29	13.08	<.001
Post-intersection	2	7.59	11.17	<.001
Left turn	2	.91	1.92	.152
Right turn	2	4.07	8.86	<.001
Straight through intersection	2	2.99	5.91	.004

Table 7

*Post-hoc analysis of the Crossing Paths category of road scenario*

Crossing Paths situation	Age group	Comparison group	Mean difference
Pre-intersection	Younger	Mid-aged	-.32078
		Older	-1.10116*
Post-intersection	Mid-aged	Younger	.32078
		Older	-.78037*
	Younger	Mid-aged	-.10344
		Older	-.92602*
Left Turn	Mid-aged	Younger	.10344
		Older	-.82258*
	Younger	Mid-aged	-.09379
		Older	-.32714
Right Turn	Mid-aged	Younger	.09379
		Older	-.23335
	Younger	Mid-aged	-.07227
		Older	-.67777*
Straight through intersection	Mid-aged	Younger	.07227
		Older	-.60550*
	Younger	Mid-aged	.08775
		Older	-.52592*
	Mid-aged	Younger	-.08775
		Older	-.61367*

*Note.* \* denotes statistical significance at .01 level.

## CHAPTER 5

### GENERAL DISCUSSION

The overarching goal of the preceding studies was to explore the attentional demands of driving events of varying complexity among young, mid-aged, and older drivers. The rationale behind this line of inquiry followed from the scientific literature documenting frequent occurrence of MVCs at highly precise road configurations, specifically while crossing paths or while following another vehicle (Najm, Sen, Smith, & Campbell, 2003). Moreover, the cognitive process of attention has been identified in the literature as being predictive of driving performance (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Patten, Kircher, Ostlund, & Nilsson, 2004; Summala & Mikkola, 1994), and aging has been associated with a decrease in attention as well as an increased risk for MVCs. These findings from the scientific literature led to the fundamental hypothesis that ultimately guided this thesis. Specifically, it was hypothesized that MVCs occur as a result of a highly complex driving environments which strain the driver's attentional resources and lead to costly driving errors. Given that older adults have been shown to have decreases in attention, it was also predicted that this effect that would be more pronounced among older drivers in comparison to other age groups.

Prior to the development of an experimental protocol and the collection of data, it was necessary to operationally define the constructs under scrutiny, based on the scientific literature. Driving is a multifactorial task, drawing on countless cognitive and behavioural processes. The task of driving was operationalized according to Michon's 3-level hierarchical model of driver behaviour, a model that has proven to be robust when understanding the challenges of older adults (Unsworth et al., 2005). Michon's hierarchical model contends that driving may be compartmentalized in terms of strategical elements (e.g., route planning, self regulation, etc),

tactical elements (e.g., steering, using the gas and brake, etc), and operational elements (e.g., processing speed, attention, etc.).

The complexity of the driving environment was characterized according to Fastenmeier's (1995) taxonomy where the environment is described in terms of the information processing (high vs low) and vehicle handling demands (high vs low). Information processing demands are those that primarily result from visual elements in the roadway while vehicle handling demands are those that result from steering and braking.

Finally, attentional demands associated with driving were assessed via the cognitive workload approach, a paradigm in which participants complete a secondary task, in this case the PDT, while driving (Cantin, Lavallière, Simoneau, & Teasdale, 2009; Stinchcombe & Gagnon, 2010).

With this core hypothesis and fundamental variables in hand, three studies were conducted, each acting as a springboard upon which to explore increasingly specific inquiries.

#### *Summary of Results*

In the first study, "Driving in dangerous territory: Complexity and road-characteristics influence attentional demand", it was of interest to examine the interplay between attentional resources and the driving environment. To this end, a series of simulated driving scenarios resembling common crash situations were developed and were manipulated according to Fastenmeier's (1995) characterization of driving complexity. Inexperienced drivers completed 20 simulated driving scenarios that varied systematically in terms of their information processing and vehicle handling demands. Attentional demands were recorded by means of objective (i.e., PDT) and subjective (i.e., NASA-TLX) measures.

The results of the first study indicated that increasing information processing demands within a scenario led to a significant increase in the attentional requirement of the task. The sample reported no additional strain of completing the PDT during the scenario, pointing to its usefulness as a measure of attention.

The successful implementation of the abovementioned protocol proved valuable in examining the intricate interplay between environmental complexity and attentional demand, and pointed to the robustness and sensitivity of the experimental approach. It was of great interest to apply this framework to a population known to exhibit decrements in attention that affect driving.

As such, the second study, entitled “Aging and driving in a complex world: exploring age differences in attentional demand while driving”, examined differences in attentional demands associated with driving between mid-aged and older drivers. In this analysis, information processing demands consistently served to increase attentional demands among all drivers. As no main effects of age were observed in the data, it was noted that the presented scenarios may not have been sufficiently complex to reveal age differences, particularly given that the older sample consisted primarily of well-educated, healthy individuals with an average age of 71 years. A brief discussion of the nature of complexity was presented and it was proposed that the complexity associated with driving is likely situated on a continuum rather than in dichotomous high vs. low framework. Along these lines, it was determined that subsequent studies seeking to examine age-differences in attention and driving would benefit from an ecologically-valid scenario that approximates naturalistic driving.

The third study, “Fluctuating attentional demand in a simulated driving assessment: the roles of age and driving complexity”, sought to address the shortcomings of the second study

while still examining age differences in the attentional demands associated with driving. To this end, drivers from three age cohorts (i.e., young, mid-aged, and older) completed a simulated driving course based on a standardized assessment protocol used by a Canadian Ministry of Transportation. In addition, cognitive tasks external to the simulator but related to attention were completed and compared with performance in the driving simulator. Consistent with the hypothesis that driving performance among older adults is related to attention, a significant correlation between a widely accepted measure of attention (i.e., UFOV divided attention subtest) and demerit points in the simulator was observed for the older cohort only. Additionally, amongst the analyses that contrasted PDT performance across age groups, main effects of age consistently emerged with older adults exhibiting greater attentional demand when faced with a variety of driving situations. Interestingly, an effect of age was also observed in the demerit-points recorded by a rater in that older adults performed poorer than the other cohorts; in contrast, no differences were observed in simulated recorded errors.

### *Implications & Considerations*

In combination with the existing literature, the three studies conducted here provide substantial evidence for the role of attention in driving. In particular, consistent with the literature (e.g., Patten, et al., 2004; Patten, Kircher, Ostlund, Nilsson, & Svenson, 2006), in all three studies it was observed that as complexity associated with the driving environment increases, performance on a measure of attentional demand decreases. This finding was found to be robust as it was observed in two studies that were highly systematized (studies 1 and 2) as well as in an assessment scenario similar to naturalistic driving (study 3). One may postulate that the relationship between road complexity and attention represents an inverse relationship in that as the number of visual stimuli in the driving environment increases, one's ability to effectively

attend and respond to stimuli decreases, increasing the potential for driving errors (e.g., Cairney & Gunatillake, 2000; Horberry, Anderson, Regan, Triggs, & Brown, 2006). While this hypothesis certainly existed in the literature, the results of the first two studies in this thesis supported this notion by means of a systematic and experimentally controlled paradigm. This finding may also explain why most MVCs occur at intersections; the complexity associated with attending to other vehicles, traffic signals, and pedestrians while concurrently manoeuvring proves difficult for all drivers, increasing the opportunity for error.

These consistent findings related to the relationship between complexity and attention were made possible through the utilization of an embedded secondary task. Indeed, in the studies described here, the PDT proved to be a direct and sensitive measure of the underlying cognitive mechanisms upon which driving relies. While this thesis showcases the usefulness of the PDT in exploring the interplay between intrinsic and extrinsic factors associated with driving, it equally opens the opportunity for the adaptation of the PDT into the realm of assessment. Specifically, it was demonstrated that the PDT may be successfully implemented within an assessment course and, as such, this paradigm could be applied to the assessment process of clinical populations who are known to have deficits in attention, such as individuals who have suffered traumatic brain injury or stroke. The field of driving assessment would benefit greatly if future research sought to determine a threshold of PDT performance at which driving safety becomes compromised.

The impact of complexity on attention was assessed through the PDT method and resulted in dramatic age-differences in the third study while no effect of age was observed in the second study. In the second study, the experimental paradigm was cast through Fastenmeier's (1995) classification scheme which states that driving complexity may be broken down into

vehicle handling and information processing elements, each of which have two levels (i.e., high vs. low). In the discussion of the second study, it was proposed that complexity may be more accurately characterized as existing on a continuum rather than as a dichotomy as Fastenmeier (1995) proposed. Indeed, given that the second study failed to show age differences in attentional demand, it seems reasonable that the Fastenmeier (1995) approach may have been overly simplistic to account for the wide variety of situations faced while driving. It would be a valuable contribution for future research to examine the nature of this continuum by identifying indicators that could be used to empirically situate driving scenarios on this continuum of complexity.

A common finding in the scientific literature is that older adults engage in behaviours (referred to as self-regulatory or compensatory behaviours) to compensate for their driving difficulties (Brouwer & Ponds, 1994; De Raedt & Ponjaert-Kristoffersen, 2000). Examples of compensatory behaviours that have been well-documented in the literature include reducing speed, avoidance of highways, avoidance of unnecessary turns, and driving at non-peak hours (e.g., Rimmö & Hakamies-Blomqvist, 2002; Simoes, 2002). Indeed, the findings presented in the third study assist in elucidating this pattern of behaviour among older drivers. Precisely, it was demonstrated that even in a healthy and educated segment of the older adult population, decrements in attention while driving were observed. These compensatory strategies effectively reduce the complexity of the driving environment and, in doing so, also reduce the strain on attentional resources. For example, if a driver chooses to take a route requiring fewer turns, the handling complexity of the trip is significantly reduced. Similarly, driving at non-peak hours reduces the information processing complexity associated with attending and reacting to other road users. Along these lines, De Raedt and Ponjaert-Kristoffersen's (2000) work demonstrated

the interaction between the three levels of Michon's model of driving behaviour in that despite operational deficits (e.g., reduced attention), older drivers engaged in strategic and tactical compensation and thereby improve their on-road safety.

While the adoption of compensatory behaviours by older adults can improve road safety, there are also factors external to the driver that could be modified which would also contribute to this outcome. More specifically, as detailed in the conclusion of the third study, this research points to the roles of both intrinsic factors and extrinsic factors that, together, contribute to safe driving. Extrinsic factors, such as the complexity of the roadway environment, must also be considered and there may be strategies to improve situations, such as intersections, so as to reduce the handling and information processing complexity and, in doing so, mitigate the attentional demand associated with the event. In the same way that older drivers adapt their driving behaviours to meet their cognitive limitations, targeted modifications to the driving environment may also serve to lessen the cognitive demands associated with driving and thereby improve road safety. Indeed, Classen and colleagues (2006), for example, have shown that highway design can be improved to facilitate safe driving among older drivers. The driving simulator is arguably the single best instrument for undertaking such research, as it allows for the measurement of fluctuations in attention that occur in response to systematic manipulations of the driving environment.

The use of a driving simulator proved to exhibit a number of advantageous within the context of the studies executed herein. First, this apparatus allowed for development of replicable and experimentally controlled protocol, two important characteristics in the domain of cognitive psychology. Second, the driving simulator also permitted the safe collection of data indicative of driving behaviour without even the slightest risk of injury resulting from a real-life

MVC. Third, the addition of the PDT in the simulated scenario facilitated the assessment of the attentional demands of specific driving situations. These advantages point to the value of the driving simulator in both research and practice contexts. In a research environment, variables need to be carefully manipulated based on a predetermined set of hypotheses and the potential harm to participants must be reduced as much as is possible. In a practice context, driving simulators have not traditionally been employed for assessment purposes. However, the studies described here suggest the usefulness of measuring cognitive variables in relation to the driving environment within an assessment protocol; the simulator may also be used to accomplish this objective.

### *Conclusions*

Older adulthood is a complex period in life. During this time, many individuals report a great deal of well-being and social connectedness (Cornwell, Laumann, & Schumm, 2008). Unfortunately, aging is also associated with diagnosis of chronic medical conditions, an increase in medication use, and a reduction in mobility (Guralnik, LaCroix, Abbott, & al., 1993; Public Health Agency of Canada, 2011). Moreover, aging is associated with a decrease in cognitive performance, notably attention, which negatively impacts driving performance (Anstey et al., 2005). On the one hand, driving cessation among older adults is linked to a reduction in social contacts, negative psychological health, and even mortality (Edwards, Perkins, Ross, & Reynolds, 2009); on the other hand, crash risk increases significantly among older adults once distance driven is considered (Lyman, Ferguson & Williams, 2002; Stamatiadis, 1996; Stamatiadis & Deacon, 1997).

This dissertation was successful in elucidating the challenges of older drivers in response to scenarios of varying complexity. Attention was found to fluctuate according to environmental

complexity and attentional demands were found to be greater for older adults in comparison to younger adults only when driving a scenario that mimicked naturalistic driving. These findings should not be construed as evidence that all older drivers exhibited attentional impairments, making them unsafe drivers. On the contrary, the older drivers that participated in the present analysis were healthy with no recent history of MVCs. Based on the literature it is likely that unsafe older drivers have been diagnosed with multiple medical conditions and are taking several medications, which, in turn, negatively affect cognitive function, including attention. Although the work described here presents a means of assessing attention in a way that is most relevant to driving, future research is needed to explicate the precise relationship between attentional performance while driving and crash risk.

The public safety issue surrounding older drivers is not likely to be solved by any single intervention, but may be mitigated by a combination of efforts bolstered by empirically-derived research findings. Of these efforts, valid assessment, license restrictions, cognitive training, promotion of compensatory behaviours, as well vehicle and environmental adaptations that take attentional limitations into consideration, are likely to facilitate safe driving among seniors. Ultimately, driving cessation may be an inevitable outcome for some drivers in the case where significant physical (e.g., arthritis) or cognitive (e.g., Alzheimer's disease) impairments prohibit continued safety.

Driving is a primary means of mobility among seniors and, given Canada's aging population, it will be necessary to explore supportive options that allow for the maintenance of safe driving privileges as well as encourage the preservation of mobility among individuals who can no longer drive safely.

## References

- Agent, K., & Deen, R. (1975). Relationship between roadway geometrics and accidents. *Transportation Research Record, 541*, 1-11.
- Anstey, K. J., Wood, J., Lord, S., & Walker, J. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65.
- Augenstein, J. (2001). Differences in clinical response between the young and the elderly. *Paper presented at the Aging and Driving Symposium, Association for the Advancement of Automotive Medicine.*
- Ball, K., Beard, B., Roenker, D. L., Miller, R., & Griggs, D. (1988). Age and visual search: expanding the useful field of view. *Journal of the Optical Society of America A, 5*, 2210-2219.
- Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science, 34*(11), 3110-3123.
- Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis and Prevention 30*, 323-330.
- Barrett, G. V., Mihal, W. L., Panek, P. E., Sterns, H. L., & Alexander, R. A. (1977). Information-processing skills predictive of accident involvement for younger and older commercial drivers. *Industrial Gerontology, 4*, 173-182.
- Battiste, V., & Bortolussi, M. R. (1988). Transport pilot workload: a comparison of two objective techniques. *Paper presented at the Human Factors Society 32nd Annual Meeting.*

- Baltes, P.B., Staudinger, U.M., & Lindenberger, U. (1999). Lifespan psychology: theory and application to intellectual function. *Annual Review of Psychology, 50*, 471-507.
- Beane, M., & Marrocco, R. (2004). Cholinergic and Noradrenergic Inputs to the Posterior Parietal Cortex Modulate the Components of Exogenous Attention. In M. I. Posner (Ed.), *Cognitive Neuroscience of Attention*. New York: The Guilford Press.
- Bédard, M., Leonard, E., McAuliffe, J., Weaver, B., Gibbons, C., & Dubois, S. (2006). Visual attention and older drivers: the contribution of inhibition of return to safe driving. *Experimental Aging Research, 32*(2), 119-135.
- Bedard, A.-C., Nichols, S., Barbosa, J. A., Schachar, R., Logan, G. D. & Tannock, R. (2002). The development of selective inhibitory control across the life span. *Developmental Neuropsychology, 21*, 93-111.
- Begg, D., & Langley, J. (2001). Changes in risky driving behavior from age 21 to 26 years. *Journal of Safety Research, 32* (4), 491-499.
- Broadbent, D. E. (1958). *Perception and communication*. London: Pergamon Press.
- Brouwer, W. H., & Ponds, R. W. (1994). Driving competence in older persons. *Disability and Rehabilitation, 16*(3), 149-161.
- Brinley, J. F. (1965). Cognitive sets, speed and accuracy of performance in the elderly. In A. T. Welford, & J. E. Birren (Eds.), *Behavior, aging, and the nervous system* (pp.114-149). Springfield, IL: Thomas.
- Caird, J., Edwards, J. D., Creaser, J. I., & Horrey, W. J. (2005). Older Driver Failures of Attention at Intersections: Using Change Blindness Methods to Assess Turn Decision Accuracy. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 47*(2), 235-249

- Cairney, P., & Gunatillake, T. (2000). *Roadside Advertising Signs-A Review of the Literature and Recommendations for Policy*. Royal Automobile Club of Victoria.
- Canadian Institutes for Health Research. (2006). *The CIHR Institute of Aging Strategic Plan 2007 to 2012*. Vancouver, BC: Canadian Institutes of Health Research.
- Cantin, V., Lavallière, M., Simoneau, M., & Teasdale, N. (2009). Mental workload when driving in a simulator: Effects of age and driving complexity. *Accident Analysis and Prevention, 41*, 763-771.
- Chapman, P. R., & Underwood, G. (1998). Visual search of driving situations: Danger and experience. *Perception, 27*, 951-964.
- Clarke, D. D., Ward, P., & Truman, W. (2005). Voluntary risk taking and skill deficits in young driver accidents in the UK. *Accident Analysis & Prevention, 37*(3), 523-529.
- Classen, S., Schetman, O., Burton, S., Davis, E., Bendixen, R., Belchior, P., Sandhu, M., Justiss, M., Posse, C., McCarthy, D., & Mann, W. (2006). The Impact of roadway intersection design on driving performance of young and senior Adults. *Topics in Geriatric Rehabilitation, 22* (1), 18-26.
- Clay, O. J., Wadley, V. G., Edwards, J. D., Roth, D. L., Roenker, D. L., & Ball, K. (2005). Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: current and future implications. *Optometry and vision science, 82*(8), 724-731.
- Corwin, W. H., Sandry-Garza, D. L., Biferno, M. H., Boucek, G. P., Logan, A. L., Jonsson, J. E., et al. (1989). *Assessment of crew workload measurement methods, techniques, and procedures*: Wright-Patterson Air Force Base, OH.

- Cornwell, B., Laumann, E. O., & Schumm, L. P. (2008). The Social Connectedness of Older Adults: A National Profile. *Am Sociol Rev*, 73(2), 185-203.
- Craik, F. I. M., Anderson, N. D. Kerr, S. A., & Li, K. Z. H. (1996) Memory changes in normal ageing. In. A. D. Baddeley, B. A. Wilson, & F. N. Watts (Eds.), *Handbook of memory disorders* (pp. 211-241). New York: Wiley.
- Cyr, A.-A., Stinchcombe, A., Gagnon, S., Marshall, S., Man-Son-Hing, M., & Finestone, H. (2009 ). Driving difficulties of brain-injured drivers in reaction to high-crash-risk simulated road events: A question of impaired divided attention? *Journal of Clinical and Experimental Neuropsychology*, 31 (4 ), 472 - 482
- Cyr, A.-A., Yamin, S., Bélanger, A., Gagnon, S., Hing, M., & Marshall, S. (2006). Effect of old age on dual task performance during driving simulations of varying complexities. *Advances in Transportation Studies: an International Journal, Special Issue*, 31-44.
- Davidson, D. J. Zacks, R. T. & Williams, C. C. (2003). Stroop interference, practice, and aging. *Neuropsychological Development and Cognition*. 10(2): 85-98.
- D’Cuhna, C. (2003). *Injury: Predictable and preventable, in 2002 Chief Medical Officer of Health Report*. Toronto: Queen's Printer for Ontario.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2000). Can strategic and tactical compensation reduce crash risk in older drivers? *Age and Ageing*, 29, 517-521.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2001). Short cognitive/neuropsychological test battery for first-tier fitness-to-drive assessment of older adults. *The Clinical Neuropsychologist*, 15(3), 329-336.
- Deutsch, J., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review*, 70, 80-90.

- Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., et al. (2006). *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment*. Washington, DC: National Highway Traffic Safety Admin. (NHTSA).
- Dobbs, B. M., Carr, D. B., & Morris, J. C. (2002). Evaluation and management of the driver with dementia. *The Neurologist*, 8(2), 61-70.
- Doherty, S. T., Andrey, J. C., & MacGregor, C. (1998). The situational risks of young drivers: The influence of passengers, time of day and day of week on accident rates. *Accident Analysis & Prevention*, 30(1), 45-52.
- Edwards, J. D., Perkins, M., Ross, L. A., & Reynolds, S. L. (2009). Driving status and three-year mortality among community-dwelling older adults. *J Gerontol A Biol Sci Med Sci*, 64(2), 300-305.
- Environment Canada. (1996). The state of Canada's Environment- 1996. Accessed from <http://www.ec.gc.ca/soer-ree/English/SOER/1996report>.
- Faust, M. E., Balota, D. A., Spieler, D. H. & Ferraro, F. R. (1999). Individual differences in information processing rate and amount: implications for group differences in response latency. *Psychological Bulletin*, 125, 777-799.
- Fan, J., Wu, Y., Fossella, J. A., & Posner, M. I. (2001). Assessing the heritability of attentional networks. *BMC Neuroscience*, 2(14).
- Fastenmeier, W. (1995). Autofahrer und Verkehrssituation. Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Strassenverkehrssysteme. *Köln: Verlag TÜV Rheinland GmbH; Bonn: Deutscher Psychologenverlag*.
- Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention*, 37(3), 461-472

- Galski, T., Bruno, R., & Ehle, H. (1992). Driving after cerebral damage: A model with implications for evaluation. *American Journal of Occupational Therapy, 46*, 324-332.
- Gartner, W. B., & Murphy, M. R. (1979). Concepts of Workload In B. O. Hartman & R. E. McKenzie (Eds.). *Survey methods to assess workload*.
- Gawron, V. J. (2000). *Human Performance Measures Handbook*. London, UK: Lawrence Erlbaum Associates.
- Grandenigo, B. (2002). Assessing and rehabilitation of car driving ability: A holistic approach. *Europa Medicophysica, 38*, 33-37.
- Guralnik, J. M., LaCroix, A. Z., Abbott, R. D., et al. (1993). Maintaining mobility in late life: demographic characteristics and chronic conditions. *Am J Epidemiol, 127*, 845-857.
- Hakamies-Blomqvist, L. (1994). Aging and fatal accidents in male and female drivers. *Journal of Gerontology Social Sciences 49*, 286-290.
- Hakamies-Blomqvist, L., Raitanen, T., & O'Neill, D. (2002). Driver ageing does not cause higher accident rates per km. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*, 271-274.
- Hakamies-Blomqvist, L. E. (1993). Fatal accidents of older drivers. *Accident Analysis and Prevention Journal, 25*, 19-27.
- Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Vol. 22* (pp. 193-225). San Diego, CA: Academic Press.
- Harms, L., & Patten, C. J. (2003). Peripheral detection as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. *Transportation Research Part F: Traffic Psychology and Behaviour, 6*(1), 23-36.

- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload*. Amsterdam: North Holland Press.
- Hatfield, J., & Fernandes, R. (2009). The role of risk-propensity in the risky driving of younger drivers. *Accident Analysis & Prevention*, 41(1), 25-35.
- Health Canada. (2002). *Canada's Aging Population*. Ottawa: Health Canada.
- Henderson, S., Gagnon, S., Bélanger, A., Tabone, R., & Collin, C. (2007). *Near Peripheral Motion Detection Threshold Predicts Detection Failure Accident Risk in Younger and Older Drivers*. Paper presented at the The 4th International Driving Symposium on Driver Assessment, Training, and Vehicle Design, Stevenson, Washington.
- Henderson, S., Gagnon, S., Collin, C., Tabone, R., & Stinchcombe, A. (2009). *Near peripheral motion contrast threshold predicts older drivers' driving simulator performance*. Paper presented at the Driving Assessment Big Sky, Montana.
- Hendricks, D. L., Fell, J. C., & Freedman, M. (1999). *The relative frequency of unsafe driving acts in serious traffic crashes*. Washington, D.C: National Highway Traffic Safety Administration.
- Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention*, 38, 185-191.
- Horn, J.L., & Hofer, S.M. (1992). Major abilities and development in the adult period. In R.J. Sternber & C.A. Berg (Eds.), *Intellectual Development (pp. 44-99)*. New York: Cambridge University Press.

- Ivers, R. Q., Mitchell, P., & Cumming, R. G. (1999). Sensory impairment and driving: The Blue Mountains Eye Study. *American Journal of Public Health, 89*, 85-87.
- Jahn, G., Oehme, A., Krems, J. F., & Gelau, C. (2005). Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(3), 255-275.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement In J. B. Long & A. D. Baddeley (Eds.), *Attention and Performance IX* (pp. 187-203). Hillsdale, NJ: Erlbaum.
- Keskinen, E., Ota, H., & Katila, A. (1998). Older drivers fail in intersections: speed discrepancies between older and younger drivers. *Accident Analysis and Prevention, 30*(3), 323-330.
- Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). *The Impact of Driver Inattention On Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data*. Washington, DC.
- Kramer, A. F. & Kray, J. (2006). Aging and Attention. Eds. Bialystok, E. & Craik, F. I. M. *Lifespan Cognition*, pp. 57-66, Oxford University Press, New York.
- Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D. & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging, 9*, 491-512.
- Kramer, A. F. & Madden, D. (1998) Attention. In: Craik FIM, Salthouse TA, editors. *The handbook of aging and cognition*. 3. Hillsdale, NJ: Lawrence Erlbaum, 189–249.

- Kweon, Y. J., & Kockelman, K. M. (2003). Overall injury risk to different drivers: combining exposure, frequency, and severity models. *Accident Analysis & Prevention, 35*(4), 441-450.
- Laberge, J., Scialfa, C., White, C., & Caird, J. (2004). Effects of Passenger and Cellular Phone Conversations on Driver Distraction. *Transportation Research Record: Journal of the Transportation Research Board, 1899* 109-116.
- Langford, J., & Koppela, S. (2006). Epidemiology of older driver crashes – Identifying older driver risk factors and exposure patterns. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(5), 309-321.
- Langford, J., Methorst, R., & Hakamies-Blomqvist, L. (2006). Older drivers do not have a high crash risk—A replication of low mileage bias. *Accident Analysis & Prevention, 38*(3), 574-578.
- Larsen, L., & Kines, P. (2002). Multidisciplinary in-depth investigations of head-on and left-turn road collisions. *Accident Analysis and Prevention, 34*(3), 367-380.
- Lyman, S., Ferguson, S. A., Braver, E. R., & Williams, A. F. (2002). Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Injury Prevention, 8*, 116-120.
- Madden, D. J., Pierce, T. W., & Allen, P. A. (1992). Adult age differences in attentional allocation during memory search. *Psychology and Aging, 7*, 594-601.
- Margolis, K. L., Kerani, R. P., McGover, P., Songer, T., & Cauley, J. A. (2002). Risk factors for motor vehicle crashes in older women. *Journal of Gerontology Biological Sciences and Medical Sciences, 57*, M186-M191.

- Marottoli, R. A., Richardson, E. D., Stowe, M. H., Miller, E. G., Brass, L. M., Cooney, L., et al. (1998). Development of a test battery to identify older drivers at risk for self-reported adverse driving events. *Journal of the American Geriatric Society, 46*, 562-568.
- Mayser, C., Piechulla, W., Weiss, K.-E., & Knig, W. (2003). Driver workload monitoring. In H. Strasser, K. Kluth, H. Rausch, & H. Bubb (Eds.). *Quality of Work and Products in Enterprises of the Future*. Proceedings of the 50th-Anniversary Conference of the GfA and the XVII Annual ISOES Conference in Munich, May 07th-09th, 2003 (pp. 41-44). Stuttgart: Ergonomia.
- McGwin, G. & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis and Prevention, 31*, 181-198.
- McKnight, A. J., & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accident Analysis and Prevention, 31*, 445-454.
- McPhee, L. C., Scialfa, C., M, D. W., Ho, G., & Caird, J. (2004). Age differences in visual search for traffic signs during a simulated conversation. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 46*(4), 674-685.
- Michon, J. A. (1985). A critical view of driver behavior models: What do we know what should we do? In L. Evans & R. C. Schwing (Eds.), *Human Behavior and Traffic Safety* (pp. 485-524). New York: Plenum Press.
- Myers, R. S., Ball, K., Kalina, T. D., Roth, D. L., & Goode, K. T. (2000). Relation of useful field of view and other screening tests to on-road driving performance. *Perceptual and Motor Skills, 91*(1), 279-290.

- Najm, W. G., Sen, B., Smith, J. D., & Campbell, B. N. (2003). *Analysis of light vehicle crashes and pre-crash scenarios based on the 2000 General Estimates*. Washington, DC: National Highway Traffic Safety Administration, US Department of Transportation.
- Nataupsky, M., & Abbott, T. S. (1987). *Comparison of workload measures on computer-generated primary flight displays*. Paper presented at the Human factors society 31st Annual Meeting.
- Neuhaus, A. H., Koehler, S., Opgen-Rhein, C., Urbanek, C., Hahn, E., & Dettling, M. (2007). Selective anterior cingulate cortex deficit during conflict solution in schizophrenia: an event-related potential study. *Journal of Psychiatric Research* 41(8), 635-644.
- Norman, D. A. (1968). Toward a theory of memory and attention. *Psychological Review*, 75, 522-536.
- Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: Safety, reliability, and validity. *Journal of Gerontology* 49, M153-M159.
- Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., White, M. F., & Overley, E. T. (1998). Visual processing impairment and risk of motor vehicle crash among adults. *Journal of the American Medical Association*, 29, 1083-1088.
- Patten, C. J., Kircher, A., Ostlund, J., & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention*, 36(3), 341-350.
- Patten, C. J., Kircher, A., Östlund, J., Nilsson, L., & Svenson, O. (2006). Driver experience and cognitive workload in different traffic environments. *Accident Analysis & Prevention*, 38(5), 887-894.

- Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain *Annual Review of Neuroscience*, 13, 25-42.
- Public Health Agency of Canada (2011). Report from the Canadian Chronic Disease Surveillance System: Hypertension in Canada, 2010, from <http://www.phac-aspc.gc.ca/cd-mc/cvd-mcv/ccdss-snsmc-2010/2-2-eng.php>.
- Rabbitt, P. (1965). Age and the use of structure in transmitted information. In G. A. Talland (Ed.), *Human aging and behavior* (pp. 75-92). New York: Academic Press.
- Ragland, D. R., Satariano, W. A., MacLeod, K. E. (2004). Reasons given by older people for limitation or avoidance of driving. *Gerontologist*, 44(2), 237-44.
- Raitanen, T., Törmäkangas, T., Mollenkopf, H., & Marcellini, F. (2003). Why do older drivers reduce driving? Findings from three European countries. *Transportation Research Part F: Traffic Psychology and Behaviour*, 6(2), 81-95.
- Rasmussen, J. (1986). *Information processing and human machine interaction*. New York: North Holland.
- Rimmö, P.-A., & Hakamies-Blomqvist, L. (2002). Older drivers' aberrant driving behaviour, impaired activity, and health as reasons for self-imposed driving limitations. *Transportation Research Part F: Traffic Psychology and Behaviour*, 5(1), 47-62.
- Roberts, S. E., Vingilis, E., Wilk, P., & Seeley, J. (2008). A comparison of self-reported motor vehicle collision injuries compared with official collision data: An analysis of age and sex trends using the Canadian National Population Health Survey and Transport Canada data. *Accident Analysis & Prevention*, 40(2), 559-566.

- Ross, L. A., Clay, O. J., Edwards, J. D., Ball, K., Wadley, V. G., Vance, D. E., et al. (2009). Do Older Drivers At-Risk for Crashes Modify Their Driving Over Time? *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 64(2), 163-170.
- Rudin-Brown, C. M., & Noy, Y. I. (2002). Investigation of Behavioral Adaptation to Lane Departure Warnings *Transportation Research Record: Journal of the Transportation Research Board*, 1803 30-37.
- Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). *Training, maturation, and genetic influences on the development of executive attention*. Paper presented at the National Academy of Sciences of the United States of America.
- Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (2<sup>nd</sup> ed. Pp 200-236). New York: Van Nostrand Reinhold.
- Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review*, 103, 403-428.
- Salthouse, T. A. (2000). Aging and measure of processing speed. *Biological Psychology*, 54, 35-54.
- Sanders, M. S., & McCormick, E. J. (1987). *Human factors in engineering and design* (6 ed.). New York: McGraw-Hill.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: Detection, search, and attention. *Psychological Review*, 84, 1-66.
- Shinar, D. (1978). *The Psychology of the Road*. New York: Wiley.
- Simoës, A. (2002). The cognitive training needs of older drivers (Les besoins de formation cognitive des conducteurs âgés). *Recherche - Transports - Sécurité*, 79, 145-155.

- Skyving, M., Berg, H.-Y., & Laflamme, L. (2009). A pattern analysis of traffic crashes fatal to older drivers *Accident Analysis & Prevention*, *41* (2), 253-258
- Spain, D. (1997). *Societal Trends: The aging baby boom and women's increased independence*. Washington, DC: Federal Highway Administration.
- Stamatiadis, N. (1996). Gender effect on the accident patterns of elderly drivers. *Journal of Applied Gerontology*, *15*, 8-22.
- Stamatiadis, N., & Deacon, J. A. (1997). Quasi-induced exposure: methodology and insight. *Accident Analysis and Prevention*, *29*, 37-52.
- Statistics Canada. (2006). *Canadian Vehicle Survey: Annual, 2000 and Canadian Vehicle Survey: Annual, 2006*. Ottawa, Statistics Canada.
- Staplin, L., Lococo, K. H., Gish, K. W., & Decina, L. E. (2003). *Model Driver Screening and Evaluation Program, final technical report, volume I: Project summary and model program recommendations*. Washington, DC: U.S. Department of Transportation.
- Staplin, L., & Lyles, R. W. (1992). Age differences in motion perception and specific traffic maneuver problems. *Transportation Research Record*, *1325*, 23-33.
- Stinchcombe, A., & Gagnon, S. (2010). Driving in dangerous territory: complexity and road-characteristics influence attentional demand. *Transportation Research Part F: Traffic Psychology and Behaviour*, *13*(66), 388-396.
- Stinchcombe, A., Weaver, B., Johnson, M., & Bédard, M. (2007). *Heart rate response to simulated driving and UFOV*. Paper presented at the St. Joseph Care Group 2007 Showcase of Applied Research, Thunder Bay, ON.
- Strayer, D. L., & Drews, F. A. (2007). Chapter 2: Attention. In F. T. Durso (Ed.), *Handbook of applied cognition*. Hoboken, NJ Wiley.

- Stutts, J. (1998). Do Older Drivers with Visual and Cognitive Impairments Drive Less? *Journal of the American Geriatrics Society*, 46(7), 854-861.
- Summala, H., & Mikkola, T. (1994). Fatal accidents among car and truck drivers: Effects of fatigue, age, and alcohol consumption. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 36, 315-326.
- Theeuwes, J., & Godijn, R. (2001). Attention and oculomotor capture. In C. Folk & B. Gibson (Eds.), *Attraction, Distraction, and Action: Multiple Perspectives on Attentional Capture* (pp. 121-150): Elsevier Science.
- Törnros, J. E. B., & Bolling, A. K. (2005). Mobile phone use - effects of handheld and handsfree phones on driving performance. *Accident Analysis & Prevention*, 37, 902-909.
- Törnros, J. E. B., & Bolling, A. K. (2006). Mobile phone use - effects of conversation on mental workload and driving speed in rural and urban environments. *Transportation Research Part F: Traffic Psychology and Behaviour* 9, 298-306.
- Transport Canada. (2001). *Trends in motor vehicle traffic collision statistics 1988 - 1997*. Ottawa: Transport Canada.
- Transport Canada. (2004). *Vulnerable road user safety: a global concern*. Ottawa: Transport Canada.
- Trick, L. M., Enns, J. T., & Vavrik, J. (2004). Paying attention behind the wheel: a framework for studying the role of attention in driving. *Theoretical Issues in Ergonomics Science*, 5(5), 385-424.
- Triesman, A. M. (1960). Contextual Cues in selective listening. *Quarterly Journal of Experimental Psychology*, 12, 242-248.
- Triesman, A. M. (1964). Selective attention in man. *British Medical Bulletin*, 20, 12-16.

- Turcotte, M. (2005). *The time it takes to get to work and back*. Ottawa: Statistics Canada.
- Ulleberg, P. (2001). Personality subtypes of young drivers. Relationship to risk-taking preferences, accident involvement, and response to a traffic safety campaign. *Transportation Research Part F: Traffic Psychology and Behaviour*, 4(4), 279-297.
- Ulmer, R. G., Williams, A. F., & Preusser, D. F. (1997). Crash Involvements of 16-Year-Old Drivers. *Journal of Safety Research*, 28(2), 97-103.
- Unsworth, C. A., Lovell, R. K., Terrington, N. S., & Thomas, S. A. (2005). Review of tests contributing to the occupational therapy off-road driver assessment. *Australian Occupational Therapy Journal*, 52, 57-74.
- Vaez, M., & Laflamme, L. (2005). Impaired driving and motor vehicle crashes among Swedish youth: An investigation into drivers' sociodemographic characteristics. *Accident Analysis & Prevention*, 37(4), 605-611.
- Valcour, V. G., Masaki, K. H., & Blanchette, P. L. (2002). Self-reported driving, cognitive status, and physician awareness of cognitive impairment. *Journal of the American Geriatric Society* 50(7), 1265-1267.
- van Zomeren, A., Brouwer, W., & Minderhoud, J. (1987). Acquired brain damage and driving: A review. *Archives of Physical Medicine and Rehabilitation*, 68, 697-705.
- Verhaeghen, P., & de Meersman, L. (1998). Aging and the Stroop effect: A meta-analysis. *Psychology and Aging*, 13, 120-126.
- Verwey, W. B. (2000). On-line driver workload estimation: Towards an adaptive human machine interface in the car of tomorrow. *Ergonomics*, 43, 187-209.

- Vodden, K., Smith, D., Eaton, F., & Mayhew, D. (2007). *Analysis and estimation of the social cost of motor vehicle collisions in Ontario*. Ottawa: Transport Canada.
- Vogel, K., Kircher, A., Alm, H., & Nilsson, L. (2003). Traffic sense--which factors influence the skill to predict the development of traffic scenes? *Accident Analysis and Prevention*, *35*(5), 749-762.
- Wang, X., & Abdel-Aty, M. (2008). Modeling left-turn crash occurrence at signalized intersections by conflicting patterns. *Accident Analysis and Prevention* *40*(1), 76-88.
- Weaver, B., Bédard, M., McAuliffe, J., & Pakkari, M. (2009). Using the Attention Network Test to predict driving test scores. *Accident Analysis and Prevention*, *41*(1), 76-83.
- Wickens, C. D., & Hollands, J. (2000). *Engineering psychology and human performance* (3rd ed.). Upper Saddle River, NJ: Prentice.
- Williams, A. F. (2003). Teenage drivers: patterns of risk. *Journal of Safety Research*, *34*(1), 5-15.
- Wood, J. (1999). The older driver: a handy tool to assess competence behind the wheel. *Geriatrics*, *51*, 36-38.
- Wood, J., Anstey, K. J., Kerr, G., Lord, S. R., & Lacherez, P. (2008). A multi-domain approach for predicting older driver safety under in-traffic road conditions. *Journal of the American Geriatric Society*, *56*, 986-993.
- Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception & Performance*, *10*, 601-621.

Zhang, J., Fraser, S., Lindsay, J., Clarke, K., & Mao, Y. (1998). Age-specific patterns of factors related to fatal motor vehicle traffic crashes: focus on young and elderly drivers. *Public Health, 112*, 289-295.

Zhang, Y., Owechko, Y., & Zhang, J. (2004). *Driver cognitive workload estimation*. Paper presented at the Intelligent Transportation Systems Conference.

Zhou, M., & Sisiopiku, V. P. (1997). Relationship Between Volume-to-Capacity Ratios and Accident Rates. *Transportation Research Record: Journal of the Transportation Research Board, Volume 1581*, 47-52.